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Aspects of Irrigation with Windmills

by A. van Vilsteren

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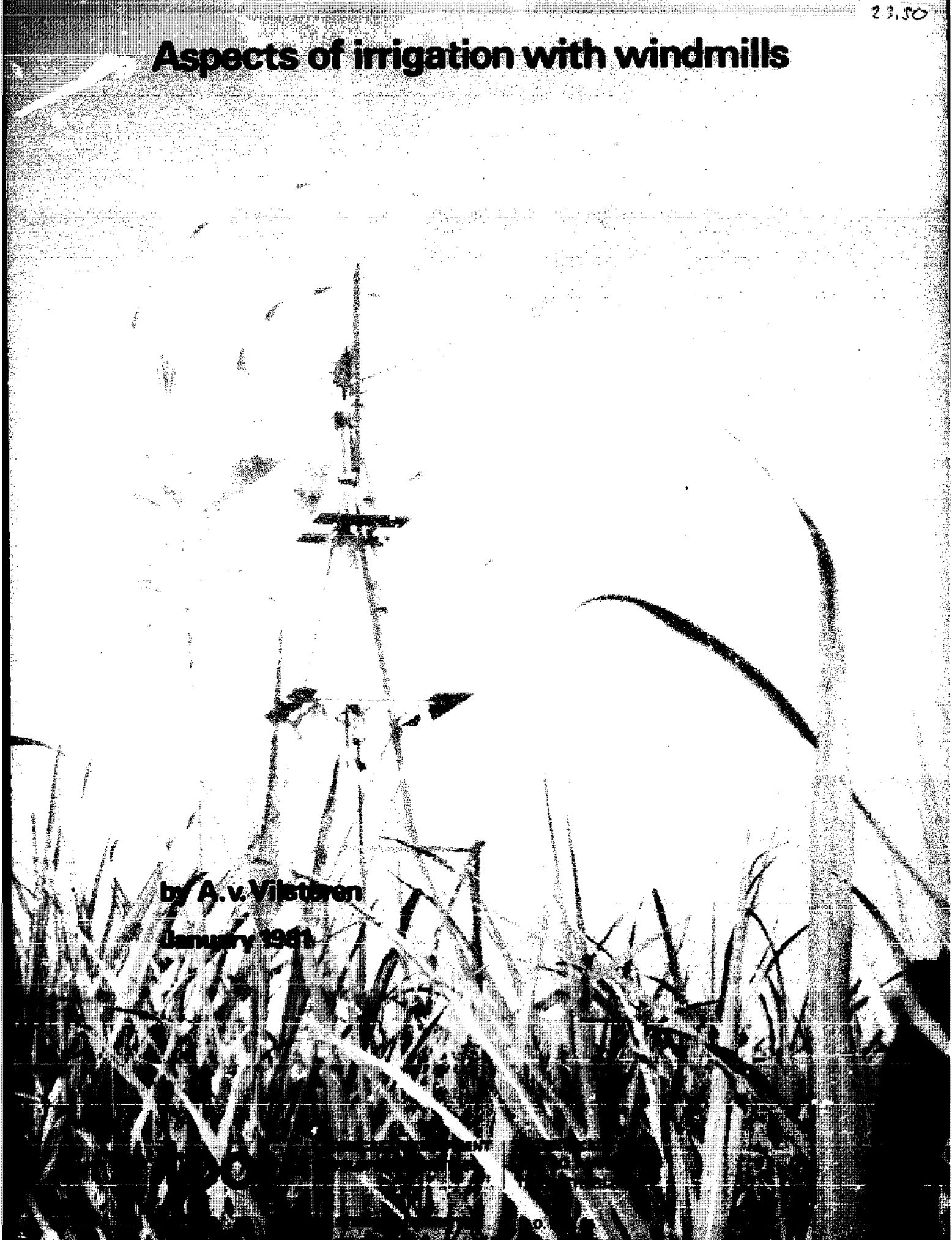> 1018 AD Amsterdam
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ASPECTS OF IRRIGATION
WITH WINDMILLS

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Anton van Vilsteren

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ACKNOWLEDGEMENTS

Hopefully this study will contribute to the further application of
windmills for irrigation, so reducing the small farmers' dependence on
fossil fuels and contributing to the alleviation of poverty and the
production of more food in the developing countries.

Anton van Vilsteren.

SUMMARY

The sharply rising prices of fossil fuels increased the interest in
alternative energy resources in the seventies. This combined with rising
interest for infinitive, environmentally sound technologies has resulted
in the development of quite a number of windmill prototypes and other
alternative energy converters. Since the late seventies several prototy-
pes have reached the implementation stage. Due to further improvements
in performance, dependability and cost effectiveness (partly due to new
price rises of fossil fuels), windmills can be applied in irrigation and
may under certain conditions provide a more attractive solution than
comparable small diesel-, petrol-, or electrical pump sets.

This study deals with aspects of this special kind of lift-irrigation,
in the context of small holder agriculture in third world countries.
The context in which small holder windmill irrigation has to be placed
is discussed as well as how such projects can be planned. Irrigation,
agricultural and social aspects are considered, and general economic
calculation methods are given.

The analysis of the wind potential for water lifting is worked out.
Special emphasis is laid on the correlation between wind, precipitation
and evaporation and its impact on irrigation.
With the help of probability analyses of the soil water balance, the
command area per windmill can be calculated. Optimization of the usage
of the water pumped (by crop plan adjustments) is another important
aspect.

The correlation between the daily evaporation and windspeed is signifi-
cant. This, combined with the increase in instantly available soil
moisture at lower evaporation rates, allows a delay in irrigation of
several days for most crops, when windspeed drops for a few days.
Guidelines are derived for increasing the flexibility of the crop plan
with regard to the irrigation interval.

The Annexes provide formulae and tables that will enable the user to
perform the necessary calculations with data from his own environment.
Some working examples are also given to illustrate the calculation
methods discussed in this paper.

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ACKNOWLEDGEMENTS

SUMMARY

REFERENCES

ANNEX I   : Panevaporation method and Penman method, including tables
               and calculation examples.
ANNEX I-A : Determination of the relative influence of windspeed on the
               evapotranspiration.
ANNEX II   : Table of salt tolerance of crops.
ANNEX III : Calculation example of the probability analysis of the wind-
               mill command area.
ANNEX IV   : Formulae and calculation examples for economic analysis of
               windmill irrigation.

1. INTRODUCTION

In the wake of the increasing world energy crisis, which hits the least developed countries most, the interest in alternative energy resources has increased considerably.
Windmills have good potentials in many areas in the world, since they are relatively efficient energy convertors and their construction is relatively simple, cheap and can often be carried out locally.

This study discusses some specific aspects of small scale irrigation with windmills, for application by individuals or groups of small and marginal farmers, with the primary aim of improving their living conditions. However the general information provided will probably be useful to all people who apply windmills for irrigation.

It should be borne in mind that the study, based on literature and three years of experience with windmill irrigation, is primarily aimed at people already working in this field. Basic knowledge of irrigation principles and windmill construction are required for sound interpretation of the suggestions made in this paper.
These suggestions can provide a basis for assessment of the potential for windmill irrigation in a certain area.

However, the study is not to be used as a manual for design and operation of windmill irrigation projects. The examples and figures given here are just examples and mostly restricted to the situation given. Therefore it is recommended to seek expert advice if windmills for irrigation projets are seriously considered.

1.1. Alternatives for irrigation

In this section it is stressed that despite the interest in windmills, irrigation and irrigation in general is not necessarily the most appropriate solution for the improvement of the living conditions of small and marginal farmers in a certain area. Especially in areas where gravitational irrigation is not possible, the rising energy costs and the required skill for operation and maintenance may make irrigation a costly and uneconomical affair. Pressure to boost national food production often leads to optimistic projections with regard to fuel prices and other costs and skills required for an irrigation project.

There are other alternatives for improvement of the living conditions of small and marginal farmers and increase of food production, such as: land reform, improved dry farming, erosion control, water saving activities and supply of, for instance, fertilizers and pesticides. Infrastructural improvements might also be more appropriate in certain areas. Under specific conditions rainwater catchment may be an alternative.

Introduction of irrigation is often justified on economic grounds, all
other inputs being taken to be optimally available, including infra-
structure for the supply of inputs and the marketing of the crops.
But farmers are often unable to change all their agricultural practices
at once and the authorities and other parties are also often unable to
supply all services and inputs at once.
A step by step approach may be more appropriate in such cases, input- and
output-levels first being improved, after which new farming practices
are gradually adopted and infrastructural improvements realized.
Irrigation, especially lift irrigation, is a costly affair and should
therefore in fact only be applied if all other cheaper alternatives for
improvement of agricultural production have been investigated. (History
of irrigation projects Hagan, 1967, Vreede 1978).

1.2. <u>Selection of irrigation device</u>

Let us assume that detailed need assessment studies and surveys have
shown small scale irrigation to be a logical next step for further
improvement of the living conditions of the small and marginal farmers
in a certain area.
Next comes the selection of the irrigation device (electrical pump sets,
pumps driven by internal combustion engines, windmills).
A direct economic comparison is made in chapter 4; other aspects that
deserve consideration are discussed in this section.

Windmills depend directly on an natural resource (wind) and are unknown
in most rural areas in developing countries.
These factors have consequences for their application in several ways:
social, agro-economical, technical and political.
The most important elements of these aspects are considered below.

Social
------
1. Many developments in the augmentation of agriculatural production are
   characterized by decreasing dependence on natural forces (fertilizers
   to improve natural fertility, new varieties and hybrids to replace
   traditional low yielding varieties, irrigation to supplement or
   replace the natural rainfall).
   Dependence on windmills for irrigation however, means increasing de-
   pendence on natural forces. This is in significant contrast with the
   developments in the last century. This aspect may reduce the accepta-
   bility of windmills by farmers as well as by the local authorities.
   Especially in developing countries all efforts and hopes are placed
   on "modernization" of agriculture.

However, with the increasing cost of the fossil fuels on which many
of these improvements depend (fertilizers, insecticides, energy for
water lifting and mechanization), the dependence on nature may become
a sound economic alternative and therefore easier to accept.
An additional advantage in this respect, especially for small and
marginal farmers is that the energy source "wind" cannot be monopoli-
sed, whereas with the fossil energy sources this is becoming more and
more the case, due to their scarcity and increasing prices.

2. If a few small farmers have to share the water pumped by one wind-
   mill, difficulties may arise with regard to distribution of the
   irrigation water, since windmills cannot be started at any moment.
   For example, it is the turn of farmer B to irrigate his wheat, but he
   has to wait for 2 days since there is not sufficient wind. The third
   day there is some wind; at that moment however, it can be more essen-
   tial to irrigate first the potatoes of farmer A, since that crop is
   much more sensitive to water shortage in a certain growing stage.
   This unpredictability of the day to day output of a windmill also
   restricts its suitability for selling irrigation water to neighbours.
   Selling irrigation water is widely practised by (small) farmers with
   pump sets in many places in Asia and elsewhere and is often a sound
   source of cash income.

Agro-economical
----

1. Besides the economic components of the above mentioned social impli-
   cations, it should be mentioned that as the availability of suffi-
   cient windenergy in a certain period often cannot be relied upon,
   safety factors have to be taken into account with regard to command
   area and crop choice. For realistic planning, it is recommended to
   make probability analyses of the combined figures of evaporation,
   rainfall and windspeed, since these phenomena are intercorrelated.
   If insufficient data are available for such an analysis, the windmill
   irrigation unit has to have an overcapacity to compensate for partial
   or total failure of rains, because this cannot be overcome by running
   a few extra hours, as with a pump set. However, a large tank for
   storage of the pumped water to meet crop water requirements at a
   later stage may be uneconomical due to the cost of construction and
   the loss of land which it occupies. Even small tanks to meet short
   windless periods during the growing season are often uneconomical.
   Chapter 3 deals in detail with this subject of meeting short windless
   periods.

2. The crop plan has to be adjusted to the existing annual wind regime.
   This may lead to reduction of the command area during the low wind
   seasons or to growing more drought resistant crops during such sea-
   sons.
   Drought resistant crops are often not the most renumerative crops. It
   will be clear that the crop plan cannot be selected solely on the
   basis of the capacity of the windpump, but that many other factors
   will be of influence (see Chapter 3).

However, recent studies in India, Indonesia and Kenya show that the
economic viability of windmills as an irrigation medium depends
largely on a (to the wind regime) adjusted crop plan for the entire
year. Than maximum use can be made of the water pumped by the windmill
(van Vilsteren 1978, 1979, 1980).
A crop plan determination in accordance with the actual wind regime
may also imply that further crop plan adjustments to future market
changes will be difficult or impossible. But this is also often a
limitation of large irrigation schemes within flexible farm supplies.

The lower reliability of windmills may also affect the level of the
other inputs (high yielding varieties, fertilizers, pesticides etc....)
and consequently the output level (yield). The same symptoms have
often been reported in evaluations on the introduction of the "green
revolution" in areas with uncertain availability of irrigation water
(risk minimization).
Due to the worldwide energy crisis and the consequent scarcity and
high prices of diesel oil and electricity, the reliability of these
irrigation sources has decreased as well.
Also unsound management of large irrigation schemes may cause unreli-
able watersupply and consequently, farmers will grow less and or
fewer risky crops and apply fewer inputs compared with areas with
good irrigation water supply.
E.g.   farmers in the Ganga-plain of North India who get their water
        from government tubewells grow fewer risky crops (no vegetables,
        no potatoes) and obtain lower yields than farmers with private
        pumping sets.

3. On the other hand, if the cost per m^3 water pumped by windmills is
    considerably less than the cost of water from other irrigation sources,
    this may compensate the limitations with regard to its reliability.
    In the same Ganga-plain of North India, farmers with diesel pump sets
    grow hardly any crops during the hot summer season.
    The water requirements of crops in that season is so high that econo-
    mic crop production with high (variable) cost per m^3 water is hardly
    possible. Yet this is the main season for the windmills due to pre-
    vailing high windspeeds during that period.

    The variable cost of water pumped by windmills is almost negligible,
    since it consists only of repair and maintenance costs (see figure
    1.1.), most of which may also be regarded as fixed costs as wear and
    tear of the windmill structure (e.g. corosion) continues even if the
    mill is not running. Only the wear and tear on the transmission (e.g.
    bearings) can be regarded a true variable cost, because it is direct-
    ly related to the running of the windmill.
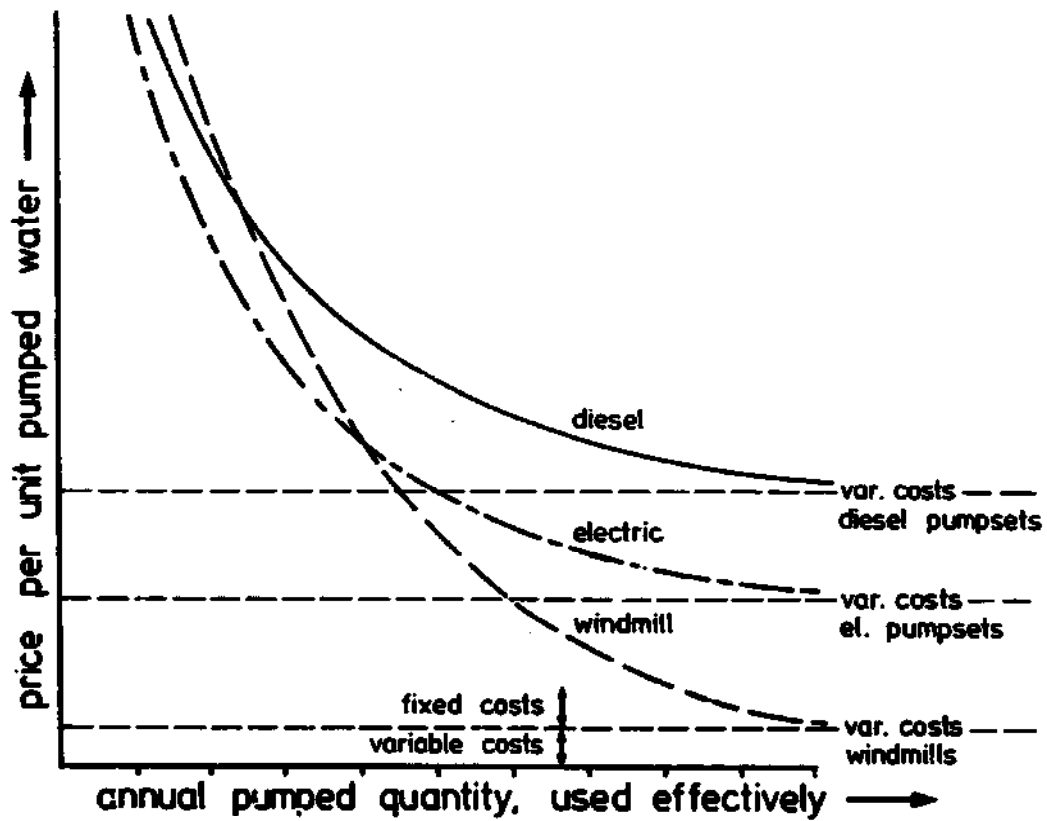
Fig. 1.1.   General relation between the price per unit of water
            pumped and the annual output for small diesel and elec-
            trical pump sets and windmills.
            Any additional amount pumped by the windmill is much
            cheaper than for the other pump sets due to the low
            level of variable costs (no fuel costs).

Technical

1. Windmills can only be applied in windy areas (see chapter 2 for wind analysis).
   It is recommended that the initial introduction of windmills in an country takes place where there is abundant wind and the water source is reliable and not too deep (E.g. average monthly windspeed above 2.5 m/sec., total elevation head less than 15 m).

2. At present, windmills have a relatively small capacity, comparable with a small pump set. Windmills with larger capacities may be constructed in the future but this is likely to be accompanied by increasing costs and technical problems.
   Windmills should be placed far from each other (more than 10 times the rotordiameter) and their water source should be nearly under them (direct mechanical transmission). In some places windmills generate eletricity for an electric pump set elsewhere. Energy losses and increasing costs limit the economic application of such systems.
   Consequently, if the number of water sources is limited, and their capacity is large, it may be more economical to install an electric or diesel powered pumping station and irrigate a larger area from the same source. For example in case of a river or lake, irrigation with windmills will only supply water to a very small area along the shores of the source. Even a well with a large capacity may be more economically pumped by electricity or diesel, provided there are no other limitations (topographical, land property, availability of energy etc....).
   However, as can be seen in fig. 1.2, windmills can sometimes provide an attractive solution. In the future they may also be used in large schemes with low lift irrigation.

3. Windmills need an open surrounding of about 20 times the rotor diameter free of trees and houses. Yet, in the nature of things, water sources are usually surrounded by trees. Removing them is often difficult and sometime even prohibited by governmental or religious authorities. Moreover surrounding trees often have an economic value (coconut, fruit trees etc.).

4. In most rural areas, diesel and electric pumps are already in use. Consequently the technology is familiar, there may be a network for marketing and spare parts and skills are available for repair and maintenance.
   However in the case of windmills, production has to be started, a marketing network has to established for the mills and their spare parts; local blacksmiths have to be trained for repair and maintenance work.
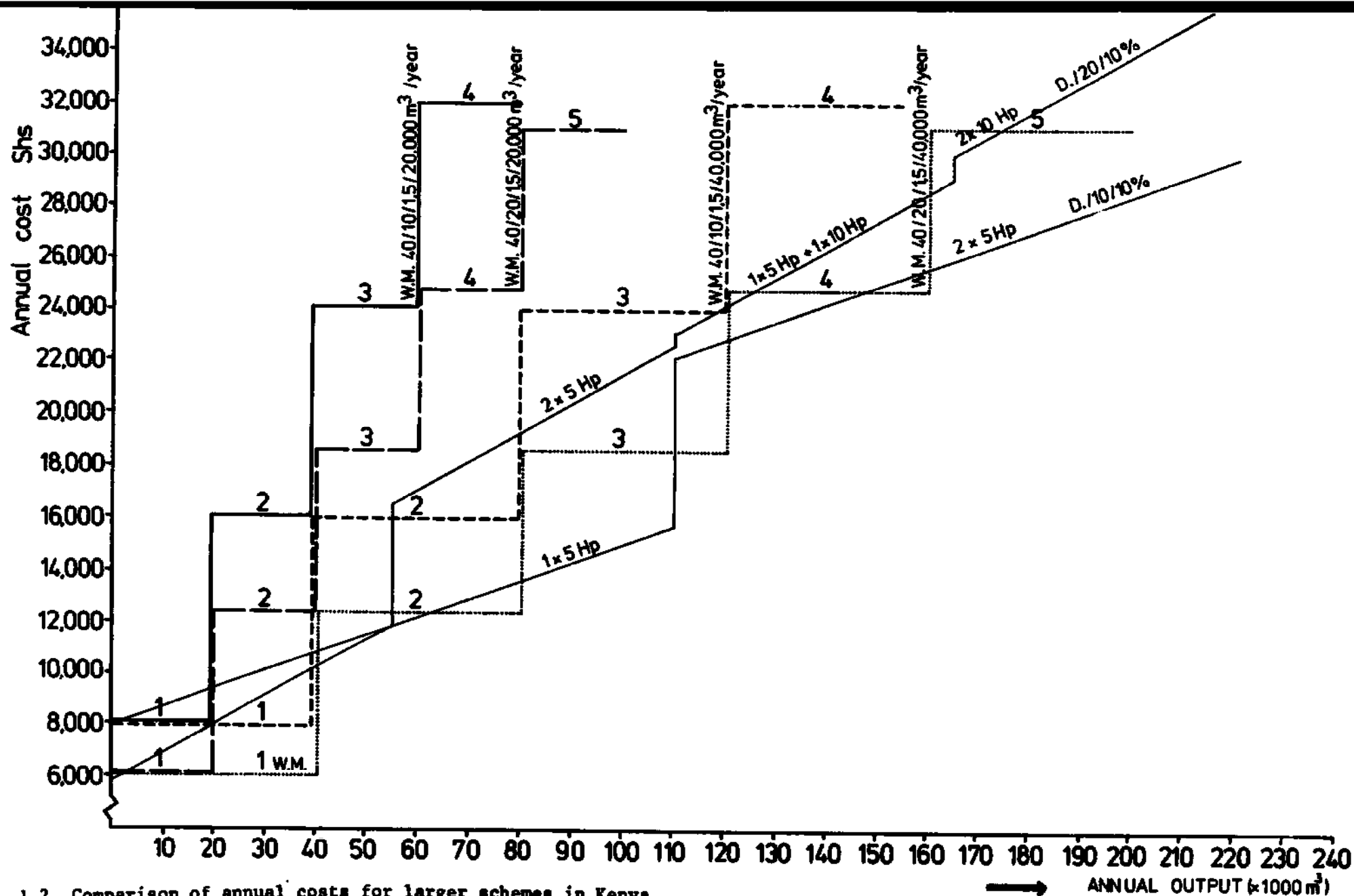
Fig. 1.2. Comparison of annual costs for larger schemes in Kenya,
using a number of windmills of a certain annual capacity
or a diesel pump set plant. Time span 10 and 20 years;
elevation head 5 m. (Vilsteren, 1980)

W.M. 40/10/1,5/20,000 m3/yr means:
Windmill plus tank: Shs. 40,000; Lifespan, 10 years;
Repair and maint, Shs. 1,500 per year;
Output, 20,000 m3/yr
D/10/10% means : Dieselpumpset; lifespan 10 years;
annual fuel pricerise 10%

If the windmills prove to be viable all these activities will expand automatically.

Political

1. Whether windmills will be accepted by governmental bodies depends on policies with regard to rural electrification, fuel import and fuel prices, and the general policy with regard to the area concerned, such as plans for hydropower plants, large gravitational irrigation schemes, employment generation etc.....

2. In areas where small scale irrigation already takes place (electricity, diesel) there are often all kinds of subsidies and credit schemes for pumpsets, such as interest subsidy on credits, subsidy on fuels etc..... These facilities should be made eligible for windmills as well, as the non availability of subsidies and credit-facilities for windmills limits their acceptance by the potential users.
This process of acceptance can take several years, during which the windmill irrigation system has to prove its viability.

3. In general, the faith of governments in windmills for irrigation is not yet great. This can only be improved by successful windmill-irrigation pilot projects.

1.3.　　　　　Planning of a windmill irrigation project

As has been made clear in the previous sections, the introduction of windmills in a certain area is fairly complicated. A planning chart is presented here to review the many aspects that can influence the introduction of windmills and to show at what phase of the project action must be taken. This chart is based on a survey of the implementation of an Appropriate Technology Programme in Indonesia. (De Iong, 1980)

Since the philosophy of Appropriate Technology emerged, windmills have been regarderd as a suitable possibility for this approach. At this moment a small number of simple, low cost windmill designs are under testing or in operation at several places around the world.
A characteristic of Appropriate Technology is that it is not easily transferable to other areas. The technology has te be appropriate to the specific conditions of the area in which it is to function.
In the first place with regard to its social appropriateness.
Are windmills the step for further development that is wanted next by the target group?
Secondly are the required skills, materials and infrastructure sufficient available locally? Appropriate Technology is not automatically

simple. Recent experiences with windmill projects show that although the
principles may be quite simple, that if the windmill is to function
optimally for a number of years, it is essential to produce it with
skill and precision.

The planning chart given is only functional if the need for small scale
irrigation has already been assessed.
Moreover, it should be discussed before each subsequent step whether
windmills can still be considered to provide the most appropriate solu-
tion.
It should be realised that windmills for irrigation, like any other
technology, will not provide (indeed cannot provide) the sole solution
for improvement of the living conditions of the weaker sections of the
community.
Introduction of windmills should preferably be decided on and planned in
the framework of an integrated rural development scheme. Here we limit
ourselves to the planning of the "windmill part" of such projects.

FEASIBILITY STUDY

Long term goal setting		
Selection pilot area	-	need for irrigation
	-	favourable wind conditions
	-	favourable water sources
Surveys	-	social
	-	economic (macro-micro)
	-	agricultural
	-	technical
Target group selection	-	counterpart organization
	-	producers of windmills
	-	users of windmills

Need assessment and target group study		
Target group segmentation	short term goal setting	selection participants of target group

DISCUSSION
- Does the realisation of the longterm objective seem to be feasible?
- If not, is a modification of the long term objective desired or required?
- Should the project be started or not?

PILOT PROJECT

Hardware selection, development and testing		
Data collection - detailed wind analyses - detailed water source study - calculation cropwater requirement	windmill design	prototype construction
- detailed survey of available material and skills	pump design	improvements

Implementation on small scale		
selection of sites selection of farmers	guidance of farmers data collection	training mechanics transfer of technoligy

Evaluation pilot project		
evalutation social appropriateness	evaluation technical/agricultural feasibility	evaluation economic feasibility

DISCUSSION
- Will the realisation of the long term objectives be feasible?
- If not, is a modification of the long term objectives desired or required?
- Should the project be continued or not?

IMPLEMENTATION

Short term goal setting
Fixation project area
Project implementation

1. windmills
   production
   quality control
   standardization
   price control
	marketing
	advertizing
	credit facilities
	subsidy facilities
		servicing
		spare parts
		servicing contracts
		quarantee period

2. agriculture
   extension service
   field worker
   demonstration farm
   mass media		

Applied research/further data collection
Transfer of technology

Evaluation

2.   SMALL SCALE IRRIGATION WITH WINDMILLS

Chapter 1 of this report comprises a review of the general aspects to be considered before a windmill project can be started. In Chapters 2 and 3 attention is given to specific aspects of irrigation with windmills .
As an introduction, the main principles of irrigation are briefly outlined and references are given. The use of windmills for water lifting is discussed more extensively. Readers with a limited knowledge of agriculture and irrigation are advised to read:
"Small scale irrigation by P. Stern" 1979. *

The determination of the command area is the main subject of this chapter. The command area is the acreage that can be irrigated by the water lifting device (e.g. windmill) under the given conditions. A simple example:
    crop water use 300 mm/month.
    rainfall   100 mm/month.
    windmill output 200 mm/month. (=2000 m³/ha since 1 mm = 10 m³/ha).
    In this situation the command area is 1 ha, since windmill output and rainfall can just compensate the crop water need.

The elements: evapotranspiration, rainfall, windmill output and crop selection are discussed in detail. A simple probability analysis is introduced to predict the probability of occurrence of a certain command area with windmills under the given climatological conditions. Finally a few remarks are made about the irrigation water source.

In Chapter 3 attention is given to typical aspects of irrigation with a variable energy source (wind) and to the calculation of the irrigation interval. Also the way in which the effects of the variable daily windmill output can be minimized (relation wind-evapotranspiration; evapotranspiration-crop production; other input levels; storage tank) is dealt with.

2.1.   Water balance

Before assessing the amount of irrigation required to grow a crop, it is necessary to evaluate the elements which can influence the balance of the water in the soil.
This water balance can be expressed as follows:

$$\Delta W = P + I + C - DR - RO - E.$$
in which: ΔW: change in amount of water present in the soil
            P: precipitation

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* P. Stern: "Small scale irrigation; Intermediate Technology Publications Ltd. Kingstreet Londen, WC 2, 8HN U.K.
(Also to be ordered from TOOL, Mauritskade 61 A, Amsterdam (NETHERLANDS.)

        I: irrigation
        C: capillary rise
        DR: drainage to lower soil layers
        RO: run off
        E: evapotranspiration

Precipitation, evapotranspiration and irrigation are discussed in detail
in the following sections. Those terms are often the main components of
the water balance of the soil for which irrigation is needed. The remai-
ning factors are brief'y considered below.

Capillary rise

Capillary rise is the transport of water from the subsoil to the topsoil
through the capillaries of the soil. As is common in all flow processes,
the capillary rise depends upon the length of the pathway, the resistan-
ce of the pathway and the difference in potential between the outer ends
of the pathway.

A significant contribution from capillary rise only occurs when the
groundwater table lies within 1-2 m. below soil surface. Lighter soils
(loamy soils or loams) allow a delivery of 2-4 mm/day at 60-100 cm above
groundwater table, whereas in clay soils, these quantities can only be
delivered at less than 40 cm above the groundwater table (Rijtema,
1970).

These figures show, that the contribution of capillary rise to the water
balance of the soil is negligible in most cases.

Drainage

Drainage is the loss of water due to percolation beyond the reach of
plant roots. If the amount of rainfall or irrigation exceeds the storage
capacity of the rootzone, drainage occurs.
If this excess of water cannot be removed naturally (percolation to the
subsoil) or artificially (drains, ditches, canals etc.) water logging
will occur, causing damage to the crop due to insufficient aeration of
the rootzone.
If, due to percolation of excess rainfall or irrigation, the groundwater
table rises within 2 m of the ground surface, artificial drainage has to
be applied to avoid salinization caused by high groundwater tables
(Unesco/FAO, 1973).
Drainage facilities are also required when the irrigation water contains
salts which can accumulate in the rootzone. Additional irrigation water
is applied for leaching purposes and then has to be drained from the
rootzone. For leaching requirements and drainage capacities see Unesco/
FAO, 1973.

In water balance studies it is often difficult to estimate the loss of
water due to drainage. By measuring groundwater tables and the discharge
from drains, an impression can be obtained about the drainage of the
area studied.

Run-off

Water which does not penetrate in the soil but flows over the soil
surface is called run-off. If the rainfall intensity, or irrigation
intensity exceeds the infiltration capacity of the soil, water remains
on the soil surface and will start to flow if there is any gradient.
This process can cause erosion in sloping areas and water logging in
small depressions in fields. The infiltration rate of the soil can be
improved and erosion reduced by cultural practices (contour plowing,
mulching, strip cropping, contour ditches etc.). Single fields should be
properly levelled.
In the case of furrow- and border-irrigation, run-off at the end of the
field is almost inevitable. Drainage ditches have to be applied in such
cases to prevent water logging and salinization. In paddy growing areas
the run-off of one field is often used to meet the water requirements of
the lower fields.
Measuring the run-off is almost as difficult as measuring drainage.
Drainage and run-off are often discounted in irrigation- and rainfall
efficiency. Inevitable irrigation losses such as deep percolation and
run-off are accounted for by introducing irrigation efficiency factors.
(See section 2.3.2.).
With the abovementioned modifications for irrigation and rainfall the
water balance equation can be simplified as follows:

$$\Delta W = P + I - E.$$

If W has to be constant over a certain period, the following balance has
to exist over that period:

$$E = P + I$$

Evapotranspiration, rainfall and irrigation are considered in more
detail in the following sections.

2.1.1.   Evapotranspiration

Evapotranspiration is a combination of evaporation from the soil surface
and transpiration from the crop, and is dependent on many factors.
In the first place, the reference evopotranspiration ETo is defined as
      "the rate of evapotranspiration from an extensive surface of green
      grass cover of uniform height (8-15 cm), actively growing, complete-
      ly shading the ground and not short of water".
As can be concluded from this definition many factors, other than the
climate, influence the evapotranspiration (crop height, colour, uniformi-
ty, growing conditions, ground cover etc.).

Several methods are available to calculate the ETo (Blaney and Criddle, Radiation, Penman, Pan Evaporation) (FAO, 1977).
The modified Penman methods offers the results with the lowest error (about 10%). However, this method requires a number of measured meteorological data and the calculation is not simple.
Calculation tables for the Penman method and the Pan evaporation method can be found in Annex I and in the literature (Penman 1948, Kijne and Baars 1971, FAO 1977).

Evapotranspiration can be divided into 2 main components:
The radiation component (sun) provides in general the energy for the evapotranspiration.
The aerodynamic component (wind) transports the water vapour.
By transporting warmer air over a cooler surface, this aerodynamic component also provides energy for evapotranspiration. This is called advection and occurs regularly in semi-arid and arid regions.

Wind is the agent for air transport. So the windspeed will influence the evapotranspiration. At low windspeeds the water vapour resulting from evapotranspiration will not be transported and consequently the evaporation will decrease.
At high windspeed the water vapour will be removed immediately and the total evapotranspiration will increase. If the wind comes from a drier and warmer area, the effect of windspeed on the evapotranspiration will be even higher.
The effect of windspeed on the total evapotranspiration can be as much as 30% (see Annex I-A). The relation between evapotranspiration and windspeed is important for the calculation of the command area (sec. 2.3.) as well as for the irrigation interval (sec. 3.2.) when irrigation with windmills is envisaged.

Crop evapotranspiration (ETcrop)

The reference evapotranspiration (ETo) refers to grass of 8-15 cm height. Other crops with other characteristics can be related to ETo with the following formula:
ETcrop=kc.ETo.

Crop Coefficients (kc)

CROP	Crop Development stages					
	Initial	Crop development	Mid-season	Late season	At harvest	Total growing period
Banana						
tropical	0.4 -0.5	0.7 -0.85	1.0 -1.1	0.9 -1.0	0.75-0.85	0.7 -0.8
subtropical	0.5 -0.65	0.8 -0.9	1.0 -1.2	1.0 -1.15	1.0 -1.15	0.85-0.95
Bean						
green	0.3 -0.4	0.65-0.75	0.95-1.05	0.9 -0.95	0.85-0.95	0.85-0.9
dry	0.3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.75	0.25-0.3	0.7 -0.8
Cabbage	0.4 -0.5	0.7 -0.8	0.95-1.1	0.9 -1.0	0.8 -0.95	0.7 -0.8
Cotton	0.4 -0.5	0.7 -0.8	1.05-1.25	0.8 -0.9	0.65-0.7	0.8 -0.9
Grape	0.35-0.55	0.6 -0.8	0.7 -0.9	0.6 -0.8	0.55-0.7	0.55-0.75
Groundnut	0.4 -0.5	0.7 -0.8	0.95-1.1	0.75-0.85	0.55-0.6	0.75-0.8
Maize						
sweet	0.3 -0.5	0.7 -0.9	1.05-1.2	1.0 -1.15	0.95-1.1	0.8 -0.95
grain	0.3 -0.5*	0.7 -0.85*	1.05-1.2*	0.8 -0.95	0.55-0.6*	0.75-0.9*
Onion						
dry	0.4 -0.6	0.7 -0.8	0.95-1.1	0.85-0.9	0.75-0.85	0.8 -0.9
green	0.4 -0.6	0.6 -0.75	0.95-1.05	0.95-1.05	0.95-1.05	0.65-0.8
Pea, fresh	0.4 -0.5	0.7 -0.85	1.05-1.2	1.0 -1.15	0.95-1.1	0.8 -0.95
Pepper, fresh	0.3 -0.4	0.6 -0.75	0.95-1.1	0.85-1.0	0.8 -0.9	0.7 -0.8
Potato	0.4 -0.5	0.7 -0.8	1.05-1.2	0.85-0.95	0.7 -0.75	0.75-0.9
Rice	1.1 -1.15	1.1 -1.5	1.1 -1.3	0.95-1.05	0.95-1.05	1.05-1.2
Safflower	0.3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.7	0.2 -0.25	0.65-0.7
Sorghum	0.3 -0.4	0.7 -0.75	1.0 -1.15	0.75-0.8	0.5 -0.55	0.75-0.85
Soybean	0.3 -0.4	0.7 -0.8	1.0 -1.15	0.7 -0.8	0.4 -0.5	0.75-0.9
Sugarbeet	0.4 -0.5	0.75-0.85	1.05-1.2	0.9 -1.0	0.6 -0.7	0.8 -0.9
Sugarcane	0.4 -0.5	0.7 -1.0	1.0 -1.3	0.75-0.8	0.5 -0.6	0.85-1.05
Sunflower	0.3 -0.4	0.7 -0.8	1.05-1.2	0.7 -0.8	0.35-0.45	0.75-0.85
Tobacco	0.3 -0.4	0.7 -0.8	1.0 -1.2	0.9 -1.0	0.75-0.85	0.85-0.95
Tomato	0.4 -0.5	0.7 -0.8	1.05-1.25	0.8 -0.95	0.6 -0.65	0.75-0.9
Watermelon	0.4 -0.5	0.7 -0.8	0.95-1.05	0.8 -0.9	0.65-0.75	0.75-0.85
Wheat	0.3 -0.4	0.7 -0.8	1.05-1.2	0.65-0.75	0.2 0.25	0.8 -0.9

CROP	Crop Development stages					Total growing period
	Initial	Crop develop-ment	Mid-season	Late season	At harvest	
Alfalfa	0.3 -0.4				1.05-1.2	0.85-1.50
Citrus						
clean weeding						0.65-0.75
no weed control						0.85-0.9
Olive						0.4 -0.6

First figure   : Under high humidity (RHmin >70%) and low wind (U<5m/sec).
Second figure   : Under low humidity (RHmin <20%) and strong wind (>5m/sec).

Table 2.1:k$_c$-values of different crops for different growing phases
        under different conditions of relative humidity and windspeed.
        (FAO, 1979).

Many studies have been carried out to analyse the influences on crop-
water requirement (Rijtema, 1970, 1975, Salter, 1969).
The following factors influence the kc-value:
-    plant physiological features (closure of stomata, waxy or hair lea-
     ves)
-    crop height and crop roughness
-    growing phase and ground cover.

A procedure for determination of kc-values of different crops at various
growth phases has been developed by FAO (FAO, 1977); kc-Values are
listed in table 2.1.

ETcrop is defined as: "The evapotranspiration of a disease-free crop,
grown in large fields under optimal soil, water and fertility condi-
tions".
This ETcrop can be used in the water balance equation. The evapotranspi-
ration under non-optimal growing conditions is discussed in section 3.4.
Attention should be given to advection winds and their effect on the
ETcrop. Fields irrigated by windmills can be regarded as green spots in
barren surroundings.
Corrections will have to be made, depending on the location of the
meteo-station from which the data used for determining ETcrop, have been
obtained (FAO, 1977).

2.1.2. Precipitation

Precipitation means rainfall in this case. Only in exceptional cases do dew, hail or snow contribute directly to the water balance of the soil in irrigated areas. To predict the contribution to the water balance, two aspects of rain are important: effectiveness and probability of occurrence.
Not all rain is effective and part of it may be lost by surface run-off, deep percolation or evaporation. The effectiveness of rain depends on rain intensity, soil type, soil depth, cropping pattern, infiltration rates, etc.

Crop intercepted water contributes only indirectly to the soil water balance, by reducing transpiration and so lessening soil water depletion. To determine the effectiviness of the precipitation within a certain interval, local information has to be gathered on the above mentioned effectivity factors. Detailed information can be found in literature (FAO 1975, Vink 1978).
In places were rainfall is variable probability analyses are inevitable. In this paper, the probability of meeting the crop water requirements (E = P + I) is analysed, (section 2.3.3.) since the features, evaporation, precipitation and irrigation (i.e. here windspeed) are not independent variables. Higher windspeed means higher evapotranspiration; high precipitation means low evapotranspiration (overcast). Details about probability analysis of rainfall can be found in literature (Ven te Chow 1964, WHO 1965).

2.2. Water lifting with wind energy

With the help of windmills, wind energy can be converted into mechanical or electric power.
The power characteristic of a windmill is given by:

$$P_o = Cp \; \eta_t \tfrac{1}{2} \; \rho_a \; AV^3 \; (W)$$

in which
P_o = power (Watt)
Cp = power coefficient of rotor (-)
η_t = efficiency of transmission (-)
ρ_a = density of the air (kg/m^3)
A = area of rotor (m^2)
V = wind velocity (m/s)

Since the power relates cubic with the windspeed, it is very important to obtain reliable windspeed data. Hourly average windspeed, measured over a great number of years (10-20) at an open representative place near or in the project area are required for a sound analysis.

Generally the height above ground surface at which observations are made is not the same as the height of the windmill rotor. Since windspeed increases with height, adjustments have to be made.
The adjustment can be made with the following empirical formula:

$$\frac{Vh}{VH} = (\frac{h}{H})a$$

where: Vh = average wind velocity at height h (m/s)
$\overline{VH}$ = average wind velocity at height H (m/s)
h = height of windmill rotor axis(m)
H = height of windspeed measuring device (m)
a = surface roughness exponent

The exponent, a, depends on the roughness of the surface. (Fig. 2.1.)

Measurements in Sudan for instance, showed a = 0.20 over the first 15 m above ground level, where the surface consisted of sand or short crops (grasses).
In open areas on land, a, will in general be between 0.2 and 0.25.

If no wind observations have been made in the project area, a rough impression can be obtained by correlating a short period of measurements in the project area with measurements of the same period from a nearby station (Beurskens 1978). It will be clear that the meteo station should be situated in the same geographical and climatic area, as the planned project.
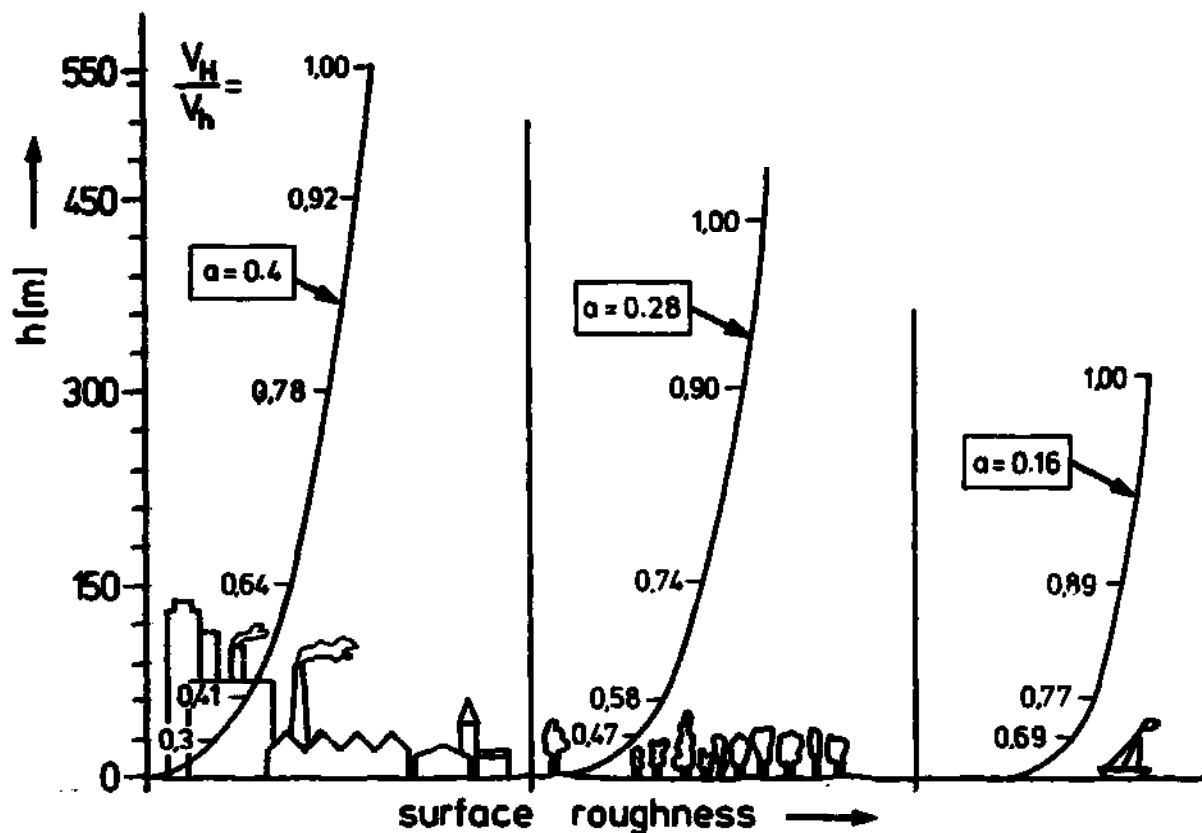
fig. 2.1. V_H/V_h as a function of surface roughness

2.2.1. Wind characteristics

The following analyses of windspeed pattern are important:
a.   daily wind pattern
b.   annual wind pattern
c.   maximum windspeeds
d.   windspeeds frequency distribution

a.   daily wind pattern

The average distribution of windspeed during the day for each month of the year (or for the irrigation season) will indicate at what time irrigation water will probably become available and, if this is inconvenient for the farmer (at night or during the hot midday hours), facilities have to be provided for storage. At meteorological stations windspeeds are often measured in detail during daytime only. If the 24 hour windpattern is known, the contribution of the night hours with regard to the windmill output can also be estimated.

September

m/s

m/s   October
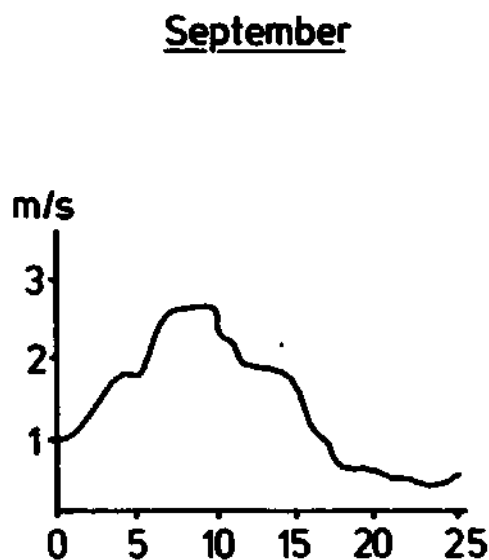
Fig. 2.2.

Daily wind pattern Jakarta, Indonesia
(average 1944, 1952, 1955).
In this month the windmill output may
be expected during the morning hours.
In general the windmill will not run
at night.
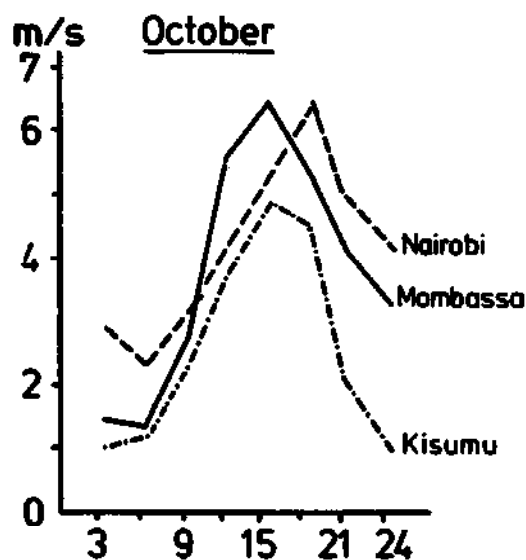
Fig. 2.3.

Daily wind pattern at 3 places in
Kenya (average 1954 - 1959). In
this month the windmill output
may be expected during day time
with a peak in the afternoon. At
Nairobi and Mombassa a windmill
will also run during the evening
hours.

b.   Annual windpattern

      The annual distribution will give a first indication whether wind-
      mills will be able to supply irrigation water when it is needed,
      and which months will be critical in regard to sufficient water
      supply.
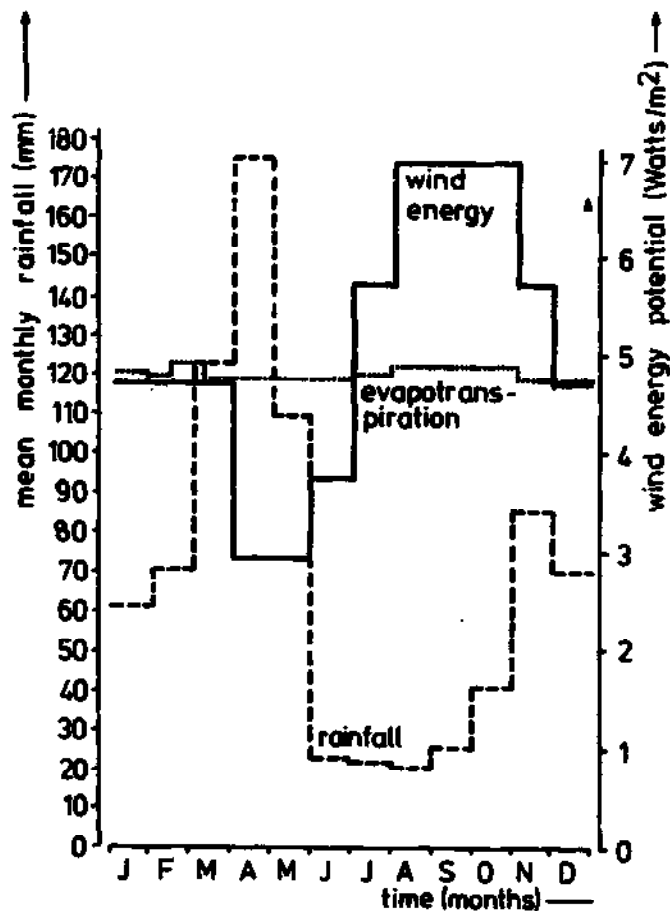
Fig. 2.4. Mean monthly rainfall, evaporation and wind energy potential
at Musoma Airport, Tanzania. (Beurskens, 1978)
Note that the available windenergy is proportional to the
amount of pumped water (for a given evaluation head).

c.   Maximum windspeeds

A good impression of peak windspeeds (gusts) can only be obtained at
places where constant windspeed recordings are made. These speeds
are important for the design of the windmill (strength calculations) and
the governing mechanism.
At places with regular low windspeeds and no gusts, a semi-automatic
governing mechanism may be appropriate whereas a fully automatic gover-
ning mechanism will be required at places with strongly varying wind-
speeds.

d.   Windspeed frequency distribution

      This wind characteristic is an important one: the total amount of
      energy which can be extracted from the wind can be calculated from
      the windspeed frequency distribution and the mill characteristics.
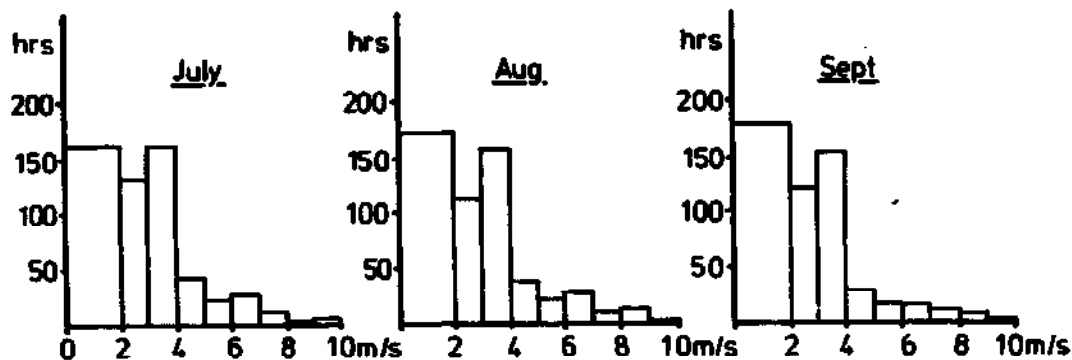
Fig. 2.5. Windspeed frequency distribution of Varanasi Airport (India)
          Average of 1975 - 1978

Montly intervals are usually chosen. For detailed analyses it is better
to use the irrigation interval as the interval for analyses. However, in
general the wind pattern does not vary much within a month, except
sometimes in one in which the weather pattern changes (monsoon starts,
rainy season ends etc.).
Very detailed analyses are often not realistic, due to the limited
reliability of the data and the number of varying parameters.

"Often hourly wind data are not available. However, with the help of
average windspeed data over longer periods, (day, month) an impression
can be obtained of wind energy potentials, using the following formula:

$$P = \frac{Vd}{\overline{V}} \ 0.1 \ V^3 \ A \ (W)$$

where P = power (W)
       Vd = design windspeed of the selected windmill (m/s)
       $\overline{V}$ = average windspeed over a certain period   (m/s)
       A = area swept by the rotor   (m)

The coefficient 0.1 is in fact derived from $\frac{1}{2}.Cp.\eta_t.\rho_a.$, as presented in
the formula on page 24.

The design windspeed is defined as the windspeed at which the energy
conversion efficiency reaches its maximum.
For water-pumping windmills the design windspeed is generally around
3-4 m/sec. For more details about these technical aspects see references
(van de Ven 1979, Lysen, 1980).

2.2.2. Windmill pump performance

The windmill pump performance presents the output of the windmill unit
for different windspeeds at a given total elevation head.
The wind energy conversion formula was stated in the previous section
as:

$$Po = Cp.(\eta_t.)^{\frac{1}{2}} \rho_a .A.V^3 \text{ (W)}$$

The general formula for the power requirements for water lifting is:
$$Po = \frac{\rho_w.g.H.Q \text{ (W)}}{\eta_p}$$

Where:
- Po = Power (W)
- η_p = efficiency of the pump
- ρ_w = density of water (kg/m^3)
- g = gravitational constant (m/sec^2)
- H = total elevation head (m)
- Q = discharge (m^3/sec)

From both formulae it can be concluded that the performance is related
linearly with the square root of the windmill rotor diameter and reci-
procally proportional to the total elevation head.

The total output over a certain period can be predicted from the windspeed
frequency distribution over that period, provided that the windmill pump
performance as well as the cut-in and cut-out windspeed are known
The cut-in windspeed, or starting windspeed, is in general around 3 m/s
for water pumping mills, depending on load and starting torque.
The cut-out windspeed, or maximum windspeed (due to aspects of safety)
is around 10 m/s. At this speed most water pumping mills are governed
out of the wind.
It is obvious that only the windspeed frequency distribution figures
between these 2 limits should be used for the performance calculations.

The windmill performance is difficult to assess accurately under field
conditions and without complex measuring equipment. Moreover the figures
presented in manufacturers manuals are often difficult to adjust to a
local situation and sometimes are rather optimistic.
However, when the mill and the pump are well designed and well keyed to
one another, there should not be much difference between the performances
of the various makes, and these should all correlate with figures derived
directly from the theoretical formulae.

Table 2.2. gives an indication of windmill performance for a windmill driving a piston pump with the following characteristics:
Cut-in: 3m/s, Vdesign: 3m/s; Cut-out. 10m/s. Those figures are derived from the theoretical formula, in which low efficiency factors based on the field test are used.

	Discharge, m³/hr											
Total head (m) elevation	5			10			15			20		
Rotor diameter (m)	3.5	5.0	7.0	3.5	5.0	7.0	3.5	5.0	7.0	3.5	5.0	7.0
W 3-4	3.2	6.5	13.0	1.6	3.2	6.5	1.1	2.2	4.4	0.8	1.6	3.2
I 4-5	4.2	8.5	17.0	2.1	4.2	8.5	1.4	2.8	5.6	1.0	2.1	4.2
N 5-6	6.5	13.0	26.0	3.5	6.5	13.0	2.2	4.4	8.8	1.7	3.5	6.5
D 6-7	8.5	17.0	34.0	4.2	8.5	17.0	2.8	5.6	11.2	2.1	4.2	8.5
S 7-8	10.7	21.5	43.0	5.4	10.7	21.5	3.6	7.2	14.4	2.7	5.4	10.7
P 8-9	13.0	26.0	52.0	6.5	13.0	26.0	4.3	8.6	15.2	3.2	6.5	13.0
E 9-10	16.5	31.0	62.0	7.7	15.5	31.0	5.2	10.3	21.0	3.8	7.8	16.5
E												
D (m/s)												

Table 2.2. General windmill-pistonpump performance figures for different rotor diameters and different elavation heads. (Cut-in windspeed: 3m/s; Vdesign: 3m/s; Cut-out: 10 m/s).

2.2.3. Working efficiency

The theoretical output of a specific windmill-pump combination in a specific wind regime can be calculated as described in section 2.2.2. However, no machine will run for all the hours it can do in theory. Therefore a working-efficiency factor (η_w) has been introduced.

$$Pmax = \eta w.Ptheor.$$

This efficiency depends on many factors but the main ones are management and time required for repairs and maintenance.
For the semi-automatic governed types of windmills, one additional factor has to be mentioned: the number of hours a windmill will be in secured position after the peak windspeeds (≥Vmax) have occurred. This depends on the wind regime (gustiness) and the accuracy of the operator. Such a loss has been estimated at 10%, based on practical data in a low wind regime (van Vilsteren 1979). The loss of working hours due to repair and maintenance will probably vary from 10-20%, depending upon the reliability of the windmill and the organization of the repair and maintenance service.

Note: The breakdown of the windmill pump system will generally occur
          at higher windspeeds, so that if 2-3 days lapses between
          breakdown and repair, the loss in total water output will then
          be considerable. If the service is centrally organized the
          delay is likely to be even greater as many windmills may need
          repair in periods of high windspeeds or storms.

To summarize, the value for working efficiency (n_w) can be estimated at
70-80%, with somewhat higher values for the fully automatic windmill
systems.
If irrigation is not practiced on religious or public holidays and
storage facilities are limited, the actual use made of the water pumped
by the windmills will further be reduced.

2.3.   **Command area**

The command area per windmill can be calculated by means of a water
balance, the main elements of which have been discussed in the previous
sections. Fig. 2.6. gives a graphical presentation of such a water
balance; all figures are expressed in mm/ha.
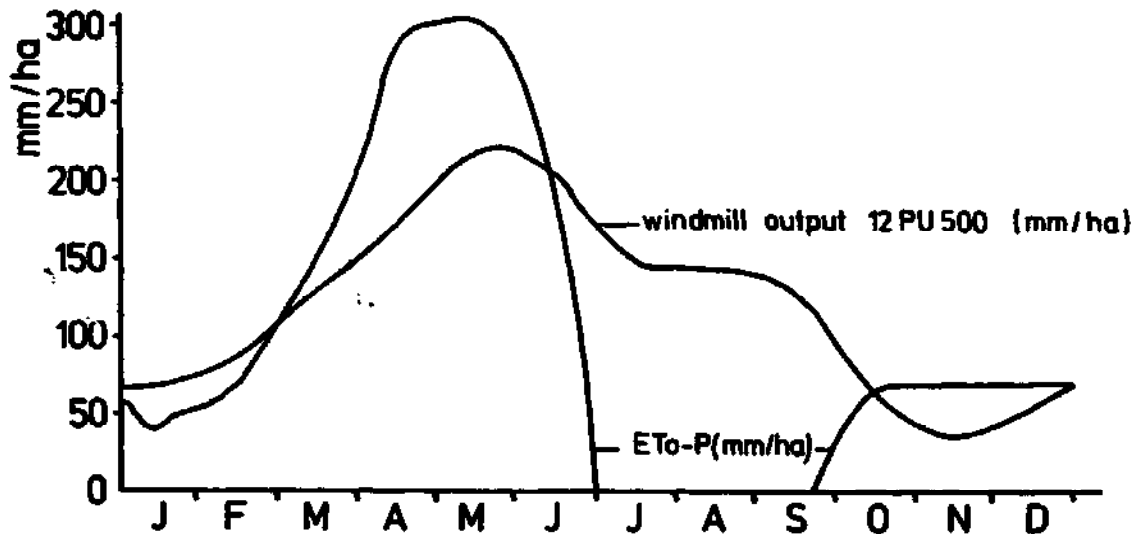
Fig. 2.6. Water balance of the Area around Ghazipur (North India)
          Expressed in mm/ha (1mm/ha = 10m^3)

It can be seen that in this situation there was no need for irrigation in the period July-September (rainy season). From March till July and in November the windmill output was insufficient to meet the requirements of 1 ha.

In such a location it is still possible, by proper crop selection and crop plan adjustment, to supply sufficient water for 1 ha all year round. This is elaborated in section 2.3.1.

Not all the water pumped by the windmill unit will contribute to the water balance of the rootzone. Water will be lost in the canals and the field. Therefore an irrigation efficiency factor has to be introduced. This factor is considered in section 2.3.2.

As stated earlier, evapotranspiration, rainfall and windspeed are inter-correlated and are variable over the years. Therefore a simple probability analysis is introduced in section 2.3.3. to calculate the windmill command area.

2.3.1.　　　　Crop selection and crop plan adjustment

Crop selection is the selection of type of crops to be grown under irrigation.

Crop plan adjustment is the adjustment of the dates of sowing to allow that the crop water requirements during the growing period can be met by the windmill water output. Both are important, since they determine irrigation requirements.

The kc value in ETcrop = kc.ETo varies from crop to crop and depends on the growing phase of the crop (see table 2.1.).

e.g. Rice in the crop development stage: kc = 1.1. - 1.5.
　　　Groundnut in the crop development stage: kc = 0.7 - 0.8.
　　　Ripening wheat: kc = 0.2 - 0.25.
　　　Germinating cotton: kc = 0.4 - 0.5.

The selection of crops for a windmill irrigation scheme is not unlimited. The following aspects have to be considered with regard to crop selection and crop plan adjustments.

a.　　wishes of the participating farmer(s)
b.　　ecological aspects
c.　　inputs and outputs
d.　　socio-ecnomic aspects.

a.　　**Wishes of the participating farmers**

　　　The farmers certainly have ideas about what to grow when irrigation becomes available. Whether it is foodcrope for themselves and their cattle, or crops for the market, farmers' involvement is essential for the success of the project!
　　　In Chapter 4 this will be discussed in more detail.

b. Ecological aspects

    The climate and the soil type determine in general which crops can be
    grown in a certain area.
    Many books about tropical crops give the ecological conditions for
    optimal growth as well as the soil type in which the crop flourishes
    best (Pursglove 1969).
    The main ecological factors are: minimum and maximum temperatures,
    daylength, light intensity, humidity.
    Main aspects of the soil type are: depth of the topsoil, texture and
    structure of the soil, salinity and natural fertility.

    In many places more than one crop can be found in the same field. If
    several crops are grown in the same field without any specific order
    (e.g. mustard and wheat, maize with soja or groundnut), this is
    called mixed cropping.
    With this cropping system optimal use can be made of the comparative
    advantages of each crop: shading, windbreak, difference in rooting
    depth and intensity.
    In areas with a high light intensity and an adequate water supply,
    mixed cropping may be more advantageous than single cropping. Risk
    minimization is another important aspect for small and marginal
    farmers.

    If one crop is planted in between the rows of another crop it is
    called intercropping (onions or black grain between young sugar
    cane, cotton sown between the ripening corns, etc.)
    Intercropping is done to optimize the use of the land, make optimal
    use of the rainy period or to let one crop protect the other (shading,
    windbreak, winderosion).
    Both mixed cropping and intercropping have their specific irrigation
    requirements in regard to interval, depth and efficiency.

    The soil fertility and the soil structure should remain constant or
    be improved by the intended crop plan, by cultural practices
    and/or by fertilizers and manure.
    Soil health can be influenced by crop sequence and crop rotation.
    e.g. -   some pulse crops fixate nitrogen in the soil
         -    deep rooting crops will improve soil permeability and drainage
              capacity
         -    green manure crops and crops with large crop residues will
              improve the organic matter content of the topsoil and conse-
              quently, the infiltration rate and water-holding capacity of
              the topsoil.
    If the project area contains slightly saline or alkanine soils or if the
    irrigation water is slightly saline or alkaline, crop species which are
    tolerant to these phenomena have to be selected. In addition, attention
    has to be given to drainage and leaching, to improve the soil condition.
    (Unesco/FAO 1973).
    A table with figures about the relative tolerance of crops to salt is
    given in Annex II.

c. Inputs and outputs

Once a certain crop plan has been designed, strict attention should
be given to the availability of all the required inputs. Good
quality seed, fertilizers, and, if required pesticides should be
available in time in the project area, as well as sprayers, dusters
and threshers if necessary. The availability of labour for land
preparation, planting, tillage and harvesting is a particularly
important aspect of crop plan designing, since labour availability
is difficult to forecast and lack of it may seriously influence the
adoption of the new crop plan and its ecnomic results.

e.g. -   labour shortage can occur due to: an existing crop plan
          in the region (paddy cultivation, cotton picking); migra-
          tion to towns; social and cultural activities (marriage
          season, religious restrictions, etc.); the climate (du-
          ring the hot period of the year there is often a high
          leisure preference).

These aspects also have to be investigated with regard to the
outputs: the main products and the by-products.
Are marketing facilities as well as processing facilities available
either at the farm or centrally?

e.g. -   fresh fruits and vegetables have to be transported to the
          market directly after harvesting
     -    is sufficient transport available and what is the condi-
          tion of the roads. Are there proper packing facilities so
          that fruit will not be damaged during transportation?

If a crop plan is to succeed, other facilities will be necessary in
addition to the physical ones.
Apart from subsidy and credit facilities for financing the windmill
pump system, small farmers may need crop loans to finance the
inputs. If new crops or different cropping systems and tillage
methods are introduced, a well organized agricultural extension
service will be needed.
Cooperation among farmers may be needed to make full use of the
windmill pumpsystem or the other farm implements such as ploughs,
sprayers, dusters, harvesting and processing machines.
Cooperatives may have to be set up to organize the supply of inputs
or the selling and/or processing of outputs.

d. Socio-economic aspects

The important socio-economic aspects of crop selection and crop
plan adjustments are discussed in Chapter 4.

Local information can be obtained by surveying the project area and
visiting local agricultural institutions (extension services, agricul-
tural research stations and testing and demonstration farms). In general
it is recommended only to introduce a few new crops at a time, while
continuing to use the crops known to the target group. Introducing too
many new items at a time may lead to slow adoption or failure of the
project.

2.3.2. Irrigation efficiency

Not all the water pumped by a windmill will be come available to the
plants in the field. Firstly seepage and evaporation losses will occur
in the storage tank and the conveyance system. Special attention should
be given to the seepage of the tank back to the watersource. Since the
tank usually lies close to the well stream or lake, pollution and
erosion may occur, damaging both the watersource and the foundation of
the windmill. Seepage losses from unlined tanks and channels vary with
the soil type and the means of construction (degree of compaction) and
may range from 5 to 50% of the total amount pumped by the irrigation
device.

Secondly, irrigation water can be lost due to run-off from the field,
specially when border and furrow irrigation methods are applied. These
losses can be minimized by training and motivating the operators.
Thirdly incorrect levelling and dishomogeneity of the soil may cause
irrigation water to percolate beyond the reach of the plant roots. Deep
percolation can partly be avoided by cultural activities (e.g. level-
ling). Losses can also be avoided by applying less water at a time:
scarcity irrigation, deficit irrigation (see fig. 2.7).
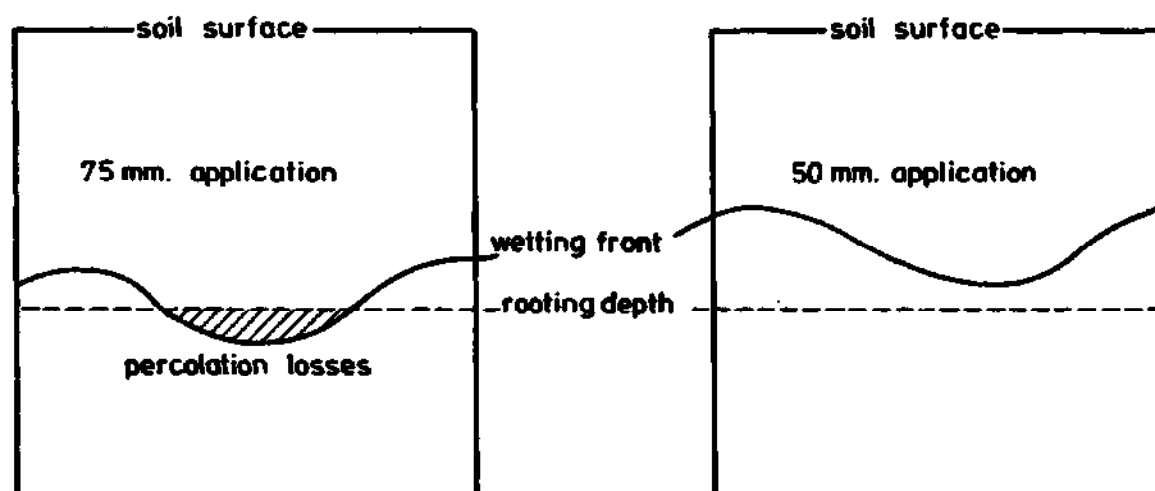
Fig. 2.7. Complete recharge of soil- moisture (left) compared with
partial recharge (right)
(= deficit irrigation)

Advantages of this deficit irrigation are an increased irrigation effi-
ciency and rainfall just after the irrigation will not be lost. Disad-
vantages, are: shortening of the irrigation interval, probably lesser
root development and slightly higher average evapotranspiration.

High losses will not only endanger the viability of the irrigation but
will lead to a rise of the groundwater table and increased risk of
salinization or alkaninization. In the later case, a drainage system
will be needed, which again increases the cost of the system.

Windmill irrigation, with its relatively low output, is especially
sensitive to irrigation efficiency. Therefore, strict attention should
be given to tank and channel design, as well as to the choice of irriga-
tion method, land preparation and training of operators.
Aspects which have a negative influence on the windmill irrigation
efficiency are the relatively small discharge rates and the fact that
the cost of the water pumped by the windmill is nil in the eyes of the
operator (Windmills deliver water free of (variable) costs). This may
affect the degree of attention that is given to irrigation.
The total irrigation efficiency will depend on many of the factors des-
cribed above and will therefore vary from place to place between ap-
proximately 75-30%. This means that where the net irrigation requirement
is 100 mm, the gross water requirement vary from 100/0.75 = 133 mm to
100/0.30 = 333 mm.
It will be clear that improving the irrigation efficiency may be more
effective and economical than increasing the pumping capacity.

Small windmill irrigation systems with direct farmers involvement, will
lead to higher irrigation efficiencies than those quoted in literature
(Hagen, Nugteren, Stern).
Especially if farmers already have some experience in water management,
soils are relatively heavy and the proper irrigation method is chosen,
irrigation efficiencies between 60-70% are realistic.

2.3.3. Probability analyses

Probability analyses of meteo data provide indications of the chance of
occurrence of wind phenomena.
In agricultural engineering, a probability of 75% or 80% is often consi-
dered to be sufficient for planning purposes.
If an irrigation system is designed with 75% probability, it means that
in 3 out of 4 years the capacity will be sufficient to meet the irrigation
requirements.

A simple probability analysis is as follows:
- Arrange the data in ascending sequence.
- Give each data a rank number.
- The probability of occurrence can be calculated with the following
  formula.

$$f_i = (\frac{i}{n + 1}) \times 100 \ (\%)$$

where: f_i = probability of occurence (%)
       i = rank no. in ascending sequence of the data
       n = total number of data

example: 15 data in ascending sequence: (e.g. evaporation in the
                month January for 15 years)
                63, 69, 71, 71, 73, 76, 78, 78, 82, 86, 93, 93, 96, 96,
                99 mm/month
rank no: 1   2   3   4   5   6   7   8   9   10 11 12 13 14
         15

                Applying the formula gives:

$$f_1 = \frac{1}{15 + 1} \cdot 100 = 6.25\%$$

$$f_4 = \frac{4}{15 + 1} \cdot 100 = 25\%$$

                In this case rank no. 4 represents the data (71 mm) which
                will be surpassed in 100-25 = 75% of the years.
                In other words: in 3 out of 4 years the monthly evaporation
                will exceed 71 mm/month.

It will be clear that these calculation can only be made if reliable
date are available from a number of years (at least 10).
If data of more years are available the accuracy of the probability
analyses will increase.
For windmill irrigation, there are three important variables (rain,
evapotranspiration and wind) which are not independent of each other.
Therefore the probability of each of them is not discussed, but their
combination as expressed in the water balance of the rootzone (Stol
1973).

In Annex III a calculation example is presented for a growing season
(March-June), using meteo data of 15 years, in which:
-     Only the effective precipitation is taken into account (Pe) (see
      section 2.1.2).
-     The wind data are converted into water output per month (see sec-
      tion 2.2.2.).
-     An irrigation efficiency factor is introduced to estimate the
      effective irrigation (Ie) (see section 2.3.2.).
-     The evapotranspiration is introduced in 2 steps:
      .   firstly using ETo, to find the critical periods with regard to
           the irrigation needs
      .   secondly using ETcrop, (=kc.ETo) after selection of crops and
           sowing dates.
      If required, part of the irrigation water should be made available
      for leaching, ponding of paddy fields, pre-irrigation etc.

The command area for each month can be found by using the following
formula:

$$\text{Command area} = \frac{ETcrop-Pe}{Ie} \ (ha)$$

Where: ETcrop = crop evapotranspiration (mm/month)
          Pe = effective precipitation (mm/month)
          Ie = effective irrigation (mm/month/ha)

If, after the introduction of a crop plan, the calculations show another criticical period, a third round of calculations may be needed, with a modified crop plan, etc.

If the area which can be irrigated by a specific windmill, does not meet expectations, the diameter of the windmill can be altered.
By changing the rotor diameter by $\sqrt{2}$ D, the power output will be doubled and consequently also the (theoretical) command area. Of course all aspects have now to be reconsidered (technical, capacity of the water source, economics, etc..)
It should be noted that predictions are made for the future on the basis of meteorological data from the past (these predictions will only be valid for the future if the climate can be considered stable).
An increase in the period of analysis increases the reliability of these predictions.

2.4.   Water resources

In Chapter 1, water resources are discussed with regard to their suita-   .
bility for windmill irrigation (openness, etc.).
Here it is again emphasised that the water quality (salinity, alkanlinity) is also a decisive factor in irrigation (Unesco, FAO, 1973).
Accurate water analyses are most essential in any irrigation study (see table 2.3.).

Quality of water	crops suited	conductivity micromhos/cm	TDS * mg/l	Boron ppm
good	all crops	50- 500	0- 600	0 -0,5
moderate	injurious to sensitive crops	500-2200	600-2000	0,5-2
poor to unsuitable	harmful to most crops	over 2200	over 2200	over 2

*)   TDS = Total dissolved solids

Table 2.3:   Standards of irrigation water (Stern, 1979)

Existing water rights are another important aspect. It should be investigated whether additional water withdrawal can be allowed and will be justified and accepted by the other users.
e.g. -   A small spring in Southern Java, Indonesia can be used for lift irrigation by a windmill near the spring. However, downstream this water is already being used for gravitational irrigation.
       -      Small wells in Northern India are used by all the surrounding farmers for bullock irrigation. In one farmer wants to install a windmill, sufficient place and capacity should be left for the other farmers to supply their fields with water by other means from the same well.

The capacity of the water source must be taken into consideration.
Especially during the peak irrigation period, sufficient water should be
available. A lake and a river might only change their waterlevels during the
year, but their capacity will often not be a limiting factor. Attention must
be given to the waterlevel fluctuation for the output calculations as well
as for the depth of installation of the pump.
Careful attention should also be paid to the foundation of the windmill
near the shore of a lake or river.
Small streams may need a small storage (dam) to meet the peak pump capa-
city of the windmill during the day.
If dams are needed to store the water for longer periods (some months)
it is questionable whether this can be organized and financed by small
or marginal farmers. However, dams that are only meant for storing a
small amount of water to meet the fluctuating demand of a windmill pump
system per day do not have to be large or costly. Nevertheless, the main
potential for windmills are the areas where shallow groundwater can be
tapped for irrigation. Of course, here too the capacity of the aquifers
and the recharge of the groundwater have to be investigated as well as
water rights, etc.

With groundwater irrigation, windmills can be placed at the point where
the water is required, so costs for conveyance systems and conveyance
water losses can be limited. In many areas wells exist already, so the
total investment for the farmer will be lower. If the capacity of the
open well is insufficient, a tube well may be needed to tap deep aquifers.

At places with deep water tables the pump can be placed either at the
bottom of the open well or in the tube-well itself. The water table
should not drop more than 6 to 7 metres below the bottom of the pump
during pumping. The capacity of the well at that depth has to be suf-
ficient to meet the capacity of the windmill pump-system.
For output predictions it is important to know how far the water table
will drop during pumping. It is difficult however, to give a general
rule for this, since the amount by which the water table drops at cer-
tain discharges rates can only be determined by pump tests.

The windmill pump system will work at different efficiencies in accor-
dance with variations in elevation head and windspeed.
If the windspeed increases, the output increases and consequently the
waterlevel in the well may drop. Due to this lowering of the watertable
(i.e. increase in windmill-load) the output will fall and finally equi-
librium will be reached. In general the performance efficiency of a
windmill diminishes at increasing windspeeds and constant workload. In
this case however (increasing workload at increasing windspeed) the
overall efficiency will diminish less or not at all.
So far preliminary windmill output predictions, it may be a sound
assumption to use the elevation head which corresponds with Vd (design
windspeed) for all windspeed intervals, since the decrease in water
table (linear) will be easily compensated by the increase in available
power (cubic) at increasing windspeeds. If windmill and well characte-
ristics are known in detail, more accurate output predictions are
possible.

3.   IRRIGATION PRACTICE

Windmill irrigation is very small scale irrigation with command areas up to 5 ha per unit. Therefore no attention is paid to irrigation methods, or irrigation organization and management. These activities take place at farm level and can be managed by the farmer, or group of farmers, if properly advised. (For references see: Stern, Hagen and F.A.O.).
The only recommendation that is again stressed here is not to introduce too many new items at a time. If possible, windmill irrigation should fit in with irrigation practices that are already known in the area.

In this chapter the aspects of irrigation with a variable power source (wind) are discussed. The effects of delayed irrigation due to windless periods are summarized and methods are given to limit the vulnerability of the farming system due to this variability.

A method is presented for the calculation of the irrigation interval and ways of extending this interval are described. The relation between crop water use and crop production is discussed as well as the influence of other inputs on the crop production.
Pre-irrigation and the introduction of drought resistant crops can also improve the application of the wind pumped water. The function of a small storage tank is also dealt with. A summary concludes the chapter.

In this chapter we use two different symbols for ETcrop:
1.   ETm: maximum crop evapotranspiration without limits in regard to water and other inputs.
2.   ETa: actual crop evapotranspiration under the given conditions (ETa $\leq$ ETm).

3.1.   Irrigation interval

The irrigation interval (IN) is defined as the period between two successive irrigations. The length of this period depends on:
-    Available moisture in the soil   : A.M. (mm/m)
-    Rooting depth of the crop   : D(m)
-    The evapotranspiration rate   : ETm (mm/day)

The amount of available moisture in the soil depends strongly on the type of soil, as can be seen in Table 3.1.

Available Moisture at Field Capacity*			
Soil type	Dry density (gr/cm³)	Available water	
		%	mm/m
Fine sand	1.60 - 1.76	2 - 3	30 - 50
Sandy loam	1.28 - 1.68	3 - 6	40 - 100
Silt loam	1.10 - 1.50	6 - 8	60 - 120
Clay loam	1.10 - 1.50	8 - 14	90 - 210
Clay	1.44 - 1.54	13 - 20	190 - 300

*   Field capacity: situation, 2-3 days after abundant irrigation or
      rainfall.

Table 3.1:   Available moisture of different soil types (Stern, 1979,
               page 85).

The rooting depth differs for different types of plants. Roots develop
from zero at the moment of sowing until the typical final depth at
full growth, provided the soil and moisture conditions are not
restricting. Table 3.2. provides a guideline for rooting depth under
optimal soil and water conditions.

Rooting depths at full growth (m)					
Shallow		Medium		Deep	
Beans	0.5-0.7	Grains	0.9-1.5	Alfalfa	1.0-2.0
Cabbage	0.4-0.5	Clover	0.6-0.9	Cotton	1.0-1.7
Grass	0.4-0.6	Eggplant	0.9-1.2	Orchards	1.0-2.0
Onions	0.3-0.5	Peas	0.6-1.0	Maize	1.0-2.0
Potatoes	0.4-0.6	Tomatoes	1.0-1.5	Sorghum	1.0-2.0
Rice	0.5-0.7	Watermelons	1.0-1.5	Sugarcane	1.0-2.0

Table 3.2:   Guidelines for rooting depths under optimal conditions
               (FAO, no. 24, table 39).

Note: It is recommended to inquire about the soil characteristics and
          crop rooting depths at a Agricultural Research Station in the
          region.

If the crop evapotranspiration is also known (ETm = kc.ETo, see sec-
tion 2.1.i) the irrigation interval can be calculated with the following
formula:

$$IN = \frac{AM \times D}{ETm} \text{ (days)}$$

example: beans in the crop development stage at a clay loam soil, with:

$$AM = 120 \text{ mm/m (table 3.1)}$$
$$D = 0.6 \text{ m} \quad \text{(table 3.2)}$$
$$ETo = 8 \text{ mm/day}$$
$$ETm = kc.ETo: \quad kc=0.8 \text{ (table 2.1)} \quad ETm = 6.4 \text{ mm/day.}$$

thus: $$IN = \frac{120 \times 0.6}{6.4} = 11 \text{ days}$$

Different crops have different rooting intensities and dif-
ferent capacities to withdraw water from the soil, which holds the water
with increasing tenacity during depletion. So not all the available
water in the soil will be easily available to the plants. The part of
the available moisture which can be depleted without causing ·
reduction in the crop evapotranspiration is represented by the frac-
tion p.
This p-fraction depends on the following variables:
1. type of plant
2. magnitude of ETm
3. type of soil.

Based on physical characteristics of plants with regard to rooting
intensities and resistance values for waterflow in the plants, four
different crop groups are distinguished. These are presented in Table 3.3.
The crops have an increasing capacity (starting from crop group 1) to
withdraw water from the soil; so the p-fraction of instantly available
moisture increases from crop group 1 upwards to 4.

Group	Crops
1	onion, pepper, potato
2	banana, cabbage, grape, pea, tomato
3	alfalfa, bean, citrus, groundnut, pineapple, sunflower, watermelon, wheat
4	cotton, maize, olive, safflower, sorghum, soybean, sugarbeet, sugarcane, tobacco

Table 3.3: Division of crops in four groups with increasing capacity
to withdraw water from the soil (FAO, 1979).

The magnitude of ETm also influences the fraction p.
This is caused by the resistance for waterflow to the roots
and through the plant. The higher ETm the larger the flow and the higher
the resistance and so the earlier the point will be reached at which the
ETa will fall below ETm.
So even with a relatively wet soil, evapotranspiration may be below
potential evapotranspiration (e.g. sugarbeets wilt in the middle of
the day due to high ETm. In the evening, the wilting is over due to
decrease of ETm).

The fraction p of instantly available soil water, in which ETa is equal to ETm, varies with the level of ETm as is shown by table 3.4 (FAO, 1979).

Crop Group	ETm mm/day								
	2	3	4	5	6	7	8	9	10
1	0.50	0.425	0.35	0.30	0.25	0.225	0.20	0.20	0.175
2	0.675	0.575	0.475	0.40	0.35	0.325	0.275	0.25	0.225
3	0.80	0.70	0.60	0.50	0.45	0.425	0.375	0.35	0.30
4	0.875	0.80	0.70	0.60	0.55	0.50	0.45	0.425	0.40

table 3.4:   The instantly availably moisture fraction (p) for four different crop groups at different levels of ETm (FAO, 1979).

Soil water is more easily transmitted to and taken up by the plant roots in light textured soils than in heavy ones. Somewhat higher values of p would seem to apply to light textured soils than to heavy textured soils. Consideration of soil texture would add little to the accuracy and therefore is not given further attention here.

The irrigation interval in which ETa = ETm can be determined according to:

$$IN = \frac{AM \times D \times p}{ETm}$$

where: IN   = irrigation interval (days)
          AM   = available moisture (mm/m)
          D   = rooting depth (m)
          p   = instantly available moisture fraction
          ETm   = crop evapotranspiration (mm/day)

Example: The same beans as in the previous example in this section:
          AM   = 120 mm/m; D = 0.6 m;
          ETo   = 8 mm/day; kc = 0.8 ETm = 6.4 mm/day
          p   = 0.44 (beans belong to crop group 3 (table 3.3/3.4)
          IN   = $\frac{120 \times 0.6 \times 0.44}{6.4}$ = 5 days

3.2   Variability of irrigation interval

The determination of the irrigation interval as presented in the previous section is based on average meteorological data. However ETo and consequently the p-fraction vary from day to day.
Here consideration is given to the influence of decreasing windspeed on the length of the irrigation interval.

In practice, the question is how many days can irrigation be delayed at periods of low windmill output, without seriously hampering crop development.

As mentioned in section 2.1.1, windspeed influences the reference evapotranspiration (ETo). In Annex I-A this effect has been calculated for three different temperatures, windspeeds and relative humidities, keeping all other factors constant. Fig. 3.1 is derived from that calculation and shows the influence of the relative windspeed $(V/\bar{V})$ on relative evapotranspiration $(ETo/\overline{ETo})$.

e.g. If the windspeed decreases by 50% $(V/\bar{V} = 0.5)$, evapotranspiration decreases to 82% of $\overline{ETo}$ $(ETo/\overline{ETo} = 0.82)$, if the relative humidity is 30%.
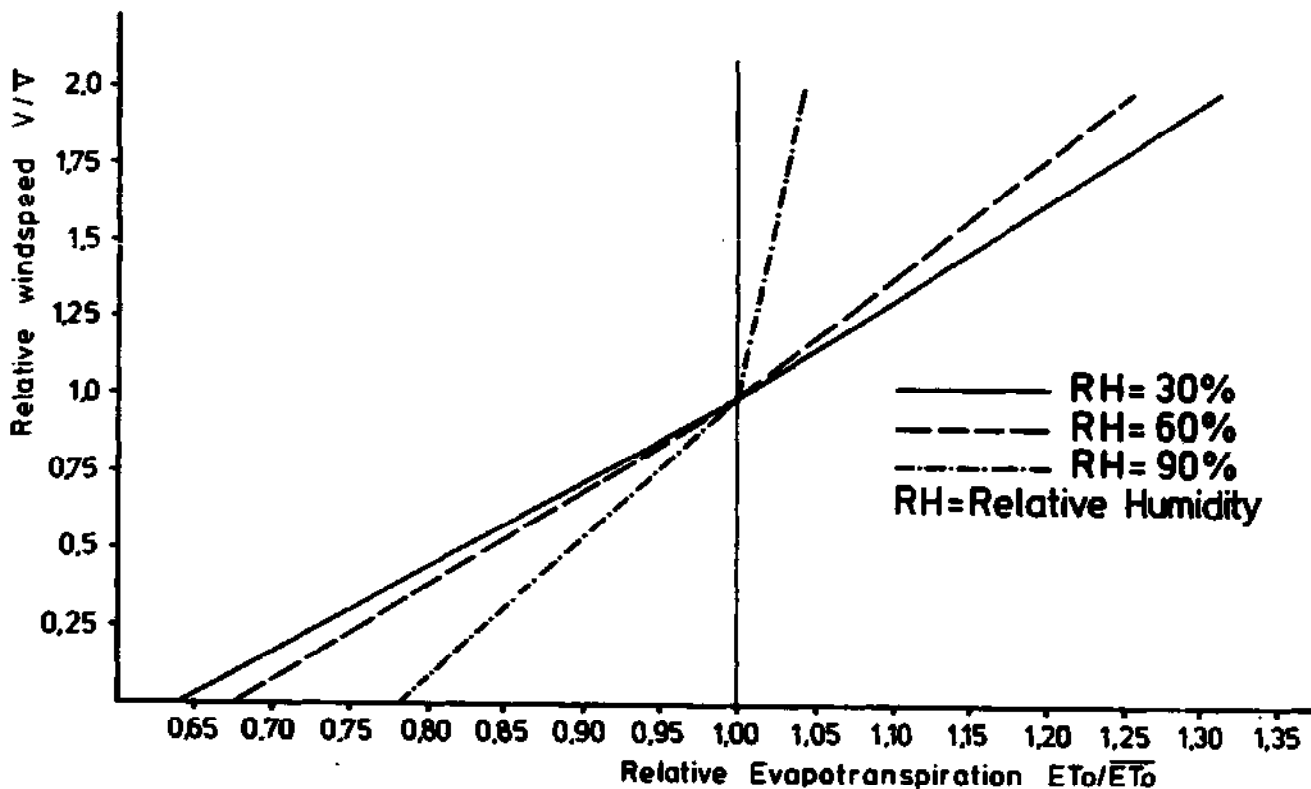
Fig. 3.1. Influence of relative windspeed on relative evapotranspiration (derived from the penman formula, with a lineair function for the aerodynamic component)

From figure 3.1 it can also be seen that windspeeds above $\bar{V}$ have
less influence on the ETo than do windspeeds below $\bar{V}$. This, combined
with the fact (section 2.2.1), that the windmill output increases more
than linearly with increasing windspeeds, may lead us to the conclusion
that high windspeeds during the irrigation interval will not shorten the
length of that interval.

Since the main interest is on the number of days (d) that irrigation can
be delayed the aspects considered here are the decrease of ETo in such a
situation and consequently the increase in irrigation interval IN.
The procentual decrease in average daily windspeed before the daily
windmill output fall to zero, depends on the daily windspeed distri-
bution (see section 2.2.1). In general a decrease in the average
daily windspeed will lead to a more than proportional decrease in
windmill output, or even no output at all.

example: 24hr average windspeed: 3 m/s   Windmill output*
            Windspeed distribution: night: 12 hr x 2m/s   -----
                                    morning: 6 hr x 3m/s   6 x 3.2 m³
                                    afternoon: 6 hr x 5m/s   6 x 6.5 m³

            24hr average windspeed: 1.5 m/sec (reduction 50%)
            Wind speed distribution I:
                             night: 12 hr x 0.5m/s   ----
                             morning: 6 hr x 2 m/s   ----
                             afternoon: 6 hr x 3 m/s   6 x 3.2 m³
            Output reduction: ± 70%

            Windspeed distribution II: night 12 hr x 1m/s   ----
                                       day   12 hr x 2m/s   ----

            Output reduction: no output at all.

With a decrease of 50% in 24hr average windspeed, ETo will decrease
to ± 83% of ETo (RH between 30 and 60%; RH of 90% is not realistic for
areas in need of irrigation).

*) Windmill output: see Table 2.2 (Rotordia 5 m, elevation head 10 m).

The kc-factor is also influenced by wind and humidity, as can be seen in
Table 2.1. In general it can be concluded that the kc-values decrease by
± 10% if the windspeed decreases to 50% of the 24hr average windspeed.
Since ETm = kc.ETo, ETm will reduce up to 90% of ± 83% or ± 75% of $\overline{ETm}$.
For further calculation examples we will use the figure of 75% of $\overline{ETm}$.

The soil moisture fraction (p) which can be depleted before irrigation
will be required, is closely related to ET_m as can be seen in Table 3.4.

Crop Group	ET$_m$ mm/day								
	2	3	4	5	6	7	8	9	10
1	0.50	0.425	0.35	0.30	0.25	0.225	0.20	0.20	0.175
2	0.675	0.575	0.475	0.40	0.35	0.325	0.275	0.25	0.225
3	0.80	0.70	0.60	0.50	0.45	0.425	0.375	0.35	0.30
4	0.875	0.80	0.70	0.60	0.55	0.50	0.45	0.425	0.40

Table 3.4:   The instantly available moisture fraction p, at different ETm levels for four different crop groups (FAO, 1979).

So a decreasing ET$_m$ due to lower windspeeds will result in an increasing soil moisture fraction p, which will be instantly available for evapotranspiration. Filling in these new data in the formula for the irrigation interval, will give an indication about the possible delay (d) which can be allowed before ETa will fall below its optimal value (ETm).

Example:
Continuation of the previous example with the beans. Given:
AM = 120 mm/m; D = 0.6 m; ETm = 6.4 mm; p = 0.44; I = 5 days.
Suppose the 5th day is a windless day, so there will be no irrigation water available for plot p1, which was scheduled for the end of that day.
Due to this windless day, ETm will decrease to, say 75% of $\overline{ETm}$ or 4.8 mm and consequently p will become 0.52 (see Table 3.4). The additional amount of available moisture will be: 120 x 0.6 x (0.52 - 0.44) = 5.8 mm. From the 5th day another 6.4 mm is still available. So the extension of the irrigation interval (d) will be now:

$$\left(\frac{(1 \times 6.4) + 5.8}{4.8}\right) - 1 = 1.5 \text{ day}$$

This means that even another 1½ windless day will not cause a decrease of ETa below its optimal level ETm.
However, before this plot p1 can be irrigated it will have to be a windy day so that the windmill runs. At that time ETm will increase and then the cropwater requirements cannot be met for 100%. Still this need not be very harmful for crop development and crop production, if it is a short period (see section 3.5).
For plots p2 and p3 which are scheduled for irrigation on days d1 and d2 respectively an even longer delay of the irrigation is possible, due to the reduction of the ETm value.

Example: continuation of previous example with the beans.

$$\text{Plot p2: } \left(\frac{(2 \times 6.4) + 5.8}{4.8}\right) - 2 = 1.9 \text{ days delay allowable}$$

$$\text{Plot p4: } \left(\frac{(4 \times 6.4) + 5.8}{4.8}\right) - 4 = 2.5 \text{ days delay allowable}$$

$$\text{Plot p5: } \left(\frac{(5 \times 6.9) + 5.8}{4.8}\right) - 5 = 2.9 \text{ days delay allowable}$$

Table 3.5 gives the possible delay period in days (d) which can be allowed during a windless period without hampering crop production. The same method of calculation has been applied as in the previous example, using Table 3.4 and a crop evapotranspiration reduction of 25%. The general formula is as follows:

$$d = \frac{\overline{ET_m}.t + TAM \ (p1 - p2)}{x \ \overline{ET_m}} - t$$

rewritten: $d = (\frac{P1-P2}{x \ \overline{ET_m}}).TA; + t \ (\frac{1}{x} - 1)$

where:

d	:	possible delay of irrigation (days)
$\overline{ET_m}$	:	average daily crop evapotranspiration (mm/day)
TAM	:	Total Available Moisture in the soil (A.M. x D) (mm)
p1	:	p-value corresponding to $\overline{ET_m}$ (see table 3.4)
p2	:	p-value corresponding to $\overline{ET_m}$ (see table 3.4)
t	:	number of days before the end of the planned irrigation interval (d)
x	:	reduction factor of $\overline{ET_m}$, depending on the magnitude of the windfunction in the evapotranspiration formula and the reduction in the kc value due to declined wind speed.

	$\overline{ET_m}$ expressed in mm/day																			
	4 mm/day				5 mm/day				6 mm/day				7 mm/day				8 mm/day			
TAM (mm)	50	100	200	400	50	100	200	400	50	100	200	400	50	100	200	400	50	100	200	400
c r o p g r o u p 1	2	3	5	10	2	3	6	12	1	2	4	7	1	1	3	5	1	1	2	4
2	2	4	7	14	2	3	6	12	1	2	4	8	1	1	3	5	1	1	3	5
3	2	4	7	14	2	4	7	14	1	2	5	9	1	1	3	5	1	1	3	5
4	2	4	7	14	2	4	7	14	1	2	5	9	1	2	4	7	1	2	4	7

Table 3.5: The number of days irrigation can be delayed, depending on the average level of crop evapotranspiration ($\overline{ET_m}$) and the soil moisture storage capacity (TAM) for the four groups of crops, if 24hr average windspeed decreases by 50% (x = 0.75).

Without taking the figures of Table 3.5 as absolute figures, it can be concluded from this table that increasing the soil moisture storage capacity (TAM) will lead to an increase in possible delay of irrigation. The same can be said with regard to the crop groups. Crop group 4 will be less hampered by windless periods than crop group 1.
The TAM can be influenced by choosing deep rooting crops. A derived advantage of a deep rooting zone is a long irrigation interval and consequently the increased manipulation possibilities with regard to the moment of irrigation: optimalization of the storage function of the soil.

The figures given above can be used in the crop selection in order to realize optimal water use even under highly variable wind conditions.

3.3. Relation between evapotranspiration and crop production

Until now all efforts have been made to ensure that the actual evapotranspiration of a crop (ETa) equals the potential crop evapotranspiration (ETm), because it is known that under limited evapotranspiration, (partial) closure of stomata will take place. This not only reduces the waterlosses but also limits the uptake of carbondioxide (CO_2) and consequently the ultimate production (Vink, 1980, FAO 1979).
The effect of reduced evapotranspiration on total yield is considered and the yield response factor k_y introduced in this section.
High k_y-values mean: high sensitivity to water shortage, low k_y-values mean: low sensitivity to water shortage.
The yiels response factor k_y quantifies the relation between relative yield decrease and relative evapotranspiration deficit as follows:

$$(1 - \frac{Ya}{Yp}) = k_y \ (1 \ \frac{ETa}{ETm})$$

Ya = actual production (kg/ha)
Yp = potential production (kg/ha)

This effect may either occur over the total growing period or over one of the different growth phases. For irrigation practice it is essential to know at what periods high k_y-factors occur, so that in cases of scarcity, priority can be given on the basis of this factor. It should be kept in mind, however, that the above mentioned linear relation only holds for water deficits up to 50%. Attention should therefore be given to the question whether supplying all the water to the crop with the highest k_y-value will produce optimal results, or if some of it must go to the other crops.

For irrigation planning it is essential to know which crops will have high k_y-values and which low ones.
By introducing crops with high- and low k_y-values together in the crop plan, more margin is provided in varying the irrigation interval.
Introducing only crops with low k_y-values may be optimal in regard to risk minimization in crop production, but will not automatically lead to the optimal economic solution. In general there will be a relation between crop sensitivity to production risks (water shortage, pests, soil quality etc.) and market prices.

In irrigation planning it is essential to avoid two or more crops reaching their k_y-sensitive period at the same time. Especially in windmill irrigation planning with its variable daily output, and the possibility of shortage of irrigation water during a number of consecutive days, this aspect deserves attention.

It will be clear that, if possible, none of the crops grown should reach the k_y-sensitive stage during the critical month for windmill irrigation. Or that only one of that type of crops covers only a relative small area, so priority can be given to that crop during shortage.
Table 3.6 gives the k_y-values for different crops during different growing phases.

Crop	Vegetative periode (1)			Flowering period (2)	Yield formation (3)	Ripening (4)	Total growing period
	early (1a)	late (1b)	total				
Alfalfa			0.7-1.1				0.7-1.1
Banana							1.2-1.35
Bean			0.2	1.1	0.75	0.2	1.15
Cabbage	0.2				0.45	0.6	0.95
Citrus							0.8-1.1
Cotton			0.2	0.5		0.25	0.85
Grape							0.85
Groundnut			0.2	0.8	0.6	0.2	0.7
Maize			0.4	1.5	0.5	0.2	1.25
Onion			0.45		0.8	0.3	1.1
Pea	0.2			0.9	0.7	0.2	1.15
Pepper							1.1
Potato	0.45	0.8			0.7	0.2	1.1
Safflower		0.3		0.55	0.6		0.8
Sorghum			0.2	0.55	0.45	0.2	0.9
Soybean			0.2	0.8	1.0		0.85
Sugarbeet							
beet							0.6-1.0
sugar							0.7-1.1
Sugarcane			0.75		0.5	0.1	1.2
Sunflower	0.25	0.5		1.0	0.8		0.95
Tobacco	0.2	1.0			0.5		0.9
Tomato			0.4	1.1	0.8	0.4	1.05
Water melon	0.45	0.7		0.8	0.8	0.3	1.1
Wheat							
winter			0.2	0.6	0.5		1.0
spring			0.2	0.65	0.55		1.15

Table 3.6: k_y values for different crops in different growing phases (FAO 1979).

Calculation example:
Three crops occupying equal areas and in the following growing phases, see table 3.6.

	Maize gr. phase 2.	Soyabean gr. phase 1.	Tomato gr. phase 3.
k_y factors	1.5	0.2	0.8
ETm mm/month (arbitrary)	250	150	200

Total net required amount of irrigation water: 250 + 150 + 200 = 600 mm.
Suppose available: 500 mm and same economic values for all 3 products (yield in kg x price per kg is equal), so average yield reduction will be the decisive factor. Thus ETa will be ETm - 33 mm for each crop.
Equal distribution of the deficit will give the following yield reduction:

Maize	Soya	Tomato
$1 - Ya/Yp = 1.5(1 - \frac{217}{250})$	$1 - Ya/Yp = 0.2(1 - \frac{117}{150})$	$1 - Ya/Yp = 0.8(1 - \frac{167}{200})$
$Ya = 80\% \ Yp$	$Ya = 96\% \ Yp$	$Ya = 87\% \ Yp$

Ya average over the 3 crops is: $\frac{80 + 96 + 87}{3} = 88\%$ of Yp

Due to the low k_y value of soya, it is preferable for the soya to bear the main part of the deficit. This can be done only upto 50 mm (arbitrary) otherwise the soya will be damaged too much. The rest of the deficit will be borne by the tomato crop (lower k_y than maize).

Maize	Soya	Tomato
	$1 - Ya/Yp = 0.2(1 - \frac{150}{100})$	$1 - Ya/Yp = 0.8(1 - \frac{150}{200})$
$Ya = 100\% \ Yp$	$Ya = 91\% \ Yp$	$Ya = 80\% \ Yp$

Ya average is now: $\frac{100 + 91 + 80}{3} = 91\%$ of Yp

However, in the case than the economic value of tomato is 3x the economic value of maize and soya, production loss will be more severe if incurred on tomatoes instead of maize, despite the maize high k_y-value. Then the deficit should be divided between maize and soya:

Maize	Soya	Tomato
$1 - Ya/Yp = 1.5(1 - \frac{200}{250})$	$1 - Ya/Yp = 0.2(1 - \frac{100}{150})$	
70%	93%	100%

Now the production in money terms will be:
$\frac{70\% + 93\% + 3.100\%}{5} = 93\%$ of the potential production.

In other cases the safeguarding of the farmer's own food production may be the decisive criterion.

For more complicated situations optimalization techniques are needed
to find the optimal solution. In practice the choice will be
limited (few crops, clear difference in production level and prizes) so
that by a simple trial and error method the optimal solution can be
found.

3.4.   Other limiting input levels

Upto now, irrigation water availability has been used as the only limiting
factor for crop production. (See also definitions of ETo and ETcrop in
section 2.1.1.). This, however, will seldom occur. As soon as one limiting
factor has been removed, another will come up (soil fertility, plant-
variety, plant-density, pests, diseases, cultural practices etc.).
Potential production levels will be reached only at research stations.
Especially small holding agriculture in third world countries, on which
this report is focused, will not reach these potential production
levels. (e.g. although potential paddy production can be 10 ton/ha, an
actual production of 2-3 ton/ha is common.)

Fig. 3.2 shows the relation between yield and evaporation for two diffe-
rent nitrogen levels.
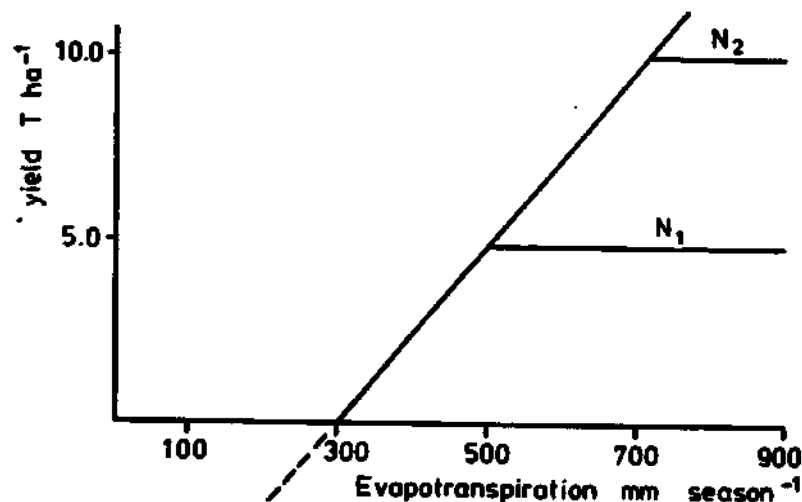
Fig. 3.2. Relation between yield and evapotranspiration for two different
          nitrogen levels (Vink, 1980)

So it will be clear that under practical field conditions with numerous
limiting production factors, the ultimate production level will probably
not be influenced significantly if ETm is not always reached during the
growing season.
This gives additional freedom to the irrigation planner. On the other
hand it places an additional burden on the irrigation operator and his
supervisor to see that all possible obstacles to optimal production are
removed. (i.e. optimize the effect of irrigation). This means in general
that the extension service should not only give attention to optimal
irrigation practices, but to all aspects with regard to crop production
(see also section 2.3.1.).

3.5.   Pre-irrigation and drought resistant crops

Besides the previously mentioned possibilities of adjusting the irri-
gation interval, the useful application of the variable windmill output
can also be increased by pre-irrigation and by including drought resis-
tant crops in the crop plan.

Pre-irrigation.

Pre-irrigation means, filling the rootzone with moisture before sowing
the crop. Often minor pre-irrigation will be required to make soil
preparation possible. The soil can also be refilled with water,
say up to 1 meter. Some of the moisture will be lost by evaporation from
the bare soil and some will percolate to deep soil layers, but the main
part will remain in the rooting zone.
Crops can make use of this moisture at a later stage.
Evaporation of the bare soil can be limited by shallow ploughing or
harrowing and by prevention of weed growth.
This pre-irrigation system makes optimal use of the capacity of the soil
to store water thus reducing the difference between monthly windmill
output and monthly cropwater requirement.

Drought resistant crops.

Some crops, like barley, sorghum and peas, are able to make use of the
remaining soil moisture by their intensive and deep rooting system. With
irrigation their yield would be higher, but they are also productive to
some extent without irrigation. By including such crops in the crop
plan, excess windmill output can be used for these crops, thus optimi-
zing the windmill irrigation system. Green manure crops and/or fodder-
crops are also suitable for this purpose.

3.6.   Need for a storage tank

In general a storage tank of sufficient capacity to meet short windless
periods (100 - 500 m³) is not feasible due to its costs and the space it
requires.
In the sections 3.2 to 3.4 it is shown that with sound crop selection
and irrigation management, windless periods of several days can be
overcome without any significant loss in final crop production.
Storage tanks of even larger capacities to overcome months with low
windspeed will only be feasible if they can be constructed at low cost,
do not occupy arable land (specific topographical situations) and the
seepage can be limited (rocky formations or heavy clay soils). These
conditions will only be met in specific situations. Moreover such a tank
may give problems to unskilled operators: over-irrigation as long as
water is available and a shortage later.
In general it will be more economical to adjust the crop plan and com-
mand area to the monthly water output of the windmill and to make use of
pre-irrigation, fallow and growing drought resistant crops during low
wind months.
In conclusion it can be said that the variable windmill output per month
can be used quite effectively by proper crop selection and crop sequence
and good water management, making all possible use of the storage capa-
city of the rootzone. No large storage tanks are needed for this purpo-
se. The situation is different for the windmill output variation during
a day.
The possibility of a small storage tank with a capacity of about 50-100%
of the average daily windmill output to collect the water pumped during
the night or parts of the day needs careful consideration in regard to:
-    increased irrigation efficiency with larger flows (upto 20 l/s)
-    freedom of the operator with regard to moment of irrigation
-    windspeed distribution over the day
-    costs of the tank and space requirements
-    multipurpose function of tank
-    cost-comparison between increased windmill diameter and cost for
     tank construction.

Increased irrigation efficiency.

If a windmill pumps continuously with a capacity of 2 - 3 l/s and the
water flows directly through the channels into the fields, evaporation,
and deep percolation losses occur continuously as well.

Freedom of operator to decide when to irrigate.

Continuous irrigation will require continuous attention. Without this,
irrigation efficiency will be reduced further, also because the flow
will vary constantly due to varying windspeeds. Constant attention for a
small flow is very inefficient and expensive. The farmer has other
things to do besides irrigation and irrigation at night as well as
during the hot midday hours is unattractive. In practice all these
factors will lead to unattended irrigation and consequently low irri-
gation efficiency. A small storage tank may (partly) solve the problem.

Windspeed distribution

Certain areas have a very specific daily windspeed pattern, with a few
hours of good wind and hardly any wind during the rest of the day (e.g.
around big lakes in Africa). In general the windspeed distribution is
less favorable, although there is mostly a peak during day time hours and
low windspeeds during the night.

Multipurpose function of tank

Windmill water will also often be used for drinking, bathing and wash-
ing. The tank is often a swimming pool for children. This may lead to
pollution of the water and development of diseases like bilharzia. The
shallow tank with standing water can also become a source for malaria
mosquitoes and other pathogens. If the tank is emptied daily and refil-
led with fresh water these problems will not easily arise.
The tank can also be used for fish breeding or growing blue-green algea.

Cost aspects

As has been discussed earlier in this chapter, the cost of tank con-
struction depends mainly on the soil type, which determines whether
lining is required or not. The space requirements for a small tank will
not be too great a barrier. (50 - 100 m^2 for a tank of 50 - 100 m^3).
If the costs of a tank are high (lining) it should be considered whether
a windmill with a larger capacity, to compensate the irrigation losses,
would provide a better solution. Depending on the daily windspeed dis-
tribution and the number of hours the farmer is willing or able to
attend the irrigation flow, an estimation can be made of the irrigation
water losses without a tank and thus the required increase in capacity
of the windmill or decrease of the command area per windmill.
A special case when no tank will be required occurs when paddy is
continuously part of the crop plan. The standing water of the paddy
field can function as a storage tank. Other crops can be irrigated
from this field if the topography allows this. The windmill can pump
the water continuously into the paddy field. Or to the other crops at
hours with high discharge and during the rest of the day into the paddy
field.

3.7.   Summary

In the planning and the management of a windmill for an irrigation
scheme, the following aspects should be considered:
-    The crop evapotranspiration will decrease significantly (10-30%) if
     the windspeed decreases considerably (40-60%).
-    If the crop evapotranspiration decreases the fraction of instantly
     available soil moisture increases and irrigation can be delayed by
     one or more days.

- The reduction of the evapotranspiration to below the optimal value, does not necessarily have severe effects on the crop development and crop production; this will depend on the growth phase of the crop.
- Often the availability of water is not the only impediment to crop production in small holder agriculture in the developing countries. Therefore making a goal of optimal water availability to the crop in all growth phases is not practical.
- By practising pre-irrigation and including drought-resistant crops in the crop-plan, the variable windmill output can be further optimized.
- Large storage tanks are generally not economical. Small storage tanks are often essential in order, to increase irrigation efficiency and to free the farmer for other duties besides irrigation.

On the basis of these considerations the following guidelines can be given for the design of crop plans that will minimize the reduction of crop production due to the day to day variable windmill output.
- The crop plan should consist of different crops known to the farmers. These crops should preferably differ in the depth and intensity of rooting and in sensitivity to water shortage.
- The sowing dates of different crops should be planned in such a way, that the growth phases with maximum sensitivity to water shortage do not coincide.
- As few crops as possible should reach their critical growth phase in the month(s) when the average windmill output is at its lowest value.

4.   SOCIAL AND ECONOMIC ASPECTS

Windmill irrigation is not a goal in itself. The ultimate aim will be
the improvement of the socio-economic situation of the project target
group (small- and marginal farmers).
Furthermore is a windmill not automatically the only and optimal device to
achieve this aim. Therefore intensive socio-economic feasibility studies
are essential before windmills are introduced on a large scale.
Such feasibility studies are difficult to carry out because windmills
(and often small scale irrigation itself) are unknown in the project
area.
So it is hard to collect opinions on and to estimate all kinds of
socio-economic effects connected with their introduction. Therefore it
is strongly recommended to start with small pilot projects. Besides
providing all kind of technical information, the socio-economic aspects
can also be studied, especially if a few windmills are placed at the
farms of the target group. If successful, these windmills will
demonstrate their possibilities and may be accepted as an alternative
waterlifting device in the area.

It is also recommended not to reserve this technology only for the target
group. This might have all kind of negative effects. The new device
should be available for everybody who wants one, but the feasibility
study and the project activities should be concentrated on the target
group, including agricultural extension, credit, subsidies, etc.

Windmill introduction should be incorporated as far as possible with
other development programmes in the area. Close cooperation with govern-
ment organizations in the same field is essential as well (e.g. Irriga-
tion Department, Extension Service, governmental credit and subsidy
agencies).
The social aspects that need consideration during the planning and
execution are mentioned in this chapter. Special attention being given
to the social aspects of crop selection and crop plan adjustment. Hardly
any research on these aspects has been done up to now. In this study we
can not do more than present a number of broad guidelines, drawn from
the literature and from experience in India, Sri Lanka, Indonesia and
Kenya.

In the second part of this chapter, the economic aspects are discussed.
The cost-element of windmills and other waterlifting devices is mentio-
ned and calculation methods are given for the economic comparison of the
devices. The cost-benefit calculation from the farmers' point of view is
often an important criterion for project feasibility and acceptability
of the new device by the target group.
Calculating the repayment capacity will also be considered.

4.1.　Social aspects

If the improvement of the living conditions of the target group is the
ultimate goal of the project, it is implicit that the project will cause
social changes. The project participants will earn more money or get
more food when the project is successful. This will change their social
status and their relations with other groups in the community. It should
be investigated whether these changes will not weaken the position of
the even less privileged sections of the community (e.g. landless people).
Clearly landless people cannot benefit direct from this technology, so
that windmills per se may not be considered a medium for improving the
living conditions of the weakest sections of the community.

Very small landholders might benefit from windmill irrigation by coope-
ration and joint ownership of a windmill. However, joint ownership of a
windmill may cause even more problems than joint ownership of other
small irrigation devices, because:
- 　a windmill cannot be moved from one place to another
- 　a windmill requires a high initial investment
- 　division of the unpredictable daily output is difficult.

A group of marginal farmers with fields at different places can still
own and operate a mobil petrol pumpset together. A windmill cannot be
moved from field to field.
A high investment means that security is needed for the loan. Often
marginal farmers cannot meet the security criteria of the banks. More-
over the repayment capacity of a group of marginal farmers is low if
there are no other sources of income. Before a family can be expected to
repay the annual installment of a loan, its minimal living requirements
have to be met.
example:　Suppose the net annual benefit of a windmill irrigation unit
　　　　　is Rs. 6000, the minimal annual living costs of an average
　　　　　family is Rs. 1500 and the annual loan repayment is Rs. 2000.
　　　　　If 4 families own the windmill together, each will get
　　　　　Rs. 1500 to meet living costs and nothing is left for loan
　　　　　repayment.
　　　　　If 2 families share the windmill, each will get Rs. 2000 and
　　　　　Rs. 2000 will be left for repayment.
　　　　　Note: 8 Indian Rupies $\cong$ 1$U.S. (1980)
Only if the windmill is given free of cost, or with a high subsidy,
this problem can be overcome. (see also section 4.2.3.).

In section 1.2. the problems with regard to the distribution of the
irrigation water of a waterlifting device with a variable daily output
were briefly discussed. After studying Chapters 2 and 3, it will be
clear that modification of the irrigation interval as well as efficient
crop selection and crop plan adjustment are much more difficult with a
group of farmers, each with his own ideas and priorities.

4.1.1. Social aspects with regard to crop selection and crop plan adjustment

Crop selection and crop plan adjustment are important to optimize the windmill irrigation system and to decrease its vulnerability, as discussed in Chapters 2 and 3. The selection of the crops to be grown under windmill irrigation, the sequence of the different crops and of the sowing dates may also be restricted by social factors.

Often a large number of social factors and customs determine agricultural practices and vice versa. This influences the crop selection (main food crops and vegetable crops as well as traditional cash crops) but also the crop sequence and the sowing dates. Especially in regard to sowing dates and harvesting periods, many customs have developed, often based on a tradition of experience with climate, rainy seasons etc. In most cases it is not simple to change these customs even if circumstances change due to the artificial water supply.

Demonstration and extension may lead to changing of these patterns, especially if social or religious leaders have agreed to it.

It may also be very important to investigate the women's role in the existing agriculture and what will alter for them if traditional patterns are changed. The women should be involved in the demonstration and extension programme and in the final decision making.

Here some of these social factors in agriculture will be mentioned. They should be considered when a crop plan is designed. However, every situation will differ from others, so no specific rules can be given.

- Function of agriculture

It is important to know what the current function of the local agriculture is. Five possible types can be distinguished:

a. provides food and cash income for the nuclear family
b. provides food for the extended family only; other family members provide cash
c. provides food for animal husbandry which is the source of cash
d. production for the market only
e. mixtures of above mentioned functions.

The crop plan that is developed should fit in with the existing function of the agriculture in that area. Additional activities can only be successfull if the primary function has been fulfilled: sufficient food for the family and/or the cattle.

- Risk minimization is another socio-economic factor.

Often the traditional systems have a balanced crop plan aimed at risk minimization in securing food production for the family and for the livestock. Mixed cropping and delayed sowing practices are examples of this as are traditional drought resistant varieties etc....

- Religious, cultural and social activities can have their influence on the existing agriculture and vice versa.

Special functions during particular seasons may require the availability of harvested products or

cash at a certain moment (marriage parties, house or road construction etc.). Religious customs about animals may mean that a part of the arable land has to be used for fodder crops all year.
In some places it is not allowed to kill animals which can destroy standing crops. Some crops are traditionally not grown because of their attractiveness for certain animals (birds, insects, rats). Other crops may not be raised continuously in a certain area to prevent the survival of certain animals which migrate from one field to another.

-    Labour requirements of certain crops, and labour availability over the year (and for the peak periods)
Paddy is a traditional example. Proper attention should be given to this aspect in new crop plan designing and establishment of new growing periods. Data about both the availability of labour and the labour costs are important. In some periods these charges will increase due to high demand for labour and also because the work has to be done in the fields during the hot period (leisure preference is high during such periods and labour productivity low). If field work is not allowed on religious or public holidays, this should be incorporated in the calculation of labour availability and the irrigation intervals. If water storage facilities are insufficient, water pumped by the windmill on these days will be lost thus reducing the total amount available for irrigation.

-    Labour differentiation between male and female is often traditionally based and difficult to change. The same holds for labour differentiation between different social groups. Care should be taken not to help only one group to improve its living conditions while depriving other groups from their income, or a part of it.

-    The chance of theft of the fruits standing in the field should not be underestimated. The farmers often live in villages situated far from the fields. Introduction of vegetable crops can be difficult because they can so easlily be stolen from the fields at night.
The same can happen with the fish bred in the shallow windmill storage tanks. It may be socially unacceptable that members of the farmer's family stay night after night guarding the fields far from home.

In conclusion it can be said that the crop plan designed for windmill irrigation should not differ too much from the traditional pattern. Proper attention should be given to the above mentioned aspects and sufficient information on the aspects mentioned should be gathered by all means to eliminate the chances of failure or unwanted developments.

If "modern" agriculture has not yet been introduced in a certain area, it is doubtful whether windmills for irrigation will form the most suitable introduction. Other, more simple, improvements might then be more appropriate.

4.2. Economic aspects

In this section economic aspects of windmill irrigation are discussed
with special attention to those of importance from the farmer's point of
view:
- Which waterlifting device is the most economical?
- What are the financial benefits of irrigation?
- Can the loan repayments be met?

Methods and examples are given for the estimation of costs and benefits
"with" windmills, with other devices and "without" irrigation.

The questions whether windmills will from a sound economic alternative
for the economy as a whole (macro-economy against opportunity costs;
important for a national windmill subsidy programma) or whether a choice
must be made between a windmill project and other projects are not
discussed here.

4.2.1. Cost comparison

Costs can be divided into fixed costs and variable costs. Fixed costs
are those which do not change, whether the device is used or not. Varia-
ble costs depend on the use of the device.
e.g. - For diesel pumpsets, the fuel is a variable cost.
- For electric pumpsets, the charge for electricity is often a
  fixed cost, since it is usually a fixed amount per month
  independent of the use of the pump set.
- For bullock irrigation, only additional food given to the
  bullock, above the normal quantity, is a variable cost. The
  other costs of bullocks are more or less fixed costs (except
  when they have to be hired).
Where applicable, insurances and taxes also have to be added to the fixed
costs. Maintenance will often be partly variable and partly fixed.
Painting of a windmill will be required, whether the windmill is working
or not and thus a fixed cost.
Table 4.1. presents the main elements of fixed and variable costs of
four different irrigation devices.

	Bullock	Windmill	Diesel	Electricity
F I X E D	bullocks structure bucket/rope well canals	windmill installation tank well tubewell canals	pumpset installation shed well tubewell canals	pumpset installation shed powerline electricity charges well tubewell canals
V A R I A B L E	add. food 2 operators rep./maint.	rep./maint.	fuel oil rep./maint.	repair/maintenance

Table 4.1:Main elements of fixed and variable costs of four different
irrigation devices.

Although here we compare the costs to the farmer including existing
subsidies on fuels or investments, it is recommended to investigate if
the different cost-elements are subsidized and if so, to see whether the
new device (the windmill) can be subsidized on the same principles. This
will increase the reliability of the comparison. Since all investments
will last for several years it is also advised to investigate whether
price rises, additional to inflation, of the variable costs (e.g. fuel)
are expected in the near future. If so, these price rises should be
included in the calculation (see Annex IV for a calculation method).

If part of the installation is used for other purposes, (engines used
for grinding, threshing, fodder cutting, sugarcane crushing, etc.) the
costs have to be divided proportionally over the different activities.
(Also: Bullocks are used for irrigation, ploushing, levelling, transport,
etc.).

A first indication of whether windmills will be economically attractive,
can be found by comparing the annual cost of the different devices at·
different output levels. If this comparison is to be valid, the value of
the water pumped by each device should be equal. Water pumped by a
windmill during a rainy season has no value!.
Whether the value of the water pumped during the irrigation season will
be of equal value for the different devices depends mainly on their
reliability.
Windmills have always had a low reliability and electric and diesel
pumpsets a higher one. However, irregular availability of electricity
and diesel is becoming more and more rule instead of the exception in
rural areas of many third world countries.

Fig. 4.1. shows an example of the annual costs of windmills and diesel-
pumpsets each with different assumptions, at different annual output
rates over an elevation head of 5 m.
For the calculation the capital recovery factor is used, which is
explained in detail in Annex IV. Cost elements which are equal for
both devices are omitted (e.g. canals, bunds).

For the viability of windmills, lifespan and the annual repair and
maintenance costs are important as well as the costs for the storage
tank. For internal combustion engines, lifespan and expected fuel price
rises are especially important.
By making different assumptions for these important variables, the
influence of the assumptions on the final results can be estimated.
Inclusion of the variable cost lines of the diesel pumpset alternatives,
(parallel to the existing costlines, but now through point 0,0) shows
at what annual output levels it is economically attractive to install a
windmill beside a diesel pumpset plant, to take over a part of the
pumping and save variable cost (fuel, oil).
The difference between the annual costs of the two devices at a certain
annual output level also indicates the sensitivity to the main assump-
tion made here: the value of the water (the benefits) pumped by each
device is equal. If the difference in annual costs is considerable, the
benefits may vary as well without affecting the conclusion based on the
costs only. The next section deals with cost benefit analyses in more
detail.
In Annex IV some rules of thumb with regard to output, lifspan and
repair and maintenance costs are given, als well as the basic calculation
methods used for Fig. 4.1.

4.2.2.   Cost-Benefit analysis

In general matters are not as simple as in the case presented in the pre-
vious section. The different devices have different functions and the
economic value of the water pumped is not always equal.
By comparing costs and benefits of each device, a better indication can
be obtained of the advantages of the different alternatives for the
farmer. Also the "with" irrigation situation has to be compared with
the "without" situation (actual agricultural practice of the targetgroup
farmers).
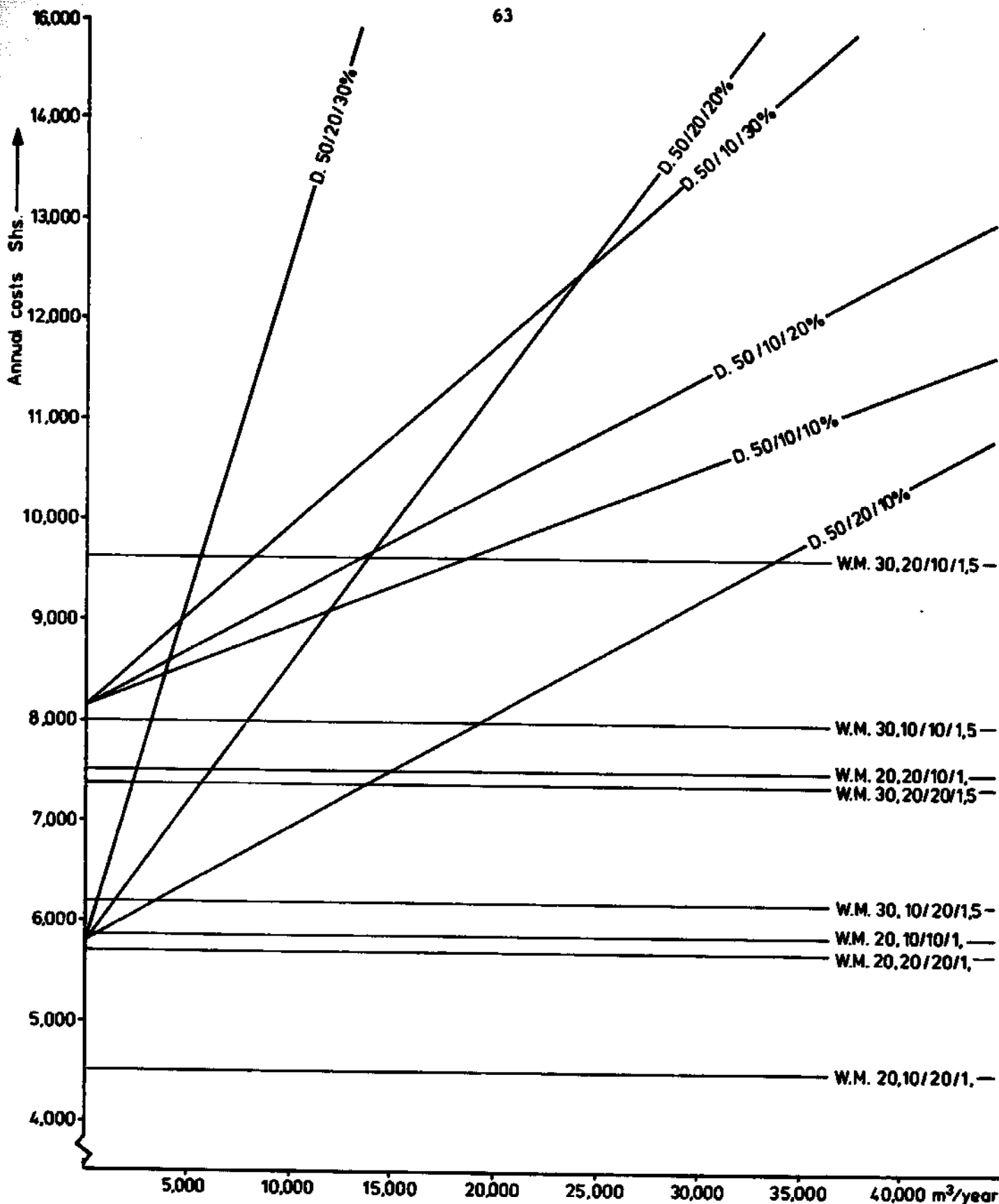
Fig. 4.1. Comparison of annual costs of windmills and 5 H.P. diesel
pump sets, for different options with regard to total investments,
lifespan and annual fuel price rises in Kenya (elevation head 5m).
(Vilsteren 1980)

W.M. 20, 10/20/1. means: Windmill Shs 20,000; Tank Shs 10,000/
Lifespan 20 years/Repair + maintenance Shs 1,000 p.a.

D. 50/20/10% means: 5 H.P. Dieselpumpset + pumphouse: Shs 50,000/

Since there will be a learning process in the new "with" situation and
there will be developments in the inputs, outputs and their price levels
in both situations, the costs and benefits over a large number of years
have to be estimated e.g. over the whole lifespan of the investment.
Therefore the Internal Rate of Return (I.R.R.) will be introduced here.
The I.R.R. is that discount rate (or interest rate) for which the sum of
the annual costs is equal to the sum of the annual benefits. In formula:

$$\sum_{1}^{t} \frac{bt}{(1+i)^{t}} = \sum_{1}^{t} \frac{ct}{(1 + 1)^{t}}$$

where: bt = benefits of year t*
         ct = costs of year t
         t = number of years included in the comparison 1, 2, 3,.....t
         i = Internal Rate of return

The I.R.R. can be found by a "trial and error" procedure in order to
solve to the former equation.
Comparing the I.R.R. with the actual interest rate indicates the profitabi-
lity of the device; comparing it with the I.R.R. of the other alternati-
ves gives an indication for the most economical alternative for the farmer.

An example:

Suppose the following data are found.

Year	0	1	2	3
Costs	6,000	300	300	300
Benefits	--	2,500	3,000	3,500

Trial and error procedure:
Suppose i = 15% thus (1+i) = 1.15
The sum of the (discounted) costs is then:
$6000 + \frac{300}{1.15^1} + \frac{300}{1.15^2} + \frac{300}{1.15^3} = 6000 + 261 + 227 + 197 = 6685$
The sum of the (discounted) benefits is:
$0 + \frac{2500}{1.15^1} + \frac{3000}{1.15^2} + \frac{3500}{1.15^3} = 0 + 2174 + 2268 + 2301 = 6743$
The sum of the discounted benefits is slightly higher than the
sum of the discounted costs, so the I.R.R. will be slightly
higher than 15 %.

*)   Using "constant" prices i.e. inflation which will affect both costs
     and benefits is eliminated. Generally current prices are taken.
     Price rises additional to the inflation rate are accounted for.
     (e.g. fuel price rises)

In annex IV, an example is presented of the I.R.R. calculation with respect to four different devices and the "without" situation (rainfed farming).

Some points are now considered for the case when the data for costs and benefits needed for this calculation are collected from different sources.
Except for the selling of irrigation water, the benefits of a pumping device can only be calculated indirectly, on the basis of increased agricultural production due to irrigation. So again proper attention has to be paid to the costs and the benefits of agriculture "with" and "without" irrigation. Then the net benefits due to the application of the irrigation device can be estimated.
Soil quality and levels of inputs (seed, manure, fertilizer, pesticides, manpower and bullockpower) often vary considerably over an area, as do the level of outputs (main product, by products, quality of products). Prices of inputs as well as outputs also differ over the year and from year to year. The capability of the farmers is another varying factor.

Nevertheless, data have to be collected (either by holding a survey among the farmers, or making use of existing surveys) and knowledge gathered at demonstration farms and agricultural research stations. Data from the latter often show results that are far above those of actual farming practice in the area.

Besides the current data something should be known about the growth rate of the production and/or expected price rises. We have to know the input and output levels for a large number of years to perform projections for the future.
It is to be expected that optimal results will not be achieved immediately after the introduction of a new device.
The farmer will go through a learning process which can take several years. Production rises may occur with any irrigation device. This is even so without irrigation, supposing a better yielding variety is introduced and more fertilizer becomes available etc.
With the help of local agricultural research stations, estimations can be made about the expected percentages of growth for the "with" and the "without" case.

In calculations of the net benefits of different crops, the amount used for home consumption should not be neglected, but added to the total benefits.
It is often difficult to estimate the contribution of bullock power, or farmyard manure, or the value of the by-products which are often fed to cattle. If the contributions are relatively small, they may compensate each other. Contribution of bullock power for ploughing and levelling and the contribution of the farmyard manure can be compensated by the supply of by-producys or by the production of a small field of fodder.

Another difficult item in calculating the net benefits is the labour
supply by the farmer and his family.
Generally it is only hired labour that is regarded as a cost factor. The
net benefits of the crop plan are often regarded as the farmers income,
but the introduction of irrigation always almost implies increased
labour requirements. To see what part of the additional benefits are
due to the irrigation device, all labour has to be included as costs.
e.g. Suppose the additional benefit of 1 ha irrigated crop will be
      Rs. 1.000,--but also requires 100 additional mandays at Rs. 5 per
      day. The additional benefit due to the irrigation device will be
      only Rs. 1.000-(100 x Rs. 5) = Rs. 500,--.
It is not only difficult to estimate the additional labour require-
ments but also its value. If there are no off-farm employment opportuni-
ties, the opportunity cost of labour is even zero. Often these off-farm
employment opportunities also vary during the year in rural areas and
so their opportunity cost.
Usually the minimum wages for farm labour are used in the calculations.

From the suggestions given above, it will be clear that the results of
the calculation largely depend on the assumptions made. Therefore here
again it is recommended to make several calculations, each with diffe-
rent assumptions for the main aspects (e.g. fuel price rises, production
level, etc.). In this way the influence of the assumptions on the final
outcome can be investigated. In case of a large uncertainty economists
can be asked for advice.

4.2.3.   Farmers repayment capacity

In general it can be stated that the I.R.R. also indicates whether the
investment will repay itself. If the I.R.R. is higher than the current
interest rate, this will usually be the case. But even then it is not automa-
tically implied that the farmer will also be able to repay the loan for
the the required investment in windmill, the well and tubewell, tank
etc. The repayment capacity of the farmer is a very critical factor in
adopting windmills.

One reason for such a limited repayment capacity can be the loan condi-
tions of the bank or other loan agencies. These institutions often
demand security in the form of owned land. This is often difficult for
the small farmer (property rights not always being officially registered
or more persons own the property) and impossible for the tenant or share
cropper.
Another aspect is formed by the repayment conditions of the loan: inte-
rest rate and repayment period. Real interest rates are sometime above
the official rates (add. charges, bribes) and the repayment period is
often shorter than the lifespan of the investment. Furthermore it starts
immediately in the first year after the investment is made.

Yet the farmer is not getting optimal benefits out of his investment in
that period, since he is still in the learning process.

A calculation example:
Investment: Rs. 10,000; Interest rate: 12%; Repayment period: 5 years.
With the capital recovery factor (discussed in Annex IV) the annual
repayment can be calculated as:

$$A = 10,000 \times \frac{0.12 \times (1.12)^5}{(1.12)^5 - 1} = Rs. 2,774$$

This is about twice the actual annual costs based on the total lifetime
of the windmill of 15 years (see Annex IV).
It will be clear that the additional benefits from windmill irrigation
may be insufficient to meet the obligations to the loan agency.
Other sources of family income or saving deposits are then required to
meet these obligations. Alternative loan conditions or subsidies can
also partly solve this problem.

Another reason for the limited repayment capacity of the farmer may be
the low family income.
If this income is insufficient to meet the primary living costs (poverty
line), the farmer will not be able to meet the loan repayment require-
ments.
This problem will increase if the windmill and thus its benefits are to
be shared by a group of farmers; each farmer will first have to meet the
minimum living expenditures. All these problems occur when there are
no opportunities for off-farm employment.

Another calculation example:
(based on data from Ghazipur, India)
    See previous example: loan repayment annually Rs. 2774
    Suppose net benefit from 1 ha irrigated by the windmill Rs 3500
    Suppose minimum living expenditures of a family Rs. 1500
    Amount left for repayment: Rs. 3500 - 1.500 = Rs. 2000
    Suppose 2 families have to live from this 1 ha irrigated land
    Repayment capacity Rs. 3500 - 2 x Rs. 1.500 = Rs. 500

Before windmill irrigation was introduced these families probably lived
below the poverty line, but that will not mean that they will continue
doing so, if they receive more money.
Meeting minimum living costs is much more important to them than the
bank loan repayment. Banks know this as well and therefore will not give
them a loan at all.
What is to be taken as the poverty line is arbitrary and will vary from
area to area.

If the repayment of the loan can just be met, this is still a risky
affair for the bank and the farmer. The moment something happens (sickness
of farmer or someone in his family, a dying bullock or a failing crop),
the repayment duties cannot be fulfilled.

The farmer employing a windmill is sometimes part of a larger family,
called extended family. It maybe possible that other members of this
unit will assist in repaying the loan.
Sometimes, it is even possible to pay the investment out of previous
savings or by selling piece of land or other valuable goods. All these
possibilities can occur in one and the same area.
Therefore a sound knowledge of the socio-economic aspects of the project
area and a flexible organization will be required to deal with all these
aspects in such a way that the introduction of windmills will ultimately
benefit the selected target group. If the repayment problems above
described are expected, proper arrangements with subsidies and possibi-
lities for delayed loan repayment should be made. This is a very diffi-
cult task and it is even harder to collect the repayment fees, even when
these are low due to all kind of arrangements. Sanctions such as remo-
ving the device are very costly, especially for windmills, and do not
solve the problems. Farmers know this very well and will act accordingly.

An effective method to examine whether the farmer will be able to meet
the repayment duties is a projection of the cash flows during the repay-
ment period of the loan.
Fig. 4.2. presents 2 examples of these cashflow projections per holding
of 1 acre in a 4 ha irrigation scheme in Kenya applying a windmill or a
diesel pump set. Adding the minimum living costs (e.g. Shs. 2,000 p.a.)
to the costs for irrigation will complete the picture and then conclusions
can be drawn with regard to the repayment capacity of the farmer.
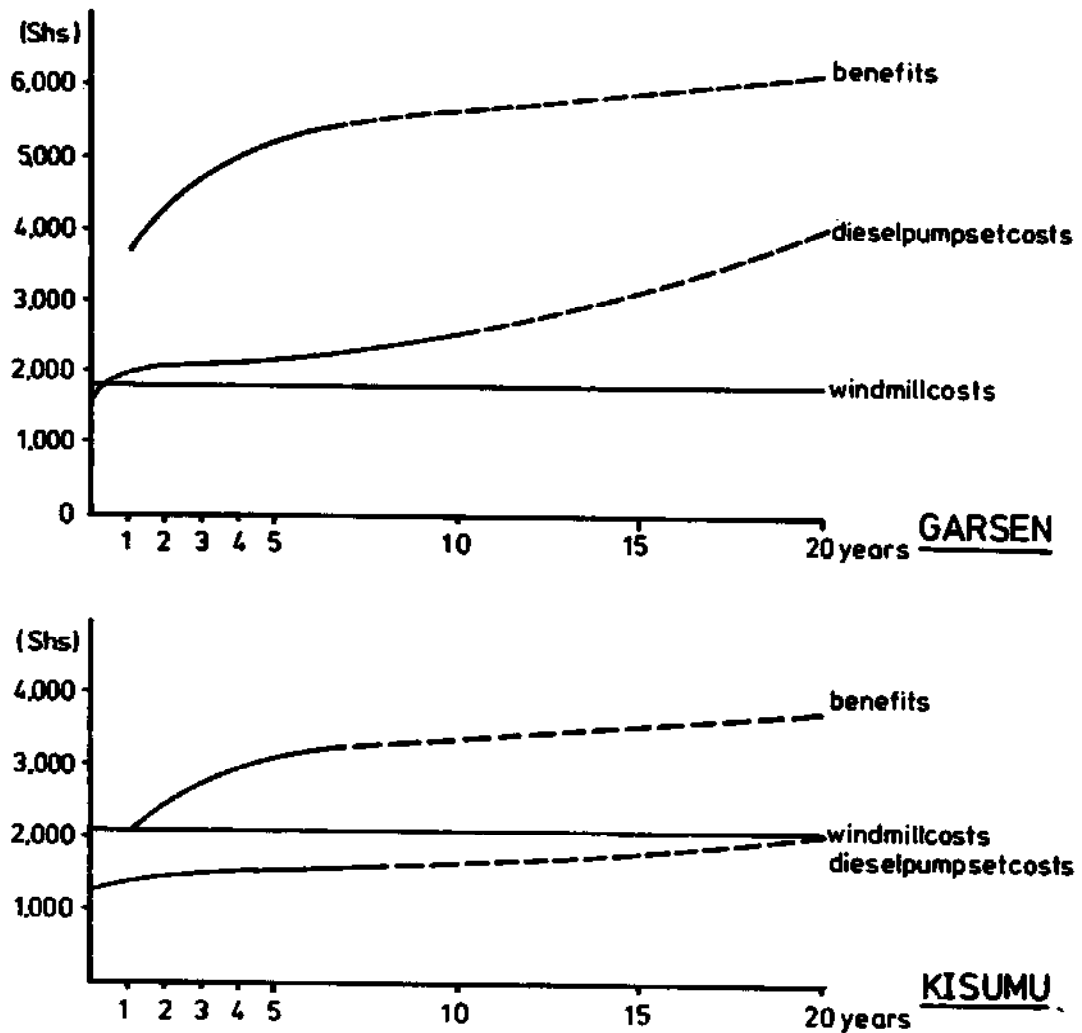
Fig. 4.2. Cashflows per acre for 4 ha. irrigationschemes with Windmills or Dieselpumpset in two places in Kenya. Repayment in 20 years. (Vilsteren, 1980)

The government will have to provide aid if it wants to promote windmill irrigation by small farmers but the repayment capacity is insufficient and also if the risks, seen from the small farmer's point of view, are too high.
Subsidizing windmills is simple, since there is only one main cost factor, the initial investment.

5. CONCLUDING REMARKS

In this chapter brief attention is given to the skills required by the
farmers to deal with windmill-irrigation and to the combination of
windmills with other pumping devices.

5.1. Farmer training

On the basis of Chapter 3, the reader might question whether the rules
for windmill irrigation can be learned by small and marginal farmers
with a low level of education.
A distinction should be made between farmers who already have some
experience with irrigation (controlled flooding, bullock irrigation,
bought water, etc) and farmers with only rainfed farming experience.
Farmers with irrigation experience already know how to irrigate and
often know by experience how crops respond to water and the economic
effects of timely irrigation. So there is no much need to teach the
farmer how to use his limited water to optimize the final economic
results and to minimize the risk of crop failure.

To facilitate adoption of windmill irrigation it is essential to show
the farmers the effect of windless days on crop water needs. So they
will understand that delayed irrigation due to windless days will not
seriously harm crop development and crop production.
Another essential point be tought is the differing capacities of the
windmill system in each season. Often farmers become enthousiastic during
the windy season and want to cultivate the same area in the next season,
which is less windy.
A third point is to teach the farmer to grow at one time crops with
different irrigation requirements and to supplement the command area
with a low input crop (fodder, green manure) or a drought resistant
crop, so little will be lost if it proves to be a poor season with
regard to windspeed. If sufficient irrigation water becomes available,
this remaining area will also benefit. The water will be used effective-
ly and ultimately the farmer will benefit from it. Another matter to be
made clear is that irrigation alone will not result in good crops (see
para 3.4.).
Finally, delayed sowing of traditional crops, to correspond with irriga-
tion water requirement and wind pattern may meet resistance, because
tradition has learned, that the existing sowing date is the optimal one
to obtain good yields as well as to minimize risks.

In conclusion it can be said that proper in-field training and demon-
stration will be essential for the introduction of windmill irrigation.
After a few years of intensive guidance of the windmill farmers expe-
rience will be available in the area and these windmill farmers will
become demonstrators for others, if they belong to the same socio-econo-
mic group.

This transfer of technology should be executed by an extension service, which is trained and activated by the windmill project. Just as with other new agricultural techniques this extension will be essential. The scope of the service may include loans and subsidies, training in windmill maintenance and minor repair and other agricultural or socio-economic aspects.

It will be clear from previous remarks that introduction of windmill irrigation to farmers with no experience in irrigation will require more training and attention. The design and layout of the field irrigation system has to be made and farmers have to be taught how to handle water efficiently. The crop plan should be kept very simple and much less critical (safety factors at all moments), the number of crops should be limited etc.
It will be clear that the extension service has a lot more
to do in such situations, but this applies for any irrigation device.
In some cases it can be questioned whether irrigation will be the most appropriate step in further development (see also section 1.1.).

5.2.   <u>Windmills combined with other irrigation devices.</u>

In discussions about windmills, often one of the first questions of the layman is whether windmills can be combined with other devices, espicially manual ones.
From previous chapters it will be clear that short windless periods can be coped with by other means. Moreover, manual power is too limited to deliver a quantity that can supplement windmill irrigation. Power output of a man will be about 75 Watt when working for a few hours continuously; this implies less than 3 m^3/hour when elevation head is 10 meter. In addition, suggesting handpumps may give rise to problems of dignity, status etc.
The difference in power levels also makes it almost impossible to use the windmill pump for hand pumping, so a lower capacity pump would have to be installed additionally for this purpose.
If irrigation with animals is known in the area, this can easily be combined with windmill irrigation, if there is sufficient space around the water source and if the water source is an open one, thus not a tubewell.
On windmill installation, attention should be given to this space aspect.
An example:
    In the Ganga-plain of North-India, bullock irrigation from
    open wells has been practiced for centuries.
    Windmill irrigation has been introduced to replace this bul-
    lock irrigation during the windy hot summer season (April-
    June).
    Due to the low water tables and the hot weather, bullock
    irrigation is a tedious job in that period for men and ani-
    mals and the output was low (0.1 - 0.2 ha per unit/day).
    During this period windmills can supply sufficient water for
    about 1 - 1.5 ha.

However during the low wind winterperiod, bullock irrigation
can supplement windmill irrigation, so the same acreage can
be irrigated as during summer season.

The additional investment costs for bullock irrigation are low, provided
bullocks are already available for other agriculatural practices (land-
preparation, transport).
However, here again, farmers may think that it is below their dignity to
continue with bullock irrigation once they have installed a modern new
irrigation device.

Combining windmills with electric or diesel pumping sets will be not
economical in most cases.
The initial investment for the two devices are often above the
financial capacity of the small farmer. Since both devices are
only used below their optimum capacity the total annual cost
(thus also the cost per m^3 water) will be quite high.
Only if both devices can be used to a nearly optimal degree or if very
high quality cash crops, which are sensitive to water shortage, are grown,
may this combination be a good solution. Often the capacity of the
pumpset is so high that it can easily pump the windmill output in addi-
tion to its own output and so reduce the cost per m^3 water, except if
the variable costs of the pumpset are far above the costs per m^3 of the
windmill (high fuel prices). In general however the small farmer will
prefer a low initial cost to low annual costs.
This aspect of high costs and low annual output of the pumpset could be
solved if a number of windmill farmers together were to operate one
mobile pumping set. However this will lead to the following problems:
- a windless period will lead to a peak demand for the pumpset, since
  all farmers are hit by the same windless period at the same time;
- joint ownership of a device which needs proper maintenance and
  operation often gives rise to difficulties;
- the capacity of the water source may be sufficient with respect to
  the (low) windmill output, but insufficient for the pumpset capacity;
- if the elevation head exceeds 5 -7 m., arrangements have to be made
  to install the pumpsets below groundlevel, which is complicated and
  needs additional facilities.

These points indicate that combined irrigation is not a simple matter
since all its aspects need carefull consideration.
Often a windmill with a rather larger capacity can solve the problems
just as well, but at lower costs.

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ANNEX I

PAN EVAPORATION METHOD AND PENMAN METHOD, INCLUDING TABLES AND CALCULATION EXAMPLES.

1.   PAN EVAPORATION

Evaporation pans provide a measurement of the integrated effect of radiation, wind, temperature and humidity on evaporation from a specific open water surface. Plants reponds to the same climatic variables in a similar fashion, but several factors may produce a significant difference in water loss. However with proper siting, evaporation pans can be used to predict crop water requirements for periods of 10 days or longer.

To relate pan evaporation (Epan) to the reference crop evapotranspiration (ETo) empirically derived coefficients (Kp) are given, which take climate and pan environment into account.
Reference crop evapotranspiration (ETo) can be obtained from the following formula:

$$ETo = Kp \times Epan.$$
where: Epan = pan evaporation in mm/day and represents the mean daily value of the period considered.
       Kp = pan coefficient

Values for Kp are given in table 1 for the class-A pan and in table 2 for the sunken Colorado pan, for different humidity and wind conditions and pan environments. The Kp-values relate to pans located in an open field with no crops taller than 1 m. within some 50 m. of the pan. The immediate surroundings, within 10 m. of the pan, are covered by a green frequently mowed, grasscover or by bare soil. The pan is unscreend.

Evaporation pans can be manufactured locally.
Descriptions and installations conditions are given below.

CLASS-A PAN.

The class-A evaporation pan is circular, 121 cm. (46 inches) in diameter and 25.5 cm. (10 inches) deep. It is made of galvanized iron (22 gauge) or Monel metal (0.8 mm.). The pan is mounted on a wooden open frame platform with its bottom 15 cm above groundlevel. The soil is built up within 5 cm of the bottom of the pan. The pan must be level. It is filled with water 5 cm. below the rim, and water level should not drop to more than 7.5 cm below the rim. Water is regularly renewed to eliminate extreme turbidity. If galvanized, the pan is painted annually with aluminium paint.

SUNKEN COLORADO PAN.

Sunken Colorado pans are sometimes preferred in crop water requirement studies, since these pans have a water level 5 cm. below the rim at soil level height and give a better direct prediciton of potential evapotranspiration of grass than does the Class-A pan. The pan is 92 cm (36 inches) square and 46 cm (18 inches) deep. It is made of galvanized iron, set in the ground with the rim 5 cm. (2 inches) above groundlevel. The water level inside the pan is maintained at or slightly below groundlevel. (Reference is made to Irrigation and Drainage Paper No. 27 Agrometeorological field stations. FAO Rome, Italy 1976).

EXAMPLE:

Given:	Cairo, July. Epan= 11.1 mm/day from Class-A pan.
	RHmean = Medium; Wind = Moderate.
	Pan station is located within a cropped area of several hectares; The pan is not screened.
Calculation:	See table 1 of this annex.
	Since the pan station is covered by grass and is surrounded by some 100 m. of cropped area, case A applies.
	From table 1 for moderate wind and medium humidity conditions the Kp value is estimated at 0.75
	ETo = Kp x Epan = 0.75 x 11.1 = 8.3 mm/day.

Table 1   Pan Coefficient (Kp) for Class A Pan for Different Groundcover
and Levels of Mean Relative Humidity and 24 hour Wind (FAO, 1977)

Class A pan	Case A: Pan placed in short green cropped area				Case B[1]: Pan placed in dry fallow area			
RH mean %		low <40	medium 40-70	high >70		low <40	medium 40-70	high >70
Wind km/day	Windward side distance of green crop ■				Windward side distance of dry fallow m			
Light <175	1	.55	.65	.75	1	.7	.8	.85
	10	.65	.75	.85	10	.6	.7	.8
	100	.7	.8	.85	100	.55	.65	.75
	1000	.75	.85	.85	1000	.5	.6	.7
Moderate 175-425	1	.5	.6	.65	1	.65	.75	.8
	10	.6	.7	.75	10	.55	.65	.7
	100	.65	.75*	.8	100	.5	.6	.65
	1000	.7	.8	.8	1000	.45	.55	.6
Strong 425-700	1	.45	.5	.6	1	.6	.65	.7
	10	.55	.6	.65	10	.5	.55	.65
	100	.6	.65	.7	100	.45	.5	.6
	1000	.65	.7	.75	1000	.4	.45	.55
Very strong >700	1	.4	.45	.5	1	.5	.6	.65
	10	.45	.55	.6	10	.45	.5	.55
	100	.5	.6	.65	100	.4	.45	.5
	1000	.55	.6	.65	1000	.35	.4	.45

[1] For extensive areas of bare-fallow soils and no agricultural development,
reduce Kpan by 20% under hot, windy conditions; by 5-10% for moderate
wind, temperature and humidity conditions.

Table 2 Pan Coefficient (Kp) for Colorado Sunken Pan for Different Groundcover and Levels of Mean Relative Humidity and 24 hour Wind (FAO, 1977)

Sunken Colorado	Case A: Pan placed in short green cropped area				Case B[1]: Pan placed in dry fallow area			
RH mean %		low <40	medium 40-70	high >70		low <40	medium 40-70	high >70
Wind km/day	Windward side distance of green crop m				Windward side distance of dry fallow m			
Light <175	1	.75	.75	.8	1	1.1	1.1	1.1
	10	1.0	1.0	1.0	10	.85	.85	.85
	≧100	1.1	1.1	1.1	100	.75	.75	.8
					1000	.7	.7	.75
Moderate 175-425	1	.65	.7	.7	1	.95	.95	.95
	10	.85	.85	.9	10	.75	.75	.75
	≧100	.95	.95	.95	100	.65	.65	.7
					1000	.6	.6	.65
Strong 425-700	1	.55	.6	.65	1	.8	.8	.8
	10	.75	.75	.75	10	.65	.65	.65
	≧100	.8	.8	.8	100	.55	.6	.65
					1000	.5	.55	.6
Very strong >700	1	.5	.55	.6	1	.7	.75	.75
	10	.65	.7	.7	10	.55	.6	.65
	≧100	.7	.75	.75	100	.5	.55	.6
					1000	.45	.5	.55

[1] For extensive areas of bare-fallow soils and no agricultural development, reduce Kpan by 20% under hot, windy conditions; by 5-10% for moderate wind, temperature and humidity conditions.

Penman Method (FAO, 1977)

Climatic data required are: mean temperature (T in °C), mean relative
humidity (RH in %), total windrun (U in km/day at 2 m height) and mean
actual sunshine duration (n in hour/day) or mean radiation (Rs or Rn
equivalent evaporation in mm/day). Also measured or estimated data on
mean maximum relative humidity (RHmax in %) and mean daytime windspeed
(Uday in m/sec at 2 m height) must be available. Reference evapotrans-
piration (ETo) representing the mean value in mm/day, over the period
considered, is obtained by:

$$ETo = [W. \, Rn + (1-W) \, . \, f(U) \, . \, (ea-ed)].c$$

where:

(ea-ed)	=	vapour pressure deficit i.e. the difference between saturation vapour pressure (ea) at Tmean in mbar (Table 3) and actual vapour pressure (ed) in mbar where: ed = ea . RH/100
f(U)	=	wind function of f(U) = 0.27 (1 + U/100) with U in km/day measured at 2 m height
Rn	=	total net radiation in mm/day or Rn = 0.75 Rs - Rnl where Rs is incoming shortwave radiation in mm/day either measured or obtained from Rs = (0.25 + 0.50 n/N)Ra. Ra is extra-terrestrial radiation in mm/day (Table 4), n is the mean actual sunshine duration in hour/day and N is maximum possible sunshine duration in hour/day (Table 5). Rnl is net longwave radiation in mm/day and is a function of temperature, f(T), of actual vapour pressure, f(ed) and sunshine duration f(n/N), or Rnl = f(T).f(n/N).f(ed) (Tables 6, 7 and 8)
W	≈	temperature and altitude dependent weighting factor (Table 9)
c	≈	adjustment factor for ratio Uday/Unight, for RHmax and for Rs (Table 10).

EXAMPLE

Given: Location 30°N; altitude 95 m; July; Tmean 28.5°C; RHmean 55%;
Umean 232 km/day; n mean 11.5 hour/day; (RHmax 80%, Uday 3 m/sec,
Uday/Unight 1.5).

<u>Calculation</u>:

ea	T = 28.5°C	Table 3	38.9 mbar
ed	ea.RH/100	calc	21.4 mbar
ea-ed		calc	<u>17.5</u> mbar
f(U)	0.27(1 + U/100); U = 232 km/day	calc	<u>0.9</u>
Ra	30°N, July	Table 4	<u>16.8</u> mm/day
N	30°N, July	Table 5	13.9 hour/day
Rs	(0.25 + 0.50 n/N)Ra	calc	11.2 mm/day
Rnl	f(T).f(ed).f(n/N)	Tables 6,7,8	1.8 mm/day
Rn	0.75 Rs - Rnl	calc	<u>6.6</u> mm/day
W	T = 28.5°C; 95 m	Table 9	<u>0.77</u>
c	RHmax 80%; Rs11.2; Uday/Unight 1.5	Table 10	<u>1.01</u>
ETo	c [W.Rn + (1-W).f(u).(ea-ed)]	calc	<u>8.8</u> mm/day

Table 3   <u>Saturation Vapour Pressure (ea) in mbar as Function of Mean Air Temperature (T) in °C</u> [1]

Temper-ature °C	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
ea mbar	6.1	6.6	7.1	7.6	8.1	8.7	9.3	10.0	10.7	11.5	12.3	13.1	14.0	15.0	16.1	17.0	18.2	19.4	20.6	22.0

Temper-ature °C	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
ea mbar	23.4	24.9	26.4	28.1	29.8	31.7	33.6	35.7	37.8	40.1	42.4	44.9	47.6	50.3	53.2	56.2	59.4	62.8	66.3	69.9

[1] Also actual vapour pressure (ed) can be obtained from this table using available Tdewpoint data.
(Example: Tdewpoint is 18°C; ed is 20.6 mbar.

Table 4   <u>Extra-terrestrial Radiation (Ra) expressed in equivalent evaporation in mm/day</u>

	Northern Hemisphere												Lat	Southern Hemisphere											
Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
6.4	8.6	11.4	14.3	16.4	17.3	16.7	15.2	12.5	9.6	7.0	5.7	40°	17.9	15.7	12.5	9.2	6.6	5.3	5.9	7.9	11.0	14.2	16.9	18.3
6.9	9.0	11.8	14.5	16.4	17.2	16.7	15.3	12.8	10.0	7.5	6.1	38	17.9	15.8	12.8	9.6	7.1	5.8	6.3	8.3	11.4	14.4	17.0	18.3
7.4	9.4	12.1	14.7	16.4	17.2	16.7	15.4	13.1	10.6	8.0	6.6	36	17.9	16.0	13.2	10.1	7.5	6.3	6.8	8.8	11.7	14.6	17.0	18.2
7.9	9.8	12.4	14.8	16.5	17.1	16.8	15.5	13.4	10.8	8.5	7.2	34	17.8	16.1	13.5	10.5	8.0	6.8	7.2	9.2	12.0	14.9	17.1	18.2
8.3	10.2	12.8	15.0	16.5	17.0	16.8	15.6	13.6	11.2	9.0	7.8	32	17.8	16.2	13.8	10.9	8.5	7.3	7.7	9.6	12.4	15.1	17.2	18.1
8.8	10.7	13.1	15.2	16.5	17.0	16.8	15.7	13.9	11.6	9.5	8.3	30	17.8	16.4	14.0	11.3	8.9	7.8	8.1	10.1	12.7	15.3	17.3	18.1
9.3	11.1	13.4	15.3	16.5	16.8	16.7	15.7	14.1	12.0	9.9	8.8	28	17.7	16.4	14.3	11.6	9.3	8.2	8.6	10.4	13.0	15.4	17.2	17.9
9.8	11.5	13.7	15.3	16.4	16.7	16.6	15.7	14.3	12.3	10.3	9.3	26	17.6	16.4	14.4	12.0	9.7	8.7	9.1	10.9	13.2	15.5	17.2	17.8
10.2	11.9	13.9	15.4	16.4	16.6	16.5	15.8	14.5	12.6	10.7	9.7	24	17.5	16.5	14.6	12.3	10.2	9.1	9.5	11.2	13.4	15.6	17.1	17.7
10.7	12.3	14.2	15.5	16.3	16.4	16.4	15.8	14.6	13.0	11.1	10.2	22	17.4	16.5	14.8	12.6	10.6	9.6	10.0	11.6	13.7	15.7	17.0	17.5
11.2	12.7	14.4	15.6	16.3	16.4	16.3	15.9	14.8	13.3	11.6	10.7	20	17.3	16.5	15.0	13.0	11.0	10.0	10.4	12.0	13.9	15.8	17.0	17.4
11.6	13.0	14.6	15.6	16.1	16.1	16.1	15.8	14.9	13.6	12.0	11.1	18	17.1	16.5	15.1	13.2	11.4	10.4	10.8	12.3	14.1	15.8	16.8	17.1
12.0	13.3	14.7	15.6	16.0	15.9	15.7	15.0	13.9	12.4	16.7	16.8	16	16.9	16.4	15.2	13.5	11.7	10.8	11.2	12.6	14.3	15.8	16.7	16.8
12.4	13.6	14.9	15.7	15.8	15.7	15.7	15.1	14.1	12.8	12.0		14	16.7	16.4	15.3	13.7	12.1	11.2	11.6	12.9	14.5	15.8	16.5	16.6
12.8	13.9	15.1	15.7	15.7	15.5	15.5	15.6	15.2	14.4	13.3	12.5	12	16.6	16.3	15.4	14.0	12.5	11.6	12.0	13.2	14.7	15.8	16.4	16.5
13.2	14.2	15.3	15.7	15.5	15.3	15.3	15.5	15.3	14.7	13.6	12.9	10	16.4	16.3	15.5	14.2	12.8	12.0	12.4	13.5	14.8	15.9	16.2	16.2
13.6	14.5	15.3	15.6	15.3	15.0	15.1	15.4	15.3	14.8	13.9	13.3	8	16.1	16.1	15.5	14.4	13.1	12.4	12.7	13.7	14.9	15.8	16.0	16.0
13.9	14.8	15.4	15.4	15.1	14.7	14.9	15.2	15.3	15.0	14.2	13.7	6	15.8	16.0	15.6	14.7	13.4	12.8	13.1	14.0	15.0	15.7	15.8	15.7
14.3	15.0	15.5	15.5	14.9	14.4	14.6	15.1	15.3	15.1	14.5	14.1	4	15.5	15.8	15.6	14.9	13.8	13.2	13.4	14.3	15.1	15.6	15.5	15.4
14.7	15.3	15.6	15.3	14.6	14.2	14.3	14.9	15.3	15.3	14.8	14.4	2	15.3	15.7	15.7	15.1	14.1	13.5	13.7	14.5	15.2	15.5	15.3	15.1
15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8	0	15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8

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Table 5   <u>Mean Daily Duration of Maximum Possible Sunshine Hours (N) for Different Months and Latitudes</u>

Northern Latitudes	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Southern Latitudes	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
40	9.6	10.7	11.9	13.3	14.4	15.0	14.7	13.7	12.5	11.2	10.0	9.3
35	10.1	11.0	11.9	13.1	14.0	14.5	14.3	13.5	12.4	11.3	10.3	9.8
30	10.4	11.1	12.0	12.9	13.6	14.0	13.9*	13.2	12.4	11.5	10.6	10.2
25	10.7	11.3	12.0	12.7	13.3	13.7	13.5	13.0	12.3	11.6	10.9	10.6
20	11.0	11.5	12.0	12.6	13.1	13.3	13.2	12.8	12.3	11.7	11.2	10.9
15	11.3	11.6	12.0	12.5	12.8	13.0	12.9	12.6	12.2	11.8	11.4	11.2
10	11.6	11.8	12.0	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5
5	11.8	11.9	12.0	12.2	12.3	12.4	12.3	12.3	12.1	12.0	11.9	11.8
0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0

Table 6   <u>Effect of Temperature f(T) on Longwave Radiation (Rnl)</u>

$T^{\circ}C$	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36
$f(T) = \delta Tk^4$	11.0	11.4	11.7	12.0	12.4	12.7	13.1	13.5	13.8	14.2	14.6	15.0	15.4	15.9	16.3*	16.7	17.2	17.7	18.1

Table 7   <u>Effect of Vapour Pressure f(ed) on Longwave Radiation (Rnl)</u>

ed mbar	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
$f(ed) = 0.34 - 0.044\sqrt{ed}$	0.23	.22	.20	.19	.18	.16	.15	.14	.13*	.12	.12	.11	.10	.09	.08	.08	.07	.06

Table 8   <u>Effect of the Ratio Actual and Maximum Bright Sunshine Hours f(n/N) on Longwave Radiation (Rnl)</u>

n/N	0	.05	.1	.15	.2	.25	.3	.35	.4	.45	.5	.55	.6	.65	.7	.75	.8	.85	.9	.95	1.0
$f(n/N) = 0.1 + 0.9n/N$	0.10	.15	.19	.24	.28	.33	.37	.42	.46	.51	.55	.60	.64	.69	.73	.78	.82*	.87	.91	.96	1.0

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Table 9   Values of Weighting Factor (W) for the Effect of Radiation on ETo at Different Temperatures and Altitudes

Temperature °C	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
W at altitude m																				
0	0.43	.46	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77*	.78	.80	.82	.83	.84	.85
500	.45	.48	.51	.54	.57	.60	.62	.65	.67	.70	.72	.74	.76	.78	.79	.81	.82	.84	.85	.86
1000	.46	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.80	.82	.83	.85	.86	.87
2000	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	.86	.87	.88
3000	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	.86	.88	.88	.89

Table 10   Adjustment Factor (c) in Presented Penman Equation

	RHmax = 30%				RHmax = 60%				RHmax = 90%			
Rs mm/day	3	6	9	12	3	6	9	12	3	6	9	12
Uday m/sec	Uday/Unight = 4.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.79	.84	.92	.97	.92	1.00	1.11	1.19	.99	1.10	1.27	1.32
6	.68	.77	.87	.93	.85	.96	1.11	1.19	.94	1.10	1.26	1.33
9	.55	.65	.78	.90	.76	.88	1.02	1.14	.88	1.01	1.16	1.27
	Uday/Unight = 3.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.76	.81	.88	.94	.87	.96	1.06	1.12	.94	1.04	1.18	1.28
6	.61	.68	.81	.88	.77	.88	1.02	1.10	.86	1.01	1.15	1.22
9	.46	.56	.72	.82	.67	.79	.88	1.05	.78	.92	1.06	1.18
	Uday/Unight = 2.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.69	.76	.85	.92	.83	.91	.99*	1.05*	.89	.98	1.10*	1.14*
6	.53	.61	.74	.84	.70	.80	.94	1.02	.79	.92	1.05	1.12
9	.37	.48	.65	.76	.59	.70	.84	.95	.71	.81	.96	1.06
	Uday/Unight = 1.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.64	.71	.82	.89	.78	.86	.94*	.99*	.85	.92	1.01*	1.05*
6	.43	.53	.68	.79	.62	.70	.84	.93	.72	.82	.95	1.00
9	.27	.41	.59	.70	.50	.60	.75	.87	.62	.72	.87	.96

Annex I-A

Determination of the <u>relative</u> influence of windspeed on ETo, derived according to Penman.
For formula and tables see ANNEX I. The results of these calculations are discussed in section 3.2 and are graphically presented in fig. 3.1.

Assumptions:

Altitude = 0	Altitude will have no influence on relative difference (see table 9).
$RH_{max} = RH_{mean}$	No variation in RH during day and night. This influences c-factor (table 10). No influences on relative differences.
n/N = 1, Ra = 17 mm/day	See table 4, 30° North, month June. This influences only radiation part of formula.
Uday/Unight = 3	This influences only c-factor (table 10). No influence on relative differences.
$\alpha=0.25$	$\alpha=$is reflection coefficient; 0.25 for full covering green crop.

Variables:

Temp.	(20, 30, 40°C)
RH	(30, 60, 90 %)
Wind	(0, 3, 6 m/sec. = 0, 260, 520 km/day)

Explanation of columns of table on next page:

column 4	: table 9
column 5, 7, 8, 10, 12, 14	: calculations
column 6	: table 3
column 9	: table 4
column 11	: table 6, 7, 8
column 13	: A = WxRN (Radiation component)
column 15	: B = (1-W).fu.(ea-ed) Aerodynamic component
column 16	. table 10
column 17	: ETo = (A+B)xC (= column (13+15)x16)
column 18	: Relative evaporation (V = 3m/sec. = 100%)

The last column on the next page shows the relative influence of the windspeed on the evaporation. This column is the basis of fig. 3.1 in section 3.2.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
T°C	RH %	Vkm/day	W	(1-W)	ea	ed	(ea-ed)	Rs	Rns	Rnl	Rn	A	fu	B	C	ETo	%
20	30	0	.68	.32	23.4	7.0	16.4	12.75	9.5	3.3	6.2	4.2	0.27	1.4	1.0	5.6	64 %
20	30	260	.68	.32	23.4	7.0	16.4			3.3	6.2	4.2	0.97	5.1	.94	8.7	100%
20	30	520	.68	.32	23.4	7.0	16.4			3.3	6.2	4.2	1.67	8.8	.88	11.4	131%
20	60	0	.68	.32	23.4	14.0	9.4			2.6	6.9	4.7	0.27	0.8	1.05	5.8	68 %
20	60	260	.68	.32	23.4	14.0	9.4			2.6	6.9	4.7	0.97	2.9	1.12	8.5	100%
20	60	520	.68	.32	23.4	14.0	9.4			2.6	6.9	4.7	1.67	5.0	1.10	10.7	126%
20	90	0	.68	.32	23.4	21.1	2.3			2.0	7.5	5.1	0.27	0.2	1.10	5.8	78 %
20	90	260	.68	.32	23.4	21.1	2.3			2.0	7.5	5.1	0.97	0.7	1.28	7.4	100%
20	90	520	.68	.32	23.4	21.1	2.3			2.0	7.5	5.1	1.67	1.2	1.22	7.7	104%
30	30	0	.78	.22	42.4	12.7	29.7			3.1	6.4	5.0	0.27	1.8	1.0	6.8	63 %
30	30	260	.78	.22	42.4	12.7	29.7			3.1	6.4	5.0	0.97	6.4	.94	10.7	100%
30	30	520	.78	.22	42.4	12.7	29.7			3.1	6.4	5.0	1.67	10.9	.88	14.0	131%
30	60	0	.78	.22	42.4	25.4	17.0			2.0	7.5	5.9	0.27	1.0	1.05	7.2	68 %
30	60	260	.78	.22	42.4	25.4	17.0			2.0	7.5	5.9	0.97	3.6	1.12	10.6	100%
30	60	520	.78	.22	42.4	25.4	17.0			2.0	7.5	5.9	1.67	6.2	1.10	13.3	125%
30	90	0	.78	.22	42.4	38.1	4.2			1.2	8.3	6.5	0.27	0.2	1.10	7.3	77 %
30	90	260	.78	.22	42.4	38.2	4.2			1.2	8.3	6.5	0.97	0.9	1.28	9.5	100%
30	90	620	.78	.22	42.4	38.2	4.2			1.2	8.3	6.5	1.67	1.5	1.22	9.8	103%
40	30	0	.85	.15	73.5	22.1	51.4			1.3	8.2	7.0	0.27	2.1	1.0	9.1	65 %
40	30	260	.85	.15	73.5	22.1	51.4			1.3	8.2	7.0	0.97	7.5	0.94	14.0	100%
40	30	520	.85	.15	73.5	22.1	51.4			1.3	8.2	7.0	1.67	12.9	.88	18.4	131%
40	60	0	.85	.15	73.5	44.1	29.4			0.9	8.6	7.3	0.27	1.2	1.05	8.9	68 %
40	60	260	.85	.15	73.5	44.1	29.4			0.9	8.6	7.3	0.97	4.3	1.12	13.0	100%
40	60	520	.85	.15	73.5	44.1	29.4			0.9	8.6	7.3	1.67	7.4	1.10	16.2	125%
40	90	0	.85	.15	73.5	66.1	7.4			0.3	9.2	7.8	0.27	0.3	1.10	8.9	78 %
40	90	260	.85	.15	73.5	66.1	7.4			0.3	9.2	7.8	0.97	1.1	1.28	11.4	100%
40	90	520	.85	.15	73.5	66.1	7.4	12.75	9.5	0.3	9.2	7.8	1.67	1.9	1.22	11.8	104%

Annex II

RELATIVE TOLERANCE OF CROPS TO SALT

FRUIT CROPS		
High salt tolerance	Medium salt tolerance	Low salt tolerance
Date palm	Pomegranate Fig Olive Grape Cantaloup	Pear Apple Orange Grapefruit Prune Plum Almond Apricot Peach Strawberry Lemon Avocado
VEGETABLE CROPS		
EC_{dw} = 12 mmhos/cm Garden beets Kale Asparagus Spinach	EC_{dw} = 10 mmhos/cm Tomato Broccoli Cabbage Bell pepper Cauliflower Lettuce Sweet corn Potatoes (White rose) Carrot Onion Peas Squash Cucumber	EC_{dw} = 4 mmhos/cm Radish Celery Green beans
EC_{dw} = 10 mmhos/cm	EC_{dw} = 4 mmhos/cm	ED_{dw} = 3 mmhos/cm

FORAGE CROPS		
High salt tolerance	Medium salt tolerance	Low salt tolerance
EC_{dw} = 18 mmhos/cm	EC_{dw} = 12 mmhos/cm	EC_{dw} = 4 mmhos/cm
Alkali sacaton	White sweetclover	White Dutch
Saltgrass	Yellow sweetclover	Clover
Nuttall Alkali grass	Perennial ryegrass	Meadow foxtail
Bermuda grass	Mountain brome	Alsike clover
Rhode grass	Strawberry clover	Red clover
Rescue grass	Dallis grass	Ladino clover
Canada wildrye	Sudan grass	Burnet
Western wheatgrass	Huban clover	
Barley (hay)	Alfalfa (California common)	
Bridsfoot trefoil	Tall fescue	
	Rye (hay)	
	Wheat (hay)	
	Oats (hay)	
	Orchard grass	
	Blue grama	
	Meadow fescue	
	Reed canary	
	Big trefoil	
	Smooth brome	
	Tall meadow oatgrass	
	Cicer milkvetch	
	Sourclover	
	Sickle milkvetch	
EC_{dw} = 12 mmhos/cm	EC_{dw} = 4 mmhos/cm	EC_{dw} = 2 mmhos/cm

FIELD CROPS

High salt tolerance	Medium salt tolerance	Low salt tolerance
EC_{dw} = 16 mmhos/cm	EC_{dw} = 10 mmhos/cm	EC_{dw} = 4 mmhos/cm
Barley (grain)	Rye (grain)	Field beans
Sugar beet	Wheat (grain)	
Rape	Oats (grain)	
Cotton	Rice	
	Sorghum (grain)	
	Corn (Field)	
	Flax	
	Sunflower	
	Castor beans	
EC_{dw} = 10 mmhos/cm	EC_{dw} = 6 mmhos/cm	

ED_{dw} = electric conductivity of drainage water (= EC_e)

Reference: Agriculture Handbook no. 60 Diagnosis and Improvement
Saline and Alkali Soils. February 1954

Annex III

CALCULATION EXAMPLE OF THE PROBABILITY ANALYSIS OF THE AREA WHICH CAN BE IRRIGATED BY A SPECIFIC WINDMILL WITH A CERTAIN ROTOR DIAMETER AND CONNECTED WITH A SUITABLE PISTON PUMP. (See section 2.3.3.)

Suppose meteorological data of 15 years are available for 4 months of the year which have a rainfall deficit. These data are adjusted for their real contribution to the soil moisture content, thus:

Pe = effective precipitation (mm/month)
ETo = reference cropwater use of a full covering, healthy crop
      (mm/month)
Ie = effective irrigation (monthly windmill output minus irrigation
      losses (mm/month)
Z   = the change in soil moisture content (mm)

ETo-Pe represents the net irrigation requirement.

$\dfrac{Ie}{ETo-Pe}$ represents the acreage which can be irrigated by one windmill.

Calculation of the 75% probability, that a certain area can be irrigated by the windmill is done as follows:

$$fi = \frac{i \times 100\%}{n + 1}$$

where fi = probability of occurrence (%)
      i = rank number in the climbing sequence of the data
      n = no. of data available.

In this calculation: n = 15 $f1 = \dfrac{1 \times 100}{16} = 6.25 \%$

$$f2 = \frac{2 \times 100}{16} = 12.50 \%$$

$$f4 = \frac{4 \times 100}{16} = 25.00 \%$$

In this case rank no. 4 represents the command area of the windmill, which can be irrigated at least 3 out of 4 years. This will be surpassed in 100% - 25% = 75% of the years. So the 4th-lowest data represents the 75% probability level in this case.

In the first round, the reference crop evapotranspiration (ETo) is used, to find the critical month with regard to the command area of the windmill pump unit.

MARCH

n (years)	Pe (mm)	ETo (mm)	ETo-Pe (mm)	Ie (mm/ha)	$\frac{Ie}{ETo-Pe}$ (ha)
1	100	100	0	90	***
2	206	86	-120	76	***
3	102	90	- 12	103	***
4	84	133	49	93	1.9(3)*
5	104	120	16	99	6.1
6	34	141	127	106	0.8(1)
7	102	118	16	105	6.6
8	143	125	- 17	83	***
9	101	105	4	92	23
10	73	131	58	66	1.1(2)
11	113	127	14	83	5.9
12	111	113	2	98	4.9
13	103	133	30	104	3.5
14	89	118	29	58	2.0(4)**
15	110	123	13	68	5.2

APRIL

n (years)	Pe (mm)	ETo (mm)	ETo-Pe (mm)	Ie (mm)	$\frac{Ie}{ETo-Pe}$ (ha)
1	102	128	26	83	3.2
2	89	131	42	110	2.6
3	109	120	11	120	10.9
4	63	148	85	76	0.9(1)
5	78	110	32	99	3.0
6	100	113	13	111	8.5
7	39	129	90	94	1.0(2)
8	68	140	72	115	1.6
9	112	99	- 13	143	***
10	131	155	24	95	3.9
11	63	143	80	123	1.5(4)
12	112	119	7	118	16.8
13	118	138	20	131	6.6
14	83	164	81	93	1.1(3)
15	111	123	12	75	6.2

MAY

n	Pe	ETo	ETo-Pe	Ie	$\frac{Ie}{ETo-Pe}$
1	23	133	110	168	1.5
2	18	118	100	183	1.8
3	0	174	174	124	0.7(1)
4	43	108	65	133	2.0
5	17	133	116	188	1.6
6	15	145	130	201	1.5
7	33	99	66	133	2.0
8	8	125	117	199	1.7
9	61	138	77	211	2.7
10	0	143	143	179	1.2(3)
11	0	164	164	148	0.9(2)
12	14	141	137	215	1.6
13	37	108	71	175	2.3
14	19	133	114	193	1.7
15	10	121	111	161	1.5(4)

JUNE

n	Pe	ETo	ETo-Pe	Ie	$\frac{Ie}{ETo-Pe}$
1	13	148	135	93	0.7
2	28	153	125	73	0.6
3	0	123	123	100	0.8
4	0	175	175	115	0.7
5	14	168	154	83	0.5(2)
6	3	183	180	125	0.7
7	11	145	134	99	0.7
8	33	123	90	110	1.2
9	0	188	188	78	0.4(1)
10	0	193	193	95	0.5(3)
11	7	146	139	88	0.6(4)
12	13	139	126	93	0.7
13	5	173	168	105	0.6
14	33	168	135	113	0.8
15	0	160	160	108	0.7

* Figures between brackets are the f·rst 4 rank numbers of the ascending sequence in that column.

** Figures in the squares are the areas which can be irrigated by the windmill in (100-25) 75% of the years.

*** No need for irrigation; ETo-Pe ≤0.

Explanation: The 4th rank of the ascending sequence presents the command area which will be realized in at least 25% of the years. So a larger command area will be realized in (100-25) 75% of the years.

Here: in March 2.0 ha; April 1.5 ha; May 1.5 ha; June 0.6
ha. The month of June is the critical month with regard to the
size of command area.

Knowing now that the month of June is critical and on the ground of all
kinds of other considerations (chapter 2), it is assumed that the following
crops can be grown:
Vegetables: March - May 25% of the area
Sugar cane: February - January 50% of the area
Cotton: January - May 25% of the area
Maize: June - September 50% of the area

This will give the following crop plan and average kc value (see tabel 2.1
in section 2.1.1.):

		March	April	May	June
A	25%	vegetables			Maize
R	25%	cotton			
E	50%	sugar cane			
A					
kc veg/maize		0.7	1.0	1.0	0.3
kc cot/maize		1.0	0.8	0.6	0.3
kc sugar c.		0.5	0.7	0.9	1.0
kc sugar c.		0.5.	0.7	0.9	1.0
kc average		0.67	0.80	0.85	0.65

Furthermore, it is assumed that leaching is not required, due to
abundant rainfall after June and since the month of June is cirtical, a
soil water depletion (Δz) of 50 mm at the end of that month will be
allowed for sugar cane (deep rooting crop, abundant rainfall in next
month). Since sugar cane covers 50% of the area, Δz will be 50% of 50 mm
= 25 mm.
Again, it is stressed here that these are only assumptions for this
calculation model. What is actually possible under the given circumstan-
ces in a specific area, has to be thoroughly investigated.
With these modifications a new probability analysis can be made with:
ETcrop = kc.ETo, and
ETcrop - Pe-ΔZ now representing the net irrigation requirement
         (ΔZ only in the month of June.)

MARCH

n (years)	Pe (mm)	ETcrop (mm)	ETcrop-Pe (mm)	Ie (mm/ha)	$\frac{Ie}{ETcrop-Pe}$ (ha)
1	100	67	- 33	90	---
2	206	58	-148	76	---
3	102	60	- 42	103	---
4	84	89	5	93	18.6(3)
5	104	80	- 24	99	---
6	34	94	60	106	1.8(1)
7	102	79	- 23	105	---
8	143	84	- 59	83	---
9	101	70	- 31	92	---
10	73	88	15	66	4.4(2)
11	113	85	- 28	83	---
12	111	76	- 35	98	---
13	103	89	- 14	104	---
14	89	79	- 10	58	---
15	110	82	- 28	68	---

APRIL

Pe (mm)	ETcrop (mm)	ETcrop-Pe (mm)	Ie (mm/ha)	$\frac{Ie}{Etcrop-Pe}$ (ha)
102	102	0	83	---
89	105	16	110	7.0
109	96	- 13	120	---
63	118	55	76	1.4(2)
78	88	10	99	9.9
100	90	- 10	111	---
39	103	64	94	1.5(2)
68	112	44	115	2.6
112	79	- 33	143	---
131	124	- 7	95	---
63	114	51	123	2.4(4)
112	95	- 17	118	---
118	110	- 8	131	---
83	131	48	93	1.9(3)
111	98	- 13	75	---

MAY

n (years)	Pe (mm)	ETcrop (mm)	ETcrop-Pe (mm)	Ie (mm/ha)	$\frac{Ie}{ETcrop-Pe}$ (ha)
1	23	113	90	168	1.9
2	18	100	82	183	2.2
3	0	148	148	124	0.8(1)
4	43	92	49	133	2.7
5	17	113	96	188	2.0
6	15	123	98	201	1.9
7	33	84	51	133	2.6
8	8	106	98	199	2.0
9	61	117	56	211	3.7
10	0	122	122	179	1.5(3)
11	0	131	131	148	1.1(2)
12	14	120	106	215	2.0
13	37	92	55	175	3.2
14	19	113	95	193	2.1
15	10	102	92	161	1.8(4)

JUNE							
n	Pe	ETcrop	ΔZ	ETcrop-Pe	Δz	Ie	Ie
							$\overline{\text{Etcrop-Pe-}\Delta z}$
(years)	(mm)	(mm)	(mm)	(mm)		(mm/ha)	(ha)
1	13	96	25	58		93	1.6
2	28	99	25	46		73	1.6
3	0	80	25	55		110	2.0
4	0	114	25	89		115	1.3(4)
5	14	109	25	70		83	1.2(3)
6	3	119	25	91		125	1.4
7	11	94	25	58		99	1.7
8	33	80	25	22		110	5.0
9	0	122	25	97		78	0.8(1)
10	0	125	25	100		95	0.9(2)
11	7	94	25	62		88	1.4
12	13	90	25	52		93	1.8
13	5	112	25	82		105	1.3
14	33	109	25	57		113	2.2
15	0	104	25	79		108	1.4

From these calculations it can be concluded that the command area of the windmill, with this crop plan and soil moisture depletion, can be 1.3 ha in the critical month of June. This area can be irrigated in 75% of the years.
It is obvious that when land is in abundance the command area can be expanded during the other months. During the month of March there will be no need for irrigation in 3 out of 4 years.

If there are possibilities to reduce the irrigation requirements further during the month June, the windmill command area can be increased even more. (c.q. planning of a harvest in June, or 1 month delayed sowing of maize.) This can only be considered in the perspective of the crop plan for a whole year. A new calculation round will show the effect of the modification in the command area.

Annex IV

FORMULAE AND CALCULATION EXAMPLES FOR ECONOMIC ANALYSES OF WINDMILL IRRIGATION

DISCOUNTING
Discounting is the process of reducing future costs and benefits to present values.

Since costs and benefits are mostly unevenly spread over a number of years, discounting to the present value is required for proper comparison of both.

Present costs and benefits are valued higher than future costs and benefits.

The discount rate used is about equal to the interest rate of bank loans.

e.g. An income in next year of Rs.* 1000 is at present valued lower than Rs. 1000 in this year, since the same amount can be obtained also by putting now Rs. 909 in a saving account with 10% interest $(Rs. 909 \times (1+0.1) = Rs. 1000)$.

The same applies for costs. A cost outlay of Rs. 1000 next year has a present value of Rs. $\dfrac{1000}{(1+i)}$ this year (i = discount rate).

A cost outlay of Rs. 1000 after 2 years will have a present value of Rs. $\dfrac{1000}{(1.1)^2} = Rs. 826$ this year. (i = 10%).

ANNUAL PRICE RISE
Suppose the price of diesel will rise annually by 10% in real terms (i.e. in excess of the inflation). Suppose the present price is Ksh.**3.50 per litre. Next year it will be: $3.50 \times (1.+0.1) = 3.85$. After 2 years it will be: $3.50 \times (1+0.1) \times (1+0.1) = 4.23$.

In formula:

Year	1	2	3............n
Price	$a(1+r)^1$	$a(1+r)^2$	$a(1+r)^3 \qquad a(1+r)^n$

where:

a = present price of diesel
r = annual price rise
n = number of years.

If all these costs have to be discounted to the present value, the formula will be:

Present value, $P = \dfrac{a(1+r)^1}{(1+i)^1} + \dfrac{a(1+r)^2}{(1+i)^2} + \dfrac{a(1+r)^3}{(1+i)^3} + \ldots\ldots\ldots + \dfrac{a(1+r)^n}{(1+i)^n}$

*) Rs. = Indian Rupies; 8Rs. $\cong$ 1 $US (1980)
**) Ksh. = Kenyan Shilling; 8Khs. $\cong$ 1 $US (1980)

Calculation example:
Suppose the diesel pumpset in the cost comparison calculation uses 1000 l.
of diesel per annum and the annual price rise is 15%. The present price
is Ksh. 3.50/l. So the cash outlay is now: (1000 x 3.50) = Ksh. 3500.
A discount rate of 10% will be used.
The present costs of the 1000 l/year over a period of 4 years is:

$$P = 3500 \times \frac{1.15^1}{1.10^1} + 3500 \times \frac{1.15^2}{1.10^2} + 3500 \times \frac{1.15^3}{1.10^3} + 3500 \times \frac{1.15^4}{1.10^4} = \text{Ksh. } 15{,}665$$

So, if the farmer wants to be sure that he will be able to buy the re-
quired 1000 liter of fuel, he has to put now (theoretically) Ksh. 15.655
in a saving deposit with an interest rate of 10%. During the 4 years
he can withdraw the required amount for buying the fuel. Of course this
is not the way the farmer will act, but these kinds of calculations are
carried out in order to obtain a real economic comparison.

Thus with the discounted costs and benefits, a comparison between the
different alternatives can be made. This is also the essential point in
the calculation of the Internal Rate of Return I.R.R., as discussed in
section 4.2.2.
Often it may also be important to know the annual costs of the devices
for different annual output levels. Therefore the capital recovery fac-
tor is introduced.

CAPITAL RECOVERY FACTOR
The capital recovery factor gives the fraction of the present value which
has to be paid in annual instalments to repay the initial amount and the
compounded interest.
In formula: $x = \dfrac{i.(1+i)^n}{(1+i)^n - 1}$

where: x = the capital recovery factor
          i = the discount rate (or interest rate)
          n = number of years of calculation, or repayment.

Example.
Suppose a windmill unit costs: Rs. 10,000 and will work for 15 years
(n = 15). The interest rate will be 12%.
The capital recovery factor is $\dfrac{0.12 \times (1+0.12)^{15}}{(1+0.12)^{15} - 1} = 0.147$
So the annual costs over a period of 15 years are: Rs. 10,000 x 0.147 =
Rs. 1470 per annum. (Compare this figure with the calculation of the far-
mers loan repayment in section 4.2.3.)

CALCULATION EXAMPLE OF ANNUAL COSTS

Here a presentation is made of the basic cost calculations needed for the comparison of different device:, at different output levels.

Firstly some estimates with regard to output levels, lifespan and repair- and maintenance costs for small waterlifting devices are given:

	Diesel pumpset	Petrol pumpset	Electric pumpset	Windmill pumpset
Energy/l.fuel	3KWH	2.3KWH	----	----
Total Efficiency	30-50%	30-50%	50-70%	20-5%
Output/l. fuel over 10m. el.head.	30-55 m^3	25-40 m^3	15-25 m^3/KWH	----
Lifespan	5,000-10,000 hours	1,000-3,000 hours	± 10,000-15,000 hours	10-20 years
Rep.+Maint.	20-50% of fuel cost	20-50% of fuel cost	10-20% of energy cost	5-10% of investement

Lifespan depends mainly on proper repair and maintenance and both depend again on the working conditions and on the quality of the used materials. Therefore local information should be collected with regard to these aspects, instead of using only these estimates.

After verifying the required variables, the calculations can be performed for the calculation of the prize per m^3, as presented in fig. 4.1. of section 4.2.1.

The windmill, pump unit.
The annual cost of four different options of a windmill pump are given in the following table, using a discount rate of 10% and the capital recovery formula.

The different options are:

costs for windmill	:	Ksh 30,000
costs for tank	:	Ksh 10,000-20,000
lifespan	:	10-20 years
cost for maintenance:		Ksh 1500 per year

	OPTIONS			
	1	2	3	4
Windmill (Shs)	30,000	30,000	30,000	30,000
Tank (Shs)	10,000	20,000	10,000	20,000
Lifespan (Years)	10	10	20	20
Cap. rec. factor	0.1627	0.1627	0.1175	0.1175
An. fixed cost (Shs)	6,508	8,135	4,700	5,875
An. repair cost (Shs)	1,500	1,500	1,500	1,500
Total an. cost (Shs)	8,008	9,635	6,200	7,375

The annual costs for four different options, at different output levels, of a windmill pump unit.

The diesel pump unit.
The different options are here: Lifespan: 10-20 years
Ann. fuel price rise: 10-20%

The actual fuel cost per m^3 water pumped over a head of 5 m. is:
1 litre fuel to 110 m^3. Price per litre diesel: Ksh. 3.75. So the actual
cost per m^3 is Ksh. 0.0341.

Lubrication costs are estimated at 10% of the fuel cost.
So the total costs are: (0.0341x1.1)=Ksh 0.0375 per m^3 water pumped by
the unit. Since prices for lubrication-oil are closely linked with the fuel
prices, this latter figure will be used for the further calculations with
regard to the annual fuel price rise.

The calculation of the annual fuel costs for the two different price
increase rates and lifespans are calculated in the table given below.
The capital recovery formula is used here again, using a discount rate
of 10%.

	OPTIONS			
	1	2	3	4
Ann. fuel price inc.	10%	10%	20%	20%
Lifespan (years)	10	20	10	20
Present value (Shs)	0.3750	0.7500	0.6242	2.1144
Capital recovery factor	0.1627	0.1175	0.1627	0.1175
Annual fuel cost/m^3 (Shs)	0.06	0.09	0.10	0.25

With these figures and the investment costs for the pumpset and pumphouse,
the total annual costs for the four options can be calculated for diffe-
rent output levels, as presented in the following table. For annual repair
and maintenance costs a fixed amount of 5% of the investment costs has
been assumed here, recalculated to cost per m^3.

		O P T I O N S			
		1	2	3	4
Diesel pumpset	(Shs)	30,000	30,000	30,000	30,00
Pumphouse	(Shs)	20,000	20,000	20,000	20,000
Lifespan	(Years)	10	20	10	20
Capital rec. factor		0.1627	0.1175	0.1627	0.1175
Annual fixed costs	(Shs)	8.135	5.875	8.135	5.875
Annual fuel price rise		10%	10%	20%	20%
Fuel costs/m³	(Shs)	0.06	0.09	0.10	0.25
Rep.+Maint. cost/m³	(Shs)	0.01	0.02	0.01	0.02
Total ann. costs	(Shs)				
at 20,000 m³/year		9,535	8,075	10,335	11,275
40,000 m³/year		10,935	10,275	12,535	16,675

The same procedure can be followed for petrol pumpsets and electrical ones.

COST-BENEFIT CALCULATION FOR FOUR DIFFERENT WATERLIFTING DEVICES AND RAINFED AGRICULTURE

B~fore such a calculation can be started, all kind of data have to be collected on costs and benefits and on the expected trends in both in the future. Crop plans have to be developed and the net benefits calculated, including a learning period etc.
There is no need to go into much detail, which will not increase the accuracy due to many possible unpredictable developments.
e.g. If the real benefits after 10 years differ Rs. 500 with your esti-
   mation, the effect on the actual value is $\frac{500}{1.1^{10}} = 200$

   at a discount rate of 10%.

We will give a simple calculation example based on fictive date, to illustrate the calculation process. The Internal Rate of Return will be calculated here for the total investment in agricultural equipment and not only for the irrigation device.

Assumptions: -   We want to start with agriculture on 1 ha. of good soil in North India.
  -   Required farm equipment: 1 pair of bullocks with plough, mouldboard etc.. Investment Rs. 2000, life-time 5 years. So additional investment of Rs. 2000 in the 6th year.
  -   Irrigation with bullocks requires a well (Rs. 2000).

- Irrigation with windmills, diesel or electric pump-
  sets requires a tubewell in addition to the well:
  (Rs. 2000).
- Windmills + tank: Rs. 10,000; Diesel pumpsets + shed:
  Rs. 8000; Electrical pumpset + farm power line + shed:
  Rs. 10,000. All irrigation devices will last 10 years.
- Engines and pumpsets are only used for irrigation of
  this 1 ha.

Investment costs and annual costs of the farm equipment and the irriga-
tion device:

Year	0	1	2	3	4	5	6	7	8	9	10
Rainfed	2000	-	-	-	-	-	2000	-	-	-	-
Bullock	4500	100	100	100	100	100	2100	100	100	100	100
Windmill	16000	300	300	300	300	300	2300	300	300	300	300
Diesel	14000	850	900	950	1050	1100	3200	1250	1350	1500	1600
Electric	16000	800	850	875	900	950	3000	1000	1050	1100	1200

Notes: 1) annual costs of bullock and windmill: only repair and
            maintenance costs
        2) annual costs of diesel and electric pumpset include repair
            and maintenance costs and fuel costs.
            An annual rise in fuel costs is assumed to be ± 10% for
            diesel and ± 5% for the electricity charges.
            This is in addition to inflation, which is not included
            in this type of calculation.

Net benefits of 1 ha of agriculture (Rs) over 10 years.

Year	0	1	2	3	4	5	6	7	8	9	10
Rainfed	-	500	505	510	515	520	525	530	535	540	550
Bullock	-	1000	1010	1020	1030	1040	1050	1060	1070	1080	1090
Windmill	-	2000	2200	2400	2650	2900	2950	2990	3020	3050	3080
Diesel	-	2500	2750	3000	3300	3650	3700	3740	3770	3810	3850
Electric	-	2500	2750	3000	3300	3650	3700	3740	3770	3810	3850

Notes : 1) rainfed and bullock irrigation are known practices for
              the small farmer. There will be no learning process.
              Only an annual production increase of ± 1% is assumed
              here
          2) windmill, diesel and electrical irrigation is new and
              a learning process of 5 years is assumed, with an
              annual increase of ± 10%. After the 5th year it will
              be ± 1%.

Calculations of the internal rate of return can be started now, following the process of trial and error as demonstrated in section 4.2.2.

The results of this calculation process are:

	Rainfed	Charsa	Windmill	Diesel	Electric
I.R.R.	8-9%	9-10%	5-6%	7-8%	6-7%

Let us suppose now that we have a 2 ha plot which can be irrigated with the same irrigation devices, without additional investments.
Investment costs and annual costs for the windmill and the diesel- and electrical pumpset per ha, if the command area is 2 ha.

	0	1	2	3	4	5	6	7	8	9	10
Windmill	8000	150	150	150	150	150	2150	150	150	150	150
Diesel	7000	850	900	950	1050	1100	3200	1250	1350	1500	1600
Electric	8000	400	425	450	475	500	2500	525	550	575	600

Note: Electricity charge is a fixed charge per month, so the annual cost per ha for an electrical pumpset will decrease.

The benefits per ha will remain the same.
The calculations of the Internal Rate of Return give the following results:

	Windmill	Diesel	Electric
I.R.R.	20-22%	23-24%	25-26%

So depending on the local conditions, the I.R.R. will change. Thus it is important to obtain the most reliable data possible.
Other examples: The use of engines for both purposes besides irrigation. Change in net benefits, or the possibility of. Off-farm employment of men and/or bullocks.

By introducing other crop plans or price rises of inputs (fuel) or outputs (selling prices), and performing the calculations again, the sensitivity of these assumptions can be studied.

SWD
STEERING COMMITTEE
WINDENERGY
DEVELOPING COUNTRIES

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THE NETHERLANDS

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

August 1982

The basis for a sound economic development of many countries in the Third World is the development of agriculture. The 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 appeared that in many countries wind energy could play an important role in satisfying the energy need for water pumping, particularly for irrigation purposes.

In July 1975 the Steering Committee Wind Energy Developing Countries (SWD) was established by the Netherlands Minister for Development Co-operation. SWD promotes the interest for wind energy in developing countries and aims to help 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. provision of 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. Also contacts exist with the Dutch national wind energy research program, co-ordinated by the Energy Research Centre (ECN).

The installation of a CWD windmill in Colombo, Sri Lanka, in the background the CWD WEU A 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 ($\lambda > 1$) results in lighter rotors and thus lighter and cheaper windmills.

Rotor of SWD 2740 prototype

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 exciting induction generator
— an induction generator equipped with a permanent magnet rotor
Also two control systems for alternators have been developed.

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

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 electric counter with extremely low energy consumption has been developed for contact-anemometers.

Theory

Theoretical models have been developed or refined on
— rotor performance
— forces on rotor blades
— output in different wind regimes
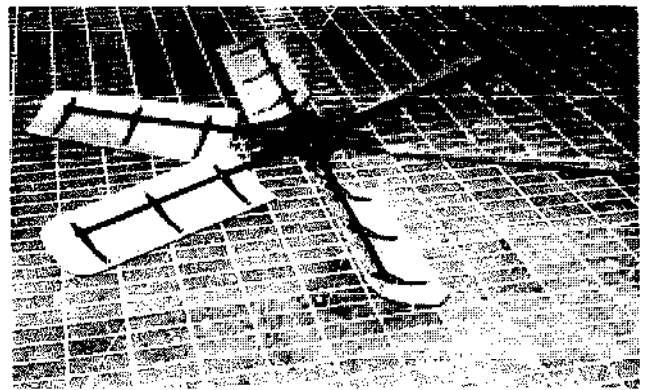— matching of rotor with generator or pump
— dynamic behaviour of pumps.

Pump test stand at Eindhoven University of Technology

Windmill prototypes

The following prototypes have been developed

	diameter	number of blades	tip speed ratio	remarks
SWD 2740	2 74 m	6	2	piston pump
SWD 4000	4 00 m	8	2	piston pump
SWD 5000 RS[1]	5 00 m	4	5	centrifugal pump Rotating Shaft
WEU 1	3 00 m	6	2	piston pump
WEU II[2]	5 00 m	8	2	piston pump
Cretan [3]	6 00 m	8	1	piston pump
Under development				
SWD 5000 HW	5 00 m	8	2	piston pump. for High Wind regime
SWD 5000 LW	5 00 m	8	2	piston pump. for Low Wind regime
SWD 2000	2 00 m	6	2	piston pump
SWD 1000 EL	1 00 m	2	4	Electricity generation

[1] developed as testmodel only
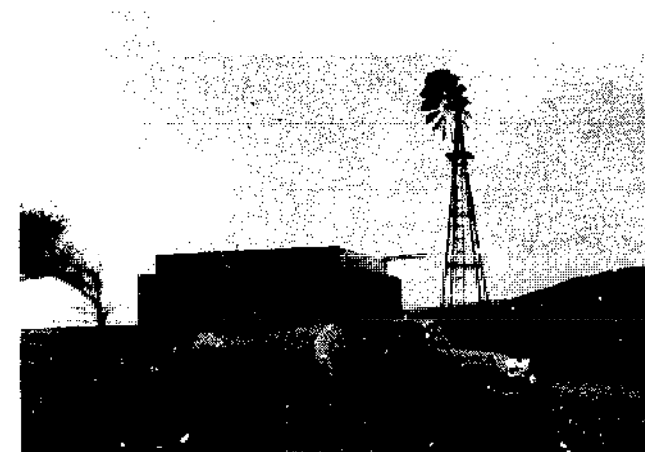[2] partially based on WOT-designed 12 PU 500

Project for rural water supply and irrigation on the Cape

Prototype installed in Hammamet, Tunisia, irrigating an orchard.

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.
— maintenance
— agricultural application analysis
— production engineering assistance
— economic programming and
— credit systems

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 energy and agriculture). In 1981 50 WEU-I prototypes were installed in pilot projects and private farms. In 1982 this program has been extended with another 180 windmills, to be produced by small and medium scale workshops. Subsidies have been arranged for this program.

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. The project focusses on training of staff in installation, repair and maintenance of windmills.
A high-wind-prototype for waterlifting of 5 m diameter is under development.

Pakistan

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

WEU-I prototype irrigating in Sri Lanka

Tanzania

The Ujuzi Leo Industries in Arusha have been supported in improving their windmill design via a two-month course in the Netherlands and short-term expert visits.

Tunisia

In support of the ASDEAR (Association pour le développement et l'animation rurale) SWD supervised in 1980 the construction of three SWD 4000 prototypes as a start of production in series by a local entrepreneur.
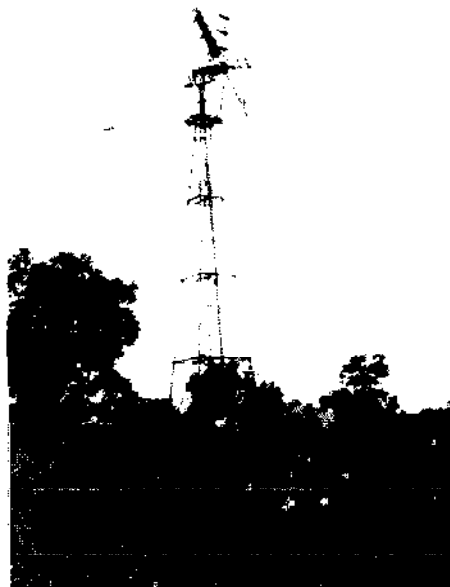
Peru

As a part of an agricultural project, supported by the Netherlands Ministry of Development Co-operation, a SWD 2740 prototype has been built. Since 1981 technical backstopping has been given to a Dutch expert in a bilateral co-operation program.

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), Kenya (1982), Netherlands Antilles (1982).

Explaining the particulars of windmill

TRANSFER OF KNOWLEDGE

Local knowledge is gathered in country projects and during visits of experts from abroad. Particularly the failures of windmill projects in the past deserve great attention. A first analysis of the causes of failure resulted in the following list:
— import restrictions on spare parts
— lack of funds
— lack of local know-how and of care for maintenance
— introduction of (subsidized) electric and diesel pumps
— drop of ground water table
— reduction on the number of windmills, making repair a non profitable job
— fear for repairs on top of a high tower
— termination of production and of supply of parts by manufacturers.

Knowledge in wind energy technology and related fields is transferred by SWD to developing countries by:
— publications
— 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 1/3 windmill in Sri Lanka has been transferred to Pakistan for example.

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

PUBLICATIONS

SWD has been issueing publications on various topics related to wind energy applications: feasibility reports, theoretical aspects, design of rotors, economics of windmills, irrigation with windmills etc. (see SWD-publications list).
SWD publications can only be ordered by letter to SWD with payment in advance. Research institutes in Third World Countries may ask for three publications (one copy each) free of charge.

Installation of windmills on Cape Verde.
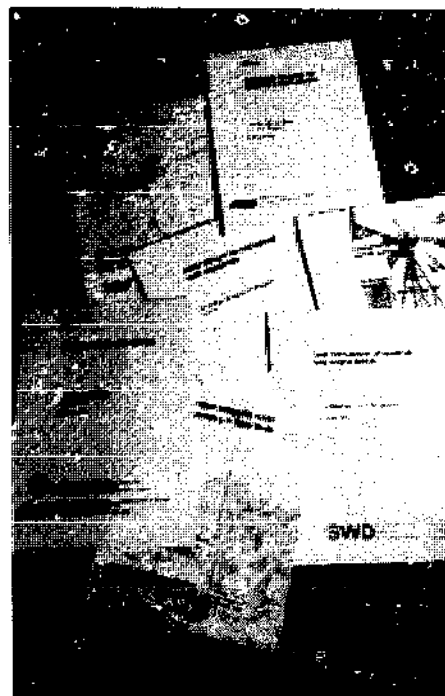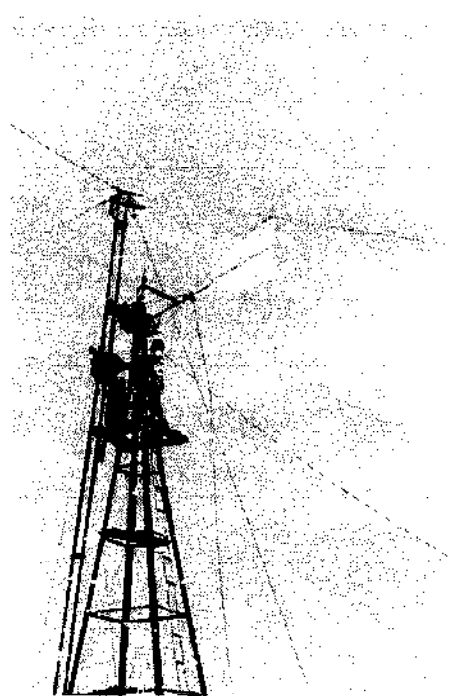
SWD issues various publications.

ADDRESSES
General address SWD:

DHV Consulting Engineers	P.O. Box 85, 3800 AB Amersfoort	The Netherlands, Tel.: 033 - 68 9111/ 68 23 66
		Telex 79348 dhv nl

Addresses of the other participants:

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Twente University of Technology Windmill Group	Department of Mechanical Engineering P.O. Box 217, 7500 AE Enschede	The Netherlands, Tel.: 053 - 89 40 98

Address of ILRI:

International Institute for Land Reclamation and Improvement	P.O. Box 45, 6700 AA Wageningen	The Netherlands, Tel.: 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, Tel.: 053 - 89 38 70

Address of ECN:

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

SWD Publications (June 1982)

Serial number		Prices for the year 1982 (mail included) US $	Dfl
SWD 76-2	**Literature survey; horizontal axis fast running wind turbines for developing countries** By W.A.M. Jansen, 43 p., March 1976	4.-	9,-
	Literature survey on theoretical aspects of rotor design and lay-out. Drag lift ratios and power coefficients are discussed.		
SWD 76-3	**Horizontal axis fast running wind turbines for developing countries.** By W.A.M. Jansen, 91 p., June 1976	8.-	19,-
	Brief review of the theories that form the basis for calculation of the design and the behaviour of a windmill, together with a report on tests of several rotors.		
SWD 77-1	**Rotor design for horizontal axis windmills** By W.A.M. Jansen & P.T. Smulders, 52 p., May 1977	5.-	11,-
	Basic aerodynamical aspects of rotors are explained. With help of formulas and graphs the design procedures for blade chord and blade setting are given. (Also available in French as SWD 80-1)		
SWD 77-2	**Cost comparison of windmill and engine pumps.** By L. Marchesini & S.F. Postma, 49 p., December 1978	4.-	10,-
	A method to compare costs of irrigation with windmills and with conventional engines, with help of break-even and sensitivity analyses		
SWD 77-3	**Static and dynamic loadings on the tower of a windmill.** By E.C. Klaver, 39 p., August 1977	3.-	8,-
	Some design considerations and the basic formulas needed for estimation of the dimensions of the tower structure.		
SWD 77-4	**Construction manual for a Cretan Windmill.** By N.J. van de Ven, 59 p., October 1977 (WOT/SWD)	5.-	12,-
	Detailed description for the construction of a sail wing windmill for water pumping, with wooden tower and head and steel pipe shaft. Illustrated with sketches, exploded views and photographs.		

Serial number		Prices for the year 1982 (mail included) US $	Dfl

SWD 77-5 Performance characteristics of some sail- and steel-bladed wind rotors. By Th. A.H. Dekker, 60 p., December 1977 — 5.- — 12,-

Report on experiments in an open windtunnel with several rotortypes. C_p-λ and C_q-λ characteristics are presented

SWD 78-1 Feasibility study of windmills for water supply Mara Region, Tanzania. By H.J.M. Beurskens, 89 p., March 1978. — 8.- — 18,-

Report on a study on wind energy potential in Mara Region, on water needs and potential windmill sites, on local production aspects and energy costs. A project proposal is elaborated.

SWD 78-2 Savonius rotors for water pumping. By E.H. Lysen, H.G. Bos & E.H. Cordes, 46 p., June 1978. — 4.- — 10,-

Report on experiments with a wood and sail Savonius rotor detailing design aspects, theory on coupling to a pump and test results.

SWD 78-3 Matching of wind rotors to low power electrical generators. By H.J. Hengeveld, E.H. Lysen & L.M.M. Paulissen, 85 p., December 1978. — 8.- — 18,-

Theoretical guidelines to the design of a small scale wind electricity conversion system with emphasis on the electrical part of the system and its matching to the rotor.

SWD 79-1 Catalogue of Windmachines. By L.E.R. van der Stelt & H. Wanders, 44 p., September 1979 (WOT/SWD) — 4.- — 9,-

Inventory of commercially available windmills for water pumping and electrically generation based on data of manufacturers; with addresses.

SWD 80-1 Conception des pales des éoliennes à axe horizontal (Version français de SWD 77-1). Par W.A.M. Jansen et P.T. Smulders, 52 p., Décembre 1980. — 5.- — 11,-

Aspects fondamentales aéro-dynamiques des hélices. Procédure-modèle pour la conception des pales de l'hélice, pour les cordes et pour l'angle de calage.

SWD 81-1 Wind energy for water pumping in Cape Verde By H.J.M. Beurskens, 162 p., February 1981. — 14.- — 34,-

Report on wind energy activities in Cape Verde, ground water resources,

wind regime, local production possibilities and economic aspects of wind energy utilization. Proposals for a project are elaborated. (Also available in Portuguese as SWD 81-3)

SWD 81-2 Wind energy in Sudan. By Dr. Yahia H. Hamid & W.A.M. Jansen, 71 p., July 1980. — 6.- — 15,-

Report on the windmill potential in Sudan detailing energy situation, wind and water situation and cost aspects, as well as a proposal for a wind energy centre in Sudan.

Serial number		Prices for the year 1982 (mail included)	
		US $	Dfl

SWD-81-3 Energia eólica para a bombagem de água em Cabo Verde (versao portuguesa de SWD 81-1).   14.-   34,-
Por H.J.M. Beurskens, 162 p., Fevereiro de 1981.

Estudo de actividades actuais de energia eõlica em Cabo Verde, recursos de agua freãtica, utilização e aspectos econõmicos de energia eõlica. E elaborado uma proposta de projecto.

SWD 81-4 Aspects of irrigation with windmills   9.-   21,-
By A.E.M. van Vilsteren, 100 p., January 1981 (TOOL/SWD).

Study on lift irrigation with windmills for smallholder agriculture in third world countries, dealing with irrigation practice, agricultural and social aspects and economic calculation methods.

SWD 82-1 Introduction to wind energy (basics and advanced)   25.-   60.-
By E.H. Lysen, 310 p., August 1982

Introduction to wind energy, with emphasis on water pumping windmills, dealing with a.o. site selection, wind-regime analysis, rotor design, economics.

SWD 82-2 A model for the economics of small-scale irrigation with windmills in Sri Lanka.   10.-   24.-
By J.A.C. Vel & L.R. v. Veldhuizen, 115 p., October 1981

Economic comparison between different cropschemes using windmill irrigation in Sri Lanka, based on assumptions and field data.
Sensitivity analyses and differentiation between national economic aspects and farmer's viewpoints.

SWD publications can be only be ordered by letter to:
SWD, c/o DHV Consulting Engineers
P.O. Box 85
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- serial numbers and requested titles

Research institutes in Third World Countries may ask for a copy of three publications free of charge.

ADDITIONAL INFORMATION ON THE PUBLICATION CWD 81-4

'ASPECTS OF IRRIGATION WITH WINDMILLS'

1.   INTRODUCTION

The publication 'Aspects of irrigation with windmills' has been written
in 1980. At that time only limited experience was gained in the field
of irrigation with windmills.
From 1981 onwards C.W.D. started to cooperate closely with the
Institute for Land Reclamation and Improvement (ILRI) Wageningen, The
Netherlands. Research on windmill-irrigation carried out by this
Institute, as well as further experiences in windmillprojects, showed
that some aspects of the publication 'Aspects of irrigation with
windmills' nowadays are considered to be out-dated.
Since still a lot of valuable information is given it was decided to
add a short note to the publication to inform the reader on the latest
information with respect to irrigation with windmills.
The remarks given below mainly deal with the relationship between wind
and irrigation requirements and with the economic aspects of
windmills.
For the information of the reader the ILRI reprint no. 32 'Windmills
for small scale irrigation' is also added.

2.   REMARKS ON THE INFORMATION GIVEN IN THE PUBLICATION
2.1.   Possibility to delay the irrigation during periods of low
        wind

paragraph	page	alnea
Summary	4	4
2.1.1 Evapotranspiration	20	2 + 3
3.2 Variability of irri- gation interval	43-48	
3.7 Summary	54	statement one and two
Annex 1-A	85-86	

In the above mentioned paragraphs of the publication it is stated that
during periods of low windvelocities (resulting in a low output of the
windmill) the irrigation of the crops can be delayed for several days
without many problems. This is because the evapotranspiration of the
crop should decrease with decreasing wind velocity. As a consequence
the amount of instantly available moisture in the soil increases. Thus,
the waterbalance changes in such a way that a delay of irrigation of
2-3 days is acceptable. One of the main aspects of windmill-irrigation
(the variable output pattern, including days without any output) is
thus reduced to a minor problem.

The above mentioned statement is proved by the influence of the wind
velocity on the theoretical calculation (formula of Penman) of the
evapotranspiration. By keeping all other factors constant it is found
that a reduction of the wind speed with 50% reduces the
evapotranspiration with 25%.
In reality, however, the evapotranspiration depends on a set of
intercorrelated as well as independently varying determinants. Since
wind only influences the areodynamic determinant, which varies in
comparison to the radiation determinant, the influence of the wind on
the evapotranspiration varies from place to place. In many places the
influence of a decreasing velocity of the wind therefore will not
result in a significant decreasing change in the evapotranspiration.
Even the reverse can take place, by which a decrease in the velocity of
wind results in an increase of the evapotranspiration and viceversa.
In 'Plant Response to Wind', by I. Grace it is stated on page 62 that
'Under many conditions an increase in windspeed leads to reduction in
transpiration rate of the crop.'
Wind can also affect the roughnes factor of the crops and thus the
evapotranspiration. Wheat for instance bends during strong winds which
results in a lower evapotranspiration of the crop.

The possible delay of irrigation is also based on the fact that due to

the reduction of the evapotranspiration the available moisture fraction
in the soil increases. This is based on the FAO Irrigation and
Drainage Paper No. 34, 1979. The possible relationship between the
evapotranspiration and the 'available moisture fraction', however,
still is a matter of discussion among scientists and the data presented
in the FAO paper only indicate an order of magnitude. According to
scientists the exact relationship is still unclear.
At this moment it should not be used in detailed calculations on
possible delay of small gifts of irrigation water.

Given the fact that a reduction in windvelocity not automatically
leads to a reduction in evapotranspiration and certainly not to a
reduction up to 75% and also given the fact that the relationship
between a reduced evapotranspiration and the instantly available
moisture fraction in the soil is still under discussion, it must be
concluded that the irrigation gift can not be delayed with 2-3 days
just because of a period of low wind. The irregular output pattern of
the wind - including days without output - surely has to be considered
as one of the major problems to be solved (see also par. 2.3 of this
note).

2.2   The use of a probability-analysis for the calculation of
           the command-area of the windmill

In the report a probability-analysis is used to calculate the
command-area of the windmill, based on the assumption that
wind, precipitation and evapotranspiration are closely related.

Although in very specific circumstances some relationship might be
there it must be said that in general these factors are not closely
related.
In using a probability-analysis wind, precipitation and
evapotranspiration therefore must be looked upon as independent
factors.

Besides this, the used method of a 75% probability-analysis - a
standard in irrigation engineering - is much under discussion
presently. The main issue is the fact that the level of probability
should not be chosen beforehand but made dependable on a cost-benefit
analysis (extra profit in years of high winds versus extra losses in
years of low wind). A probability model which can be used for
windmill-irrigation is being developed by C.W.D.

2.3   Need for a storagetank

The report states that a storagetank can be used to overcome windless
periods of several days. This, however, is based on the assumptions as
discussed in par. 2.1 of this note. Recent research has shown that
storagetanks with a capacity to overcome windless periods of several
days in general are too large to be economical attractive.
Computerized model study's have shown that with a tank volume of 50% of
the daily output in the peak irrigation period the major problems can
be solved. For Sri Lanka this resulted in a storagetank with a capacity
of 50 m^3. With such a tank only during short periods the irrigation by
windmills was sub-optimal.

2.4   Determination of the economic attractiveness of the use of
           the windmill

The report uses three criteria by which from a farmers point of view
the attractiveness of a windmill can be determined:
- cost-comparison
- internal rate of return
- repayment period

These criteria, however, cannot be commonly used, especially not if one
wants to determine the attractiveness from a farmers point of view. In
fact, only a cost-comparison can be used in the specific case when
irrigation already is a common and proved profitable enterprise among
farmers and when the output pattern of the windmill is equal to that of
the other irrigation devices used by the farmers. The internal rate of
return as well as the repayment period better should not be used at
all. If one wants to determine whether or not windmill are attractive
for farmers the methodology to be used should be the cost-benefit
analysis. A clear and handy publication on this is C.W.D. publication
No.84-1, 'Farm economics of waterlifting windmills' by A.M. Mueller.

2.5   Conclusions

Due to continuous research and ongoing experiences with
windmillprojects some aspects of the publication 'Aspects of irrigation
with windmills' had to be 'renewed'. It is the intention of the C.W.D.
to publish in 1985 a complete new publication, called 'Small scale
irrigation with windmills'.

Literature consulted for this note.

1.   1. Grace 'Plant Response to Wind'.
2.   FAO Irrigation and Drainage Paper No. 24:
     Crop water requirements.

3.   L.R. van Veldhuizen: The choice of the design windspeed and
     storagetank capacity influencing water availability via windmill
     irrigation system. Interim report.
4.   A.M. Mueller, Farmeconomics of waterpumping windmills. Draft report

SEDE BOQER, MC G

16 25 mm2,   CALCULATED SQUARE
DEPTH : 155 cm.   • MEASURED

CALCULATED SQUARE
• MEASURED