A design methodology for the supply of subterranean water through the use of wind energy.

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Abstract

The Reconstruction and Development Programme adopted by the Government of National Unity is more than a list of the services required to improve the quality of life of the majority of South Africans. It is not just a call for South Africans to unite to build a country free of poverty and misery; it is a programme designed to achieve this objective in an integrated and principled manner.

Based on the strategic objectives, as highlighted in the *White Paper on Water Supply and Sanitation Policy*, with regard to alleviating the chronic potable water shortages in South Africa, this thesis investigates a design methodology to supply potable water through the use of wind energy. The design focuses on small rural off-grid developments where grid electricity either has not or will not reach, and where renewable energy is the only viable option.

This thesis provides an overview of wind energy and presents the fundamentals of wind power calculations. It also formulates an overview of the historic and present situation with regards to potable water supply, and reflects on the need for urgent intervention.

The feasibility of using wind energy to supply potable water to rural communities in South Africa is explored in a case study. The various problem areas are identified and examined and a wide range of possible solutions are recommended. A final flow chart for the system design is proposed, thus ensuring comprehensive design methodology from which future design of similar systems can be based.

Dedication

To my wife, Debbie.

Declaration

This thesis, with the exception of that indicated in the text, is the candidate's own work and has not been submitted in part, or in whole, at any other University or Technikon.

The research was conducted at the Durban Institute of Technology under the supervision of Dr Dhiren Allopi.

APPROVED FOR FINAL SUBMISSION

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To the Durban Institute of Technology: Thank you for your moral and financial support. My research has not only increased my knowledge of this topic, but has fuelled my interest for research, which will have a positive effect on the subjects that I lecture.

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To Turbex: Thanks to Hans for his absolute dedication to the topic of wind energy, his depth of knowledge and his patient assistance.

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All symbols unless otherwise indicated will be SI units.

/	per
%	percentage
p	person
d	day
min	minute
V	volt
DC	direct current
l	litres
#	number

List of symbols

OPEC - Organization of Petroleum Exporting Countries.
DME - Department of Minerals and Energy.
EC - European Commission.
PDF - Probability density function.
NPV - Nett present value.
SA - South Africa
BWR - Basic Water Requirement
RDP - Reconstruction and Development Programme
BoTT - Build, Operate, Train and Transfer
NGO - Non Governmental Organization
HDPE - High Density Poly Ethylene
PPP - Public Private Partnerships
USA - United States of America
WPWSSP - White Paper on Water Supply and Sanitation Policy
WRC - Water Research Council
UNFCC - United Nations Framework Convention on Climate Change
AWEA- Australian Wind Energy Association
DWEA - Danish Wind Energy Association
O&M - Operation and maintenance

Appendices

Appendices

Chapter 1: Introduction

1.0 Background to this study.

The author has been involved for many years in the design and installation of rural water schemes, with particular emphasis on renewable energy. However, little literature is available on this topic, with most publications being either of electrical or mechanical engineering origin. In these schemes, system design, with particular focus on wind energy, was conducted with little or no regard to civil engineering principles. The candidate has therefore chosen to research the feasibility of introducing a typical design methodology, focussing towards a civil engineered solution.

1.1 An overview of the historic development of potable water supply in SA.

The historic development of water supply in South Africa (SA) mirrored the general development of the nation as a whole under the apartheid system. The development of SA's water resources has been linked more with supporting the progress of the county's wealthy agricultural and industrial sectors than with alleviating the plight of the poor, particularly in the rural areas. By the end of the 19th century most of the water supply in SA was for white commercial farming.

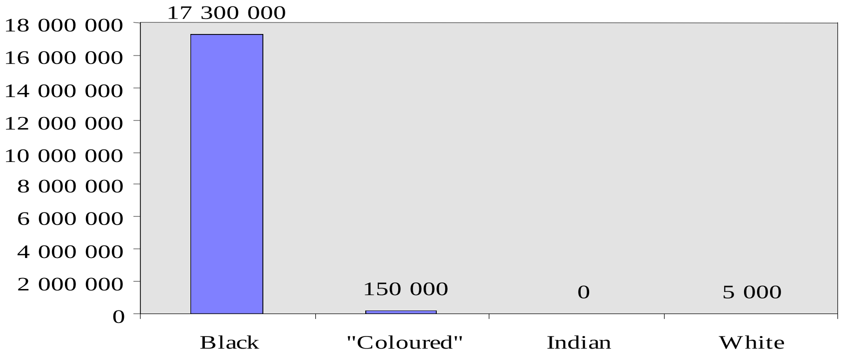
During the period 1929-1956 subsidies were introduced to accelerate the development of private irrigation schemes. However the existing legislation with its emphasis on agricultural irrigation proved inadequate for the requirements of an expanding industrial base, so in 1956 a new Water Act (Act 54 of 1956) was passed, which was intended to provide equity to all users as well as providing strict control over, amongst other things, extraction, use, supply, distribution and pollution.

Post second world war years saw the introduction of subsidies to smaller municipalities to improve the standard of supply, but due to the geographical mismatching of demand and supply, huge inter-basin transfer schemes such as the Orange - Fish, Tugela - Vaal and the Lesotho Highlands water scheme had to be implemented to alleviate the shortfall in supply.

With the introduction of apartheid in 1948 and the division of the country into homeland territories, it became clear that virtually all the vast water related projects serviced the white sections of SA. The government then engaged in some form of water development but the investments were very unevenly distributed and totally inadequate. This partial or half-hearted investment attempt was further aggravated by the fact that due to the lack of political legitimacy of the homelands, enforcement of any kind of tariff policy was almost impossible and homeland budgets became increasingly absorbed in the payment of operating subsidies. Under illegitimate and inefficient management the meagre services which did exist in the townships could not survive the protracted boycotts of black civil society. Furthermore in rural areas, 75% of existing water schemes were out of order [WPWSSP, 1994].

1.2 Challenges facing potable water supply in South Africa.

According to Statistics SA (2001), 21% of households in SA do not have access to piped water and the water supply industry in the country therefore faces enormous challenges due particularly to the country's past. Water is central to development, a small potable quantity is essential for people's physical survival, and a limited amount is needed for basic personal hygiene and household uses. In principle, this water for domestic consumption always receives priority.



However, despite the fact that water for human consumption is but a small proportion of the total available, many communities have totally inadequate access to drinking water (Figures 1 & 2). In contrast, farmers often use large volumes of water for irrigation and stock farming in the mainly arid areas of the country. This is a contradiction which is deeply felt and widely resented (WPWSSP, 1994).

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Figure 1 : Population without piped water

(Source: WPWSSP, 1994)

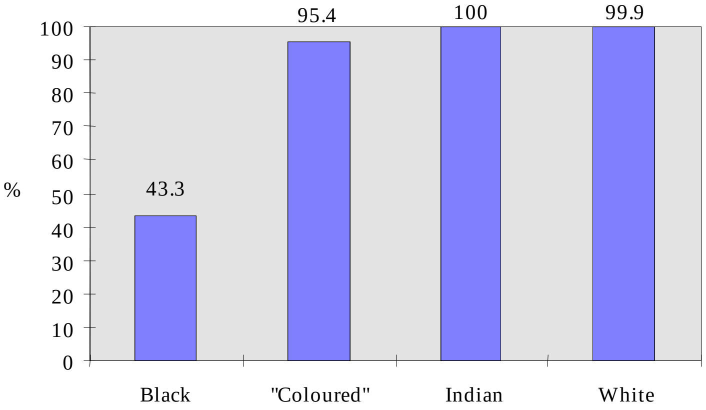


Figure 2 : Piped water distribution

(Source: WPWSSP, 1994)

1981 to 1990 has been referred to as the 'International drinking water and sanitation decade' by the UN General Assembly and attention has focussed on core problems with the provision of minimum services to everyone throughout the world. According to Bond *et al* [1999], during the first half-decade of democracy, water and, especially, sanitation services to the majority of SA consumers deteriorated in relative terms. They argue that *"a lower percentage of South Africans enjoyed access to affordable water in their homes or yards in 1999 than in 1994 (given population growth in excess of 2% and low water system installation rates*)". While a figure of 3 000 000 people newly-supplied with water through the governments rural communal taps between 1994 and 1999 is often cited, the authors claim that "by mid 1999 it was semi-officially acknowledged that far fewer than half those taps still worked, in the wake of systematic design flaws and affordability constraints." They are also critical of the fact that despite the spending of billions of rands on such projects, "no systematic evaluation was available to give a precise percentage of failed water projects."

Furthermore, it was found that economic pressures imposed tight constraints on investments in water supply and sanitation [Ralo *et al*, 2000], especially in countries with flagging economies and high debts. It became clear that governments and donors could provide only a fraction of the resources needed and that communities themselves had to carry out much of the cost of service provision.

In light of these economic pressures and tight constraints which face water provision, it may seem harsh but it is essential that rural communities pay for the provision of these demand-driven services, as only demand-driven income generating services are sustainable.

1.2.1 Correlation between the national electrical grid and water supply.

Approximately 60% of all South Africans do not have access to electricity from the national grid, nor will they have in the foreseeable future. This is because several areas in South Africa have little or no grid penetration. The worst affected areas are the Eastern Cape and KwaZulu-Natal [Kotze ,1995]. Kotze further notes that electrification of rural households is particularly problematic, with the main reasons being:

- Settlement density (i.e. the cost of interconnecting houses in a local grid).
- Distance of the local grid from the existing grid (i.e. cost of the feed line).
- Projected load on the local grid (i.e. the expected consumption levels).

On the operational side, apart from maintenance, is the cost of revenue collection. It was also noted that because of the low consumption rates observed, monthly sales were just able to balance normal operating costs, with nil return on the capital employed.

Water supply relies heavily on grid electricity for purification and distribution. Electricity is needed to power the pumps which distribute water and, hence, the same problems which affect electrical supply, affect water supply. Therefore there is a need for a non-grid, stand-alone water supply system.

1.3 Possible solution for rural water supply in South Africa.

Although there are various methods of producing off-grid power with renewable energy ie. biogas, solar, wind and hydro, this study will focus on wind. Wind energy will be explored as a viable energy supply for the provision of potable water to rural communities. The present preference for wind pumping is based on criteria such as lower investment costs, the existing infrastructure, flexibility, reliability or simply familiarity with the technology [Renekarotti *et al*, 2001].

1.4 Objectives of this research.

The objectives of this research was to :

- Introduce wind as a sustainable source of rural energy.
- Develop a design methodology for a typical off-grid, potable rural water supply scheme for wind machines which drive mechanical pumps as well as those which generate electricity.
- Analyse a case study and examine the findings.
- Develop a design flow chart for off-grid rural water supply schemes.

1.5 Overview of the chapters.

This thesis is structured as follows:

- Chapter 2 deals with the literature review and forms the basis from which this thesis is developed.
- Chapter 3 introduces the reader to the fundamentals of wind energy, and formulates a design methodology utilising all basic design parameters which should be considered when designing a wind powered water supply scheme.
- Chapter 4 assesses a case study where the design criteria in chapter 3

are tested.

- Chapter 5 discusses conclusions drawn from the case study.
- Chapter 6 lists all recommendations from the conclusions and proposes a practical design flow chart.

1.6 Limitations of this study.

The broader study of both water supply and energy generation are topics worthy of greater study, however, this thesis focuses on small off-grid primary water supply. The design will use the minimum standards as laid down in the WPWSSP as a basis.

It must also be noted that because of the size of these schemes, investment in large scale wind assessment is not expected and assumptions based on generic values or wind data from weather stations are used. Although these schemes are small, it is intended that they have enough reserve capacity for short-term expansion and local economic development, however, the design inputs as well as budget constraints determine the end result.

A further limitation is that of the assessment of the water supply. This type of system generally utilizes subterranean water and it is assumed that a complete study has been undertaken to verify the suitability of the water supply.

1.7 Methodology of the research.

The following points outline the research methodology:

- A literature survey was conducted to establish possible solutions to the problem posed.

- A wind driven solution was chosen.
- The theoretical background to wind is explored.
- A design approach or methodology is introduced.
- An evaluation of an existing design is undertaken.
- The proposed design method is evaluated.
- Conclusions are reached as to whether objectives have been met
- Recommendations are made on the value of methodology and means of its implementation.

Chapter 2: Review of related literature.

2.0 Introduction.

A new democracy was born in 1994 and together with the Reconstruction and Development Programme (RDP), plans were formalised whereby all South Africans would have the right to a healthy environment in accordance with the constitution. This included safe and clean water supply. However, the world is littered with failed first-world solutions to third-world problems, implemented by qualified engineers, economists and development *'specialists'*. A thorough understanding of all the local conditions including social, environmental and practical dynamics is essential so that SA can avoid following the same rocky road.

The following policy principles are suggested for rural water schemes is SA [WPWSSP,1994]:

- Development should be demand driven.
  Water supply should be based on what the communities are able to afford, with the communities accepting responsibility for the system development and governance, assisted by the state.

- Basic services are a human right.
  Although 25 litres/person/day is accepted as the minimum [WPWSSP, 1994], it is considered inadequate for a healthy existence and a minimum of 50 l/p/day is recognized as the Basic Water Requirement (BWR) for fundamental human needs [World Health Organization, 2004].

- ‘Some for all’ rather than ‘all for some’.

  It is the government’s view that far more people can be serviced by adopting an entry level or basic supply system, rather than a typical all encompassing water system. The idea is that the cost savings realised from the cheaper system means that more systems can be installed for a given amount of money and therefore more people will be serviced.

- Equitable regional allocation of development resources.

  The limited national resources available to support the provision of basic services should be equitably distributed among the regions, taking into account the population and level of development.

- Water has an economic value.

  Good quality water is a scarce resource in South Africa, hence a healthy understanding of its value should be propagated and understood.

- The user pays.

  This must form the core of any supply system. If the consumer pays, not only will the system be economically sustainable, but a certain amount of care is exercised in its use and, hence, scarce resources like water will be used sparingly.

- Integrated development.

  Development of a resource without consideration of its subsequent direct and indirect benefits must be avoided. Job creation, education and training must all be included.

- Environmental integrity.

Protection of the environment must be enshrined in all development activities.

2.1 Factors affecting water supply schemes in South Africa.

2.1.1 Climate.

South Africa is a typically semi-arid country with areas of very sparse population. South Africa's annual rainfall of 500 mm is only 60% of the world average. Sixty five percent of the country receives less than 500 mm annually (minimum required for dry land farming). Twenty one percent of the country receives less than 200 mm. Over most of the country the average annual potential evaporation (between 1100 mm - 3000 mm) exceeds the annual precipitation which reduces the surface runoff greatly.

The areas with inadequate water are coincidently inhabited by people with very limited incomes. Provision of first-world services proves elusive for many South Africans; 12 million people do not have access to potable water and 21 million people lack basic sanitation [WPWSSP, 1994].

South Africa receives about 50 billion cubic metres of water from its rivers and a further 6 billion cubic metres of water is available in underground aquifers. The exploitation of underground reserves is largely used for livestock, with little emphasis on mainstream water provision.

2.1.2 Collection practices.

Recent studies in the Eastern Cape [Ralo *et al*, 2000] suggest that due to the installation of new water schemes, 80% of rural communities can now obtain their water from communal taps, but the amount obtained is not always the stipulated minimum of 25 l/p/day. The remaining 20% are forced to obtain their drinking water from rivers or springs which, in all likelihood, is unfit for human consumption. Contamination resulting from either animal or human excrement draining into the catchment areas or directly into the rivers is common. Furthermore, the location of these unprotected sources is normally far from the home, which results in a major part of the day being spent collecting water; the ones doing the collection are normally the woman or children (Figure 3a and 3b).

Studies conducted by eThekwini Water and Sanitation [eThekwini Water and Sanitation, 2001] indicate that fresh, safe water collected from municipal taps showed, scarcely 4 hours after collection, high rates of faecal contamination; up to 10 times the acceptable limit of 100 coliforms/ml [CSIR, 1994]. This contamination is attributed to dirty water containers, or lids as well as incidents of unhygienic practices amongst the children who collect the water.

Figure 3a : Woman carrying water.

Social development is also impeded by the collection of drinking water as the time wasted by collecting water could be spent, in the case of children, at school, or in the case of women, performing tasks which could result in some form of economic return, thus increasing their family's standard of living.

Figure 3b: Boy transporting water.

2.1.3 Unemployment and dependancy on Government grants.

Rural South Africa, due to past geographical mismatching of rural townships and employment opportunities, has a very low employment rate with most rural families dependant on money sent back by breadwinners who work away from home. Remuneration is thus very erratic and often non-existent resulting in an overwhelming dependance on government pensions and grants. According to a recent report, 74% of the population in the Eastern Cape live below the poverty line [Daily Despatch, 2000]. This lack of financial means translates into very little funds available to purchase water from existing or proposed water schemes. Furthermore, poverty also appears to inhibit effective community participation in water committees [Ralo *et al*, 2000].

2.1.4 Local economic development.

Arising from the lack of employment and resultant poor communities as well as the government's minimum allowance of 25 l/p/day, an opportunity to alleviate the plight of the poor has been missed. The National Water Policy does not recognize the potential impact rural water schemes could have on local economic development and, as such, has ignored a dynamic, which, in conjunction with a water supply system, could kick-start local economic empowerment. An example of this form of income generation would be market gardening and concrete block making.

2.1.5 '*Culture of entitlement*'.

A paradigm shift in people's expectations has taken place since the 1994 elections. Post election reality has brought about a realization that service provision is a costly exercise for which one has to pay. Although water is a natural resource which should be freely available, costs are incurred in the extraction, processing and supply of the resources, for which the consumers have to pay. Recent research tends to disprove the *'culture of entitlement'* ethos which is attached to rural communities. An overwhelming majority of the rural population surveyed (73%) agreed that, in principle, consumers should pay for the water that they use, and that they do not expect water for free [Ralo *et al*, 2000]. However owing to poverty and unemployment, there is a serious affordability problem, which suggests a free basic water supply.

2.1.6 Communal taps verses metered yard taps

The government’s present system of providing communal taps, charged out at a flat rate regardless of consumption, has been met with mixed reaction. On the one hand there is safe water available, but there is little or no control over the use of these communal taps. Current consumers feel that metered yard taps would be more beneficial as they will only be charged for the water they use and they will be able to exercise more control over them [Ralo *et al*, 2000].

2.1.7 Appropriate technology.

There is a common misconception that standard main stream systems are more beneficial than systems which employ alternative or renewable energy; hence these alternatives are deemed inappropriate. Renewable technologies are viewed as *‘second best*’, even though first world nations around the world, in an effort to reduce greenhouse gas emissions, are looking towards renewable energy as an alternative. However, education can change this misconception [Renekarotti *et al*, 2001].

2.1.8 Sustainability of water committees and community involvement.

Accountability and administering water service delivery at grass roots level is the function of locally elected community structures. This system, however, does have some rudimentary flaws, which if left unsolved, will result in a total breakdown in service delivery. Typically, these committees are voluntary in nature with the result that members gradually lose interest and involvement. Members also lack appropriate power to enforce payment of services delivered and more often than not affordability is an insurmountable problem. The voluntary nature of these committees, together with inadequate training, proves unattractive to new members [Ralo *et al*, 2000].

2.1.9 Price disparity and community involvement.

The Rural Support Services (RSS) was commissioned by the Water Research Commission (WRC) to conduct research on the impact of government water policies in rural areas. These studies indicated a serious crisis in delivery and a general failure to meet planned targets. Ralo *et al*,(2000) indicates that there are serious problems in supplied community water projects with a failure rate as high as 90%. Apart from possible affordability constraints and an unwillingness to pay for communal stand pipes, other reasons for failure include poor quality of construction, isolated un-serviced areas within the community, and intermittent supply.

Due to the wide variety of systems available, water tariffs are not uniform, with adjacent communities paying different amounts for water. Rural households must pay for water from stand pipes, whereas urban households who get water delivered on site get the first 6 kilolitres, per month free, (according to eThekwini Water, 6 kilolitres is the break even point between the cost of collecting revenue and the revenue collected). Communities with new water systems must pay for the ongoing upkeep of the system whereas some communities supplied by the former Bantustan governments get their water for free. These inequalities have led to tension within and between communities and, despite the claim to provide “some to all”, vast areas have not received water services to date [Bond *et al,* 2000].

An evaluation of completed RDP community water supply projects in the Eastern Cape during 1998 [Ralo *et al*, 2000] has highlighted the extent of the problem. The evaluation aimed at assessing primarily the sustainability, operation and maintenance of the projects.

Four main areas were investigated:

- community participation and management
- training
- technical aspects
- post project activities

The investigation found that, with regard to community participation and management, communities felt that they were not properly consulted and were merely informed that they were to receive a water project. This led to inappropriate services, conflict and vandalism of the system. Recipients were not informed of their responsibility for costs of operation and maintenance prior to the work commencing. Communities had too little to do with organising labour and were dissatisfied with wage rates and job allocation. Labour equity was also not adhered to with men being favoured over women. Training of community members was also inadequate.

Key findings were:

- most training was not project specific and did not equip committees to undertake operation and maintenance (O&M),

- most training was received too late to be useful in implementation,
- there was little assistance in setting up organisation and methods systems,
- training would have been more appropriate in the project area.

The extent of the problem becomes clear when looking at technical issues:

- of 29 water supply schemes, only 48% were working and operational,
- if, however, scheme management and collection systems are included, the number of operational projects were dramatically less,
- of 19 RDP systems, only 26% were working,
- gravity systems were found to be more likely to be working than pumped systems, especially where there was inadequate capacity building and no development of an O&M system.

While there was virtually 100% willingness to pay an average of R5 per household per month for working water services, many schemes were not operational. The key reason for this was that most projects had no O&M system due to:

- lack of training and support
- lack of consultation on responsibilities
- lack of awareness of the need to pay for services
- political conflict on the ground.

There was no cost recovery on most systems and a general feeling of lack of consultation with the community [SAPA, 2000].

Other studies of rural water schemes have discovered similar problems to those already discovered in the Eastern Cape study [WPWSSP, 1994]. Furthermore the problems noted are common to both local and international projects. One international response to a generalised crisis in rural water delivery is the World Bank's proposal for a transition from supply orientated to demand responsive services [Sara *et al*, 1998].

The four principles, which form a basis of the demand responsive approach are:

- water should be managed as an economic as well as a social requirement
- management should be focussed at the lowest appropriate level
- a holistic approach to the use of water sources should be employed
- women should play a key role in the management of water [Sara *et al*, 1998].

2.1.10 Theft.

One of the major obstacles to development is theft of various components. Most rural development takes place in areas where there is very little or no security and visible components are always targets for vandals and thieves. Installing a rural reticulation system is not immune to this problem, with theft of items of perceived value being high on the list.

The most common items subject to theft are the brass tap fittings and copper piping. This can be alleviated by using low cost plastic taps and fittings as well as High Density Poly Ethylene (HDPE) piping and, where possible, to bury the piping. Pumps and solar panels are also highly susceptible to theft and with these items being very costly to replace, loss thereof often results in total system breakdown and decommissioning. Although new technology renders the solar panels useless once they have been removed from the array structure, the damage has already been done and the system no longer operates (Figure 4).

Figure 4 : Solar array showing theft of panels.

"Every time there is a theft, we know somebody in the community is involved, who is either collaborating or at least saw it happen. The community must not allow thieves to come in from other areas and deprive them"[Daily Dispatch, 2002]

In another solar project, [Myika High School in Inanda, KwaZulu-Natal] the success of which was widely publicized in KwaZulu-Natal, panels have also been stolen, although the system is in a fenced school yard, behind a razor wire, wire mesh and electric fence. This has also rendered the system inoperative.

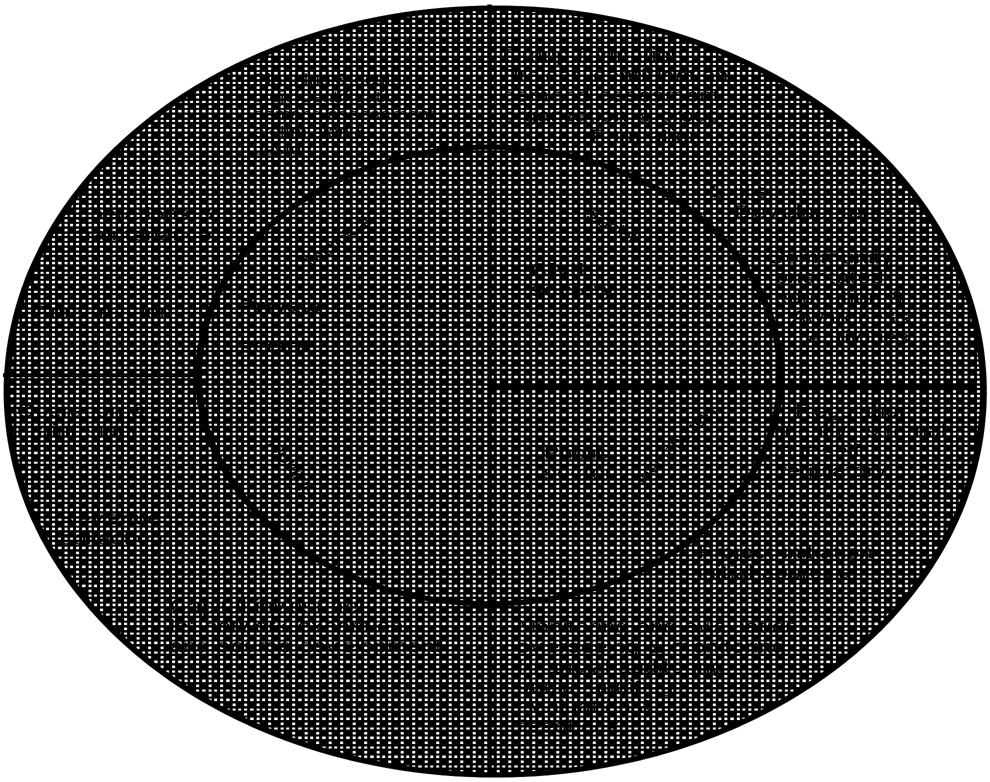
In contrast, however, the approximately 300 000 wind machines in existence in South Africa have shown little or no interference due to theft [Sami, Murray, 1998].

2.1.11 Scheme implementation.

In studies conducted by the Water Research Commission [Ralo *et al*, 2000] it was noted that the so-called Build, Operate, Train and Transfer (BoTT) schemes had been criticised, amongst other things, for causing administrative confusion, lengthening implementation time, and being more expensive and overly bureaucratic. The researchers concluded that this approach draws resources away from the priority development area of rural local government capacity building.

During system evaluation and evolution Public Private Partnerships (PPP) are seen as the way to approach water system delivery. Water supply systems cannot only be evaluated on purely social, technical or political grounds, but on a combination of the three, which can only be achieved by combining civil society, Non Governmental Organizations (NGO) (which are normally the government's watch dog), government and private sector.

Tri-sector or multi-sector partnerships bring together the private, public and civil society in an effort better to tackle the challenge of providing water and sanitation services to the poor. The basic tenet underlying the concept is that each of these



sectors has something valuable to contribute and through working together they can achieve their goals more effectively than by working alone (Figure 5).

Figure 5 : Typical structure of Public Private Partnerships

(Source: Caplan *et al*, 2001)

2.2 Sources of rural water

According to Sami and Murray (1998), there are several possible water source options that can be considered. These include:

- the purchase of water from nearby towns or communities;
- the purchase of water from a nearby irrigation project;
- the development of a regional supply scheme;
- the abstraction of water from underground aquifers using shallow wells or boreholes;
- the collection of groundwater from springs or infiltration galleries;
- abstraction of surface water from perennial streams;
- impoundment of surface water;
- collection of rainwater.

The main criteria for evaluating the suitability of a source are that it should be of a suitable quality, have a suitable sustainable yield to meet the requirements, and that it is technically and economically feasible to develop.

The selection and development of a source will require data concerning topography, precipitation, soils, groundwater and aquifer characteristics such as permeability, depth recharge and runoff.

Standards South Africa, (2004), indicate further that the distribution of water on our planet is highly uneven, with 97.4% being in the oceans and 2.6% on land. Of the 2.6% only 0.014% is available for humans and other organisms of which 97% is groundwater. According to a study conducted by the Department of Water Affairs and Forestry, the total estimated yearly groundwater use of approximately 3600 million cubic metres in South Africa accounts for only 58% of the total quantity of 6200 million cubic metres available annually for exploitation [Standards South Africa, 2004].

2.3 Current rural off-grid water supply systems.

Sami and Murray (1998), indicate that there are many types of pumps driven by a variety of power sources. The most commonly used types for rural water supply systems are hand pumps, wind pumps, turbine, centrifugal and positive displacement pumps with solar, hydraulic ram and air lift pumps being used to a lesser extent.

The three main off-grid water supply systems considered in this study are :

- The hand pump
- Solar powered water pump.
- Wind powered water pump.

2.3.1 The hand pump

Basic water supply systems most often used are various types of hand pumps which extract ground water (Figure 6). These hand pumps are able to extract water to a depth of approximately 60 m with delivery rates in the region of eight litres per minute [Ralo *et al*, 2000]. One of the major drawbacks of hand pumps is that physical energy is required to extract the water and therefore very little surplus water is available.

2.3.2 Solar powered water pump.

Renewable energy supply systems are also utilised with varying degrees of success, with solar and wind being the sources most often used. Solar powered systems utilise the sun’s radiation, converting this energy into electrical energy which in turn can be used to drive submersible pumps (Figure 7). The perceived value of the solar panels makes this system extremely susceptible to theft, and once the panels have been tampered with, the electrical supply is interrupted and the system no longer works (Figure 7).

Figure 6: Typical hand pump installation

2.3.3 Wind powered water supply system.

Wind power is one of the older technologies which has been in use in S.A. since the 1800s. Low speed, high torque machines (Figure 8) are relatively simple and robust, and can deliver as much as 3000 l/min at a wind speed of 20 km/hr [Turbex Wind Turbines,2004]. There are two basic types of wind turbines; a reciprocating or a rotary type. Both types convert wind energy into mechanical energy, which is used to drive a direct shaft driven pump. However, with the rotary type, the shaft can also drive a generator which can generate electricity, which in turn can drive an electrical pump. The very nature of wind turbines renders them unattractive to would-be thieves and thereby reduces breakdowns due to theft. In excess of 300 000 predominantly locally manufactured wind-turbines are already installed as a low cost option for the supply of water, mostly for livestock.


Turbex

Figure 8 : Typical wind powered water supply system.

2.4 Efficiency of wind driven systems.

The overriding factor, when all else is considered, is the cost per kilolitre. The huge cost which renewable energy solutions exclude is the cost of fuel, as both sun and wind are free. Table 1 and Figure 9 details a study undertaken by Turbex Wind Turbines, of the various common systems available for water supply.

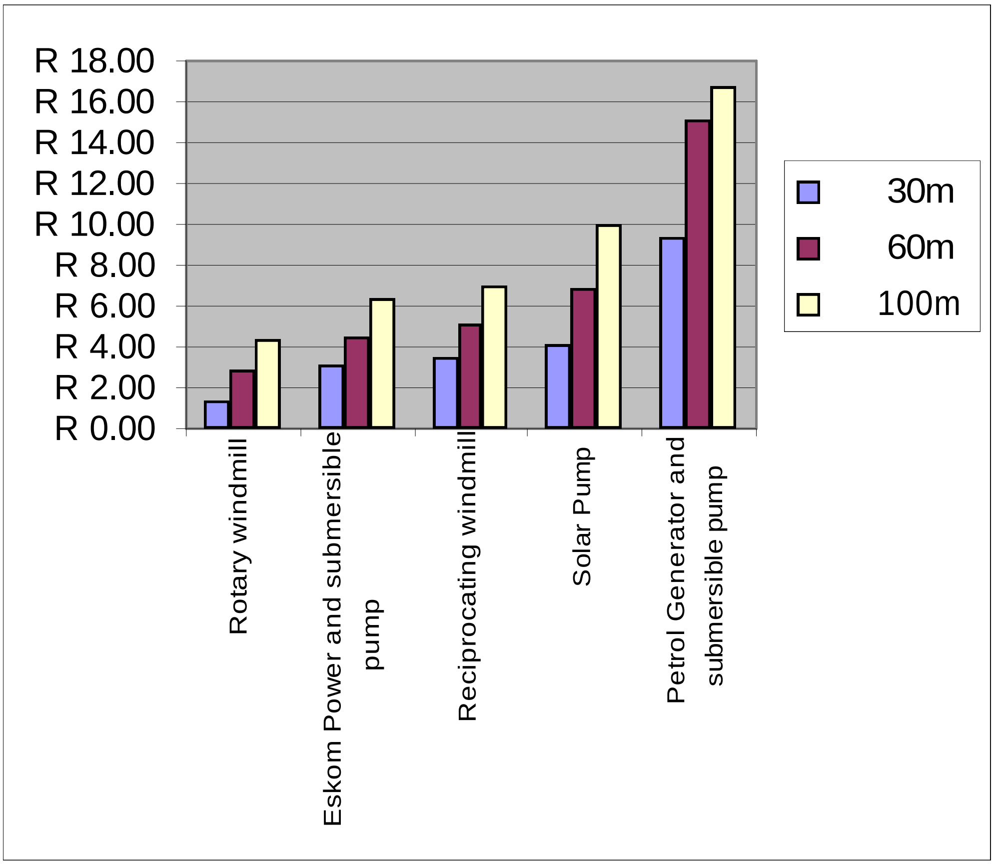


Figure 9 : Cost for pumping 10000 litres at varying depths.

(Source: Turbex Wind Turbines, 2004)

A typical scenario of 10000 l/day was required from depths of 30m, 60m, and 100m. The total cost, namely capital outlay, installation, operating costs and replacements were calculated for a period of 20 years. The nett present values [Gitman, 1994] were then calculated and used to make a fair evaluation of the different systems. Due to the lack of other similar studies, verification of the above data was not undertaken.

Pumping System	30m	60m	100m
Rotary windmill	R 1.35	R 2.86	R 4.32
Eskom Power and submersible pump	R 3.12	R 4.44	R 6.32
Reciprocating windmill	R 3.44	R 5.15	R 6.95
Solar Pump	R 4.17	R 6.90	R 10.06
Petrol Generator and submersible pump	R 9.40	R 15.16	R 16.70
Diesel engine and mono pump	R 10.20	R 12.49	R 15.27

Table 1 : Cost to pump 10000 litres of water

(Source: Turbex Wind Turbines, 2004)

2.5 Summary.

The basic criteria as outlined in chapter 2, for a successful supply system can be summarised as follows:

- Development should be demand driven.
- Basic services are a human right.

- An entry level service which can be enjoyed by many.
- Integrated development - kick start local economic development.
- Availability of subterranean water as an alternative.
- Provide safe, clean water.
- Free basic water - 6000 litres per household per month.
- Surplus availability - for income generation and system maintenance.
- Ease of access - yard taps.
- Education - understand and appreciate alternatives.
- Accountability to the system and to one another.

Furthermore the cost advantage of renewable energy, coupled with the low theft incidence of wind machine components, indicates that this system, if properly modelled, can provide a solution to rural potable water supply.

Chapter 3: Fundamentals of wind energy.

3.0 Introduction.

Generally speaking, the world is moving towards renewable energy, not only in rural areas but in the urban context as well. Damage to the environment is becoming increasingly evident, with global warming being prevalent. Following the Organization of Petroleum Exporting Countries (OPEC) oil embargo of 1973, renewable energy has resurfaced in response to climbing energy prices and a questionable availability and reliance on conventional fossil fuels [OPEC, 1973].

Small, rural, renewable energy has in the past been viewed as a stop gap approach to providing energy, a temporary inefficient solution . Today however, with ongoing development and testing, it is becoming more appropriate, and as with most emerging technologies, ongoing development and refinements result in lower unit costs. Furthermore, wind is the fastest growing renewable energy source in the world today. Wind turbine development has encompassed both large and small scale models, from large turbines (rotor diameters up to 100 m), capable of providing power to over 700 homes, to small battery charging turbines with rotor diameters of less than one metre. Since 1980, ‘wind farms’ have become an option for electricity generation, with areas such as California in the USA obtaining approximately 2% of their electricity from wind, and Germany, which possesses one third of the world’s wind energy generation, obtaining almost 4% of its national energy required from wind [WWEC, 2003].

The signing of the Kyoto Protocol [Kyoto Protocol, 2004] at the United Nations

Framework Convention on Climate Change, adopted in New York on 9 May 2002, has meant that parties to this agreement, of which South Africa is not yet a full signatory, have pledged that they will pursue limitation or reduction of greenhouse emissions [UNFCCC, 2004]. This reduction in emissions will be accommodated in part by the development of domestic policy, in each member state, encouraging rigorous renewable energy programmes which will form a growing part of overall energy production, thereby reducing the reliance on fossil fuels and reducing greenhouse gas emissions.

3.1 The popularity of wind energy.

Wind energy is one of the most popular renewable energy technologies. Opinion surveys regularly show that just over eight out of ten people are in favour of wind energy, and less than one in ten (around 10%) are against it. The rest are undecided [AWEA, 2003].

Wind energy is already an important source of energy in South Africa, mainly in the agricultural sector. In excess of 300 000 predominantly locally manufactured wind driven water pumps are installed as a reliable low-cost option for the supply of water, mostly for livestock. Yet South Africa’s potential for using wind energy is much greater than that. Further development of this option can contribute to the country’s overall socio-economic objectives by stimulating economic activity in rural areas [Renekarotti *et al*, 2001].

Wind energy can also help South Africa to respond to the increasing international pressure to reduce greenhouse gas emissions, and at the same time access the international financial resources that are allocated for these reductions, including carbon credits.

‘*Under the carbon market,* CO_2 *emitters can buy or sell emissions of carbon in order to meet a pollution target.*

Companies that are over their target can buy emissions from companies that are under their target. The idea is to provide a carrot and stick that will help the EU meet its overall emissions reduction’ [Kyoto Protocol, 2004].

These potential benefits are recognized at the political level and policies supportive of modern wind power are under development [WWEC, 2003].

3.2 An overview of wind as a resource.

3.2.1 Where does wind energy come from?

All renewable energy, and even the energy in fossil fuels, ultimately comes from the sun. The sun radiates 1.74 x 10^{17} Watts, of which approximately 1% to 2% is converted into wind energy on earth. This is about 50 to 100 times more than the energy converted into biomass by all plants on earth.

3.2.2 Temperature differences.

The regions around the equator are heated more by the sun than the rest of the globe. Hot air is pushed upward by denser descending cold air, and this hot air will rise into the sky until it reaches approximately 10 km altitude, where it will spread to the north and south. If the globe did not rotate, the air would simply arrive at the North and South poles, sink down, and return to the equator. However, since there is rotation, any movement in the Northern hemisphere is diverted to the east and visa versa in the south. This apparent bending force is known as Coriolis force; named after the French mathematician Gustave Gaspard Coriolis, 1792 - 1843 [Coriolis, 2002].

3.2.2.1 How Coriolis force affects global winds.

As the air rises and moves towards the poles, the Coriolis force begins to take effect, and at around 30^{o} latitude, in both hemispheres, it is prevented from moving much further. At this point there is a high pressure area, and the air begins to sink down again. Thus, as the air rises at the equator, a low pressure develops close to the ground, attracting winds from the North and South. At the poles there will be a high pressure due to the cooling of the air and hence the following general results for prevailing winds will be applicable (Table 2).

Latitude	90-60^{o}N	60-30^{o}N	30-0^{o}N	0-30^{o}S	30-60^{o}S	60-90^{o}S
Direction	NE	SW	NE	SE	NW	SE

Table 2 : Prevailing wind directions.

(Source: DEA, 2004)

The global winds are known as geostrophic winds, and are largely driven by temperature differences and thus pressure differences. These winds are found at altitudes above 1000 m above ground level, and thus not influenced by surface conditions.

3.2.3 Surface winds.

Surface winds on the other hand, are influenced by ground conditions up to 100 m. These winds will be slowed down by the earth's topography; surface roughness and obstacles. It is these surface winds that are used for the calculation of useable energy. The prevailing winds are obviously important when siting wind turbines, as they should be placed in areas with the least obstruction to the prevailing wind.

3.2.4 Local winds.

Although global winds are important in determining prevailing winds in a given area, local climatic conditions may have a marked effect on local wind directions. Local winds are always superimposed upon the larger scale wind systems, i.e. the wind direction is influenced by the sum of global and local effects. When larger scale winds are light, local winds may dominate the wind patterns.

- **Sea breezes**

  Land masses are heated by the sun more quickly than the sea during the day. The air rises, flows out to sea, and creates a low pressure at ground level, which in turn attracts cool air from the sea. This is called sea breeze. At nightfall there is often a period of calm when land and sea temperatures are equal, and then a breeze in the opposite direction will blow but at lower speeds, as the temperature differences are lower at night. The monsoon in South East Asia is, in reality, a large scale form of sea breeze.

- **Mountain winds**

  Valley winds in the Southern hemisphere originate on the North facing slopes, when the air on these slopes are heated, thus becoming less dense and ascending to the top of the slope. At night this is reversed and a downward slope wind results. If the valley floor is sloped then the wind may blow up or down the valley. Winds blowing down the leeward slopes can be very powerful e.g. The Foehn in the Alps, Chinook in the Rockeys and the Zonda in the Andes.

3.2.5 Pitfalls in using Meteorology data.

Meteorologists already collect wind data for weather forecasts and aviation, and that information is often used to assess the general wind conditions for wind energy in the area. However, the importance of accurate wind speed measurement is not as critical for weather forecasting as it is for wind energy planning. Wind speeds are heavily influenced by the surface roughness of the surrounding area, of nearby obstacles, such as trees and buildings, and by the contours of the local terrain. Often wind measurements are taken at 2-3m above ground level where surface friction slows the wind down. Unless calculated adjustments are made to compensate for the local conditions under which the meteorological measurements are made, the true wind energy potential in the area will be underestimated. Wind measurements should be made at the predetermined hub height (hub height is the distance from ground level to the centre of the hub of the turbine, see Appendix B for position of hub), which could be anything from 9 m to 40 m, depending on how high the turbine must be sighted to avoid obstacles, or to allow for safe clearance of the rotors.

3.2.6 Quality of anemometers.

The correctness of wind speed measurements cannot be over emphasised. This can be further illustrated by the inherent inaccuracies of various anemometers, which may be as high as 5% to 10%. Although these may be appropriate for weather stations, they are not acceptable for wind speed measurement. Poor calibration and measuring error, because of the cubed effect of wind speed on wind energy content, is likely to cause an error in excess of 33% ($1.1^3 - 1 = 33\%$).

Coupled with an extrapolation to a different hub height, from say 10m to 50 m, the error may be multiplied by a further factor of 1.3, so that the end result has an error of nearly 75%. This clearly illustrates how important it is to obtain wind data from the most accurate source possible, at the correct hub height, and not to rely on weather station information. The most accurate source would be to perform wind speed measurements at the proposed site, at the desired hub height, for as long as possible, preferably for 1 to 2 years, and with an anemometer with an error of less than 1%.

3.2.7 Direct drive vs electrical turbine and pump.

There are two methods of drawing water up from a borehole with a wind turbine, and they are namely direct drive, where the turbine drives a series of shafts connected to a submerged pump which pumps the water up, and an electrical turbine and pump. The generator is powered by the turbine, which in turn generates electricity which is fed down the borehole to a submerged electrical pump. The pump then pumps the water up and out of the borehole. Both systems have advantages and disadvantages and should be viewed in their own context. Table 3 compares the two types. It should also be noted that the rotary wind turbine can perform both functions of direct drive and electrical generation.

3.3 Wind potential for South Africa.

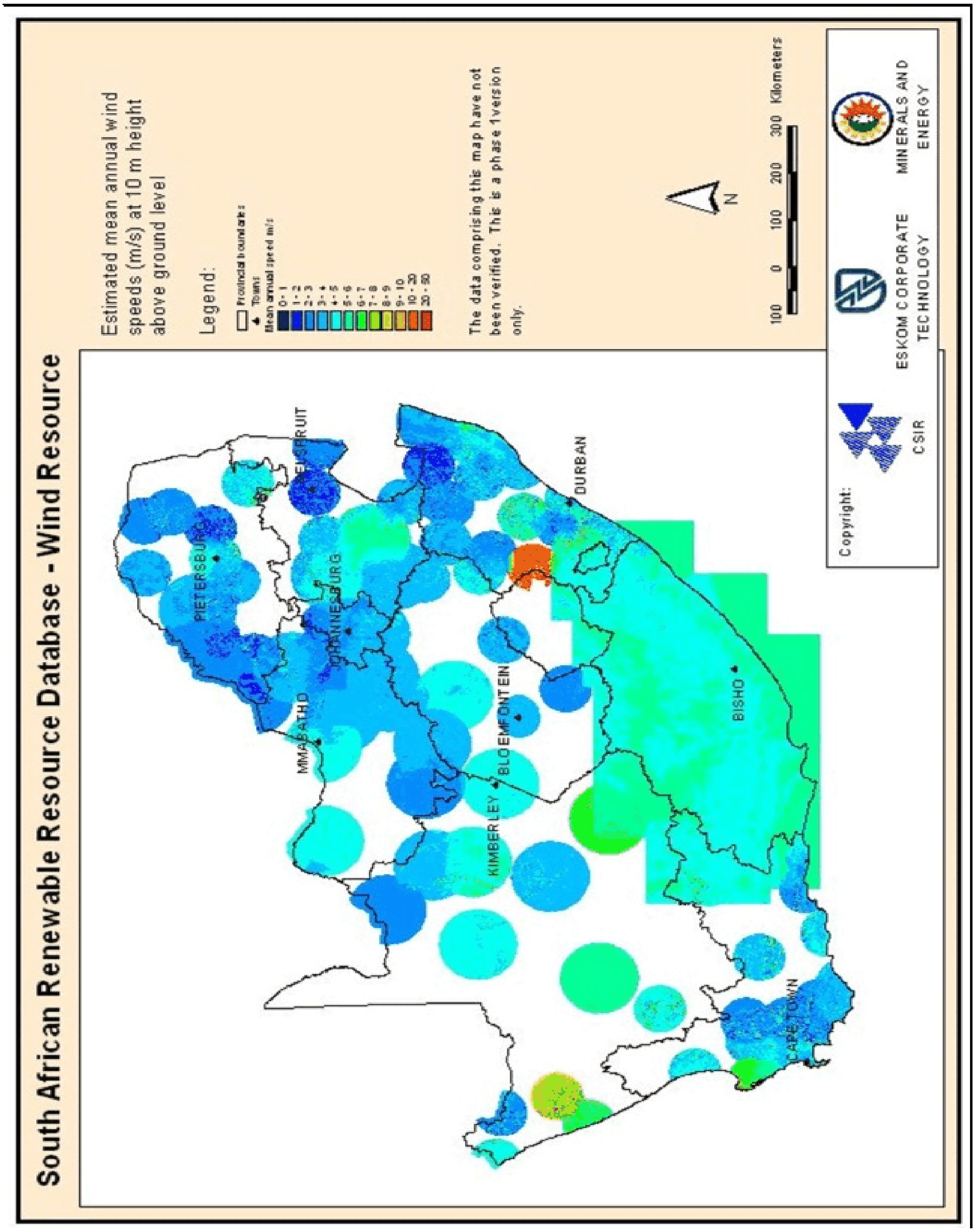
Whereas the traditional, multi-bladed wind-powered pumps operate at the moderate wind speeds experienced over most of the country, sufficient wind potential for economical generation of electricity is only found along the coastline and the Drakensberg escarpment.

Direct drive	Electrical turbine
Turbine has to be sited directly over the borehole.	Turbine can be sited away from borehole where wind is more available.
Produces more water per revolution.	Energy is lost through generator, cable and pump inefficiencies.
Cannot produce electricity.	Can be used to produce electricity for other uses such as lighting and battery charging.
Less complicated.	Needs more skill to install and maintain.
Costs less than pump and generator	Costs more than direct drive.

Table 3 : Comparison between direct drive and electrical turbines.

The first Wind Atlas of South Africa was published in 1995 with financial support from the DME [Diab, 1995]. The atlas was based on existing data from South Africa's approximately 170 meteorological stations. The coastal and escarpment areas were identified as having a mean annual wind speed of greater than 4 metres/second at 10 metres above ground level (see Figure 10). Information on sites with higher potential was insufficient to mobilize interest in wind power.(The bench mark height at which wind speed is measured is 10 m).

The possibility of more attractive sites within this broader region has only recently begun to be explored. The resource is substantial when compared with sites abroad. For example, sites in Denmark with wind speeds of approximately 4.7 metres/second have been effectively developed during the last 10 years.[DEA, 2004].



Computer modelling, based on data from 17 meteorological stations covering the Eastern Cape province, funded by the European Commission (EC) shows several sites with mean annual wind speeds in excess of 6 metres/second at 10 metres above ground level. These estimates call for additional measurements to verify the wind resource of the coastal mountain range.

Figure 10 : Wind map showing annual average wind speeds at 10 metres

above ground level.

(Source: CSIR, 1994)

3.4 Pumping water - the traditional use of wind energy.

Mechanical water pumping windmills have been manufactured in South Africa since 1871. It is estimated that more than 300 000 windmills are installed, and that more than 90% of these were manufactured locally. The wind pumps are situated in areas with mean annual wind speeds as low as 3 m/s. The water is used predominantly for livestock. The wind pumps are highly reliable, with an annual maintenance cost in the order of 5% of capital cost, a lifetime of 30 years for components such as the gearbox, wheel and tail, stub tower and windmill tower, and 10 years for the pump itself. Innovations in pump and gearbox design has meant that the traditional reciprocating (up and down) pump can now be replaced with a highly efficient helical mono pump, which is capable of excellent delivery rates against a head of 250 m.

3.5 Siting a small wind turbine.

Many potential users of small wind turbines think how nice it would be to put up a wind turbine next to their house and use the free power of the wind. Unfortunately, whilst the wind is free, the means to extract the power from it is not. Buying and installing a turbine costs money, and there are also operation and maintenance costs. Consequently, serious consideration must be given to siting the turbine to get the best performance and reliability from it.

The output from a wind turbine is highly sensitive to wind speed. It is essential that turbines be sited away from obstructions, with a clear exposure or fetch to the prevailing wind. Wind speed also increases with height so it is best to have the turbine high up. Most small turbines have towers much higher relative to their diameter than larger ones.

It is generally agreed that the ideal position for a wind turbine generator is a smooth hill top, with a flat clear fetch, at least in the prevailing wind direction. The wind speeds up significantly near the top of the hill and the air flow should be reasonably smooth and free from excessive turbulence. Excessive turbulence, (caused but the uneven heating of the earth’s surface, and associated high and low pressures), causes fatigue damage and shortens a turbine's working life.

In practice, especially for very small machines which need to be located near the user, ideal siting will not be easy. As far as possible though, site away from local obstructions such as large trees and houses, or use a taller tower to ensure that the turbine is situated in an optimum wind flow site (Figure11).

Before considering the installation of a wind turbine, the potential site should be assessed. Initial indications of wind strength and direction can be obtained by observing the deformation of vegetation and trees, and in many cases the user may already have a good feel for the winds in the locality. However, impressions can be deceptive.

A more reliable way to evaluate the wind resource, which is strongly recommended when there is doubt over whether the wind is strong enough, is to take regular measurements over a period of several months, preferably a year. It is not straightforward to use data even from nearby sites, and probably the nearest meteorological station or airfield where records have been kept is many kilometers away. However, measurements taken at a proposed site can be compared with measurements taken elsewhere at the same time, and used as a guide to the probable correlation over longer periods. In addition, computer models are available for professionals to use, although such predictions should be applied with care.

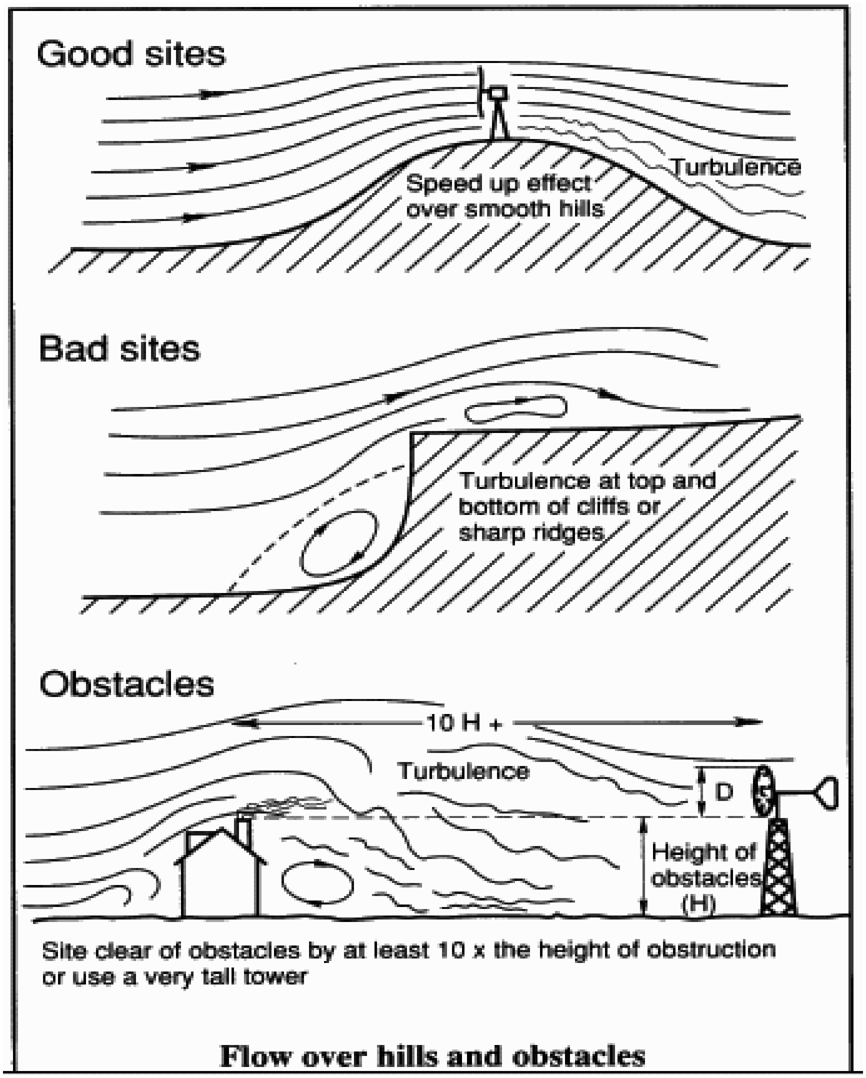


Figure 11 : Effects of obstacles and topography on wind speed.

(Source: AWEA, 2003)

Clearly, the expenditure on site assessment should be in relation to the proposed size and cost of the installation. Very little or no cost is justified in evaluating a site for a 50 W battery charger, whereas a 60 kW wind turbine, for example, would in general merit site measurements.

3.5.1 Basic requirements.(source: AWEA, 2003)

- **Get a reliable estimate of the winds to be expected at the proposed site**. There is no substitute for actual measurements. The turbine manufacturers should be prepared to help. However, the Wind Atlas of South Africa can help if there is no recorded data for the specific area.

- **Mount the turbine on as high a tower as possible and well clear of obstructions, but do not go to extremes.** Obstacles will decrease the wind speed downstream. The decrease of the wind speed depends on the porosity of the obstacle. (Porosity is defined as the open area divided by the total area of the obstacle facing the wind) The slowdown effect on the wind from an obstacle increases with the height and length of the obstacle. The effect is obviously more pronounced close to the obstacle and close to the ground (Figure 11).

- **Try to have a clear, smooth fetch to the prevailing wind,** e.g. over open water or smooth ground. If possible, site the turbine on a smooth hill (Figure 11).

- **Use cable of adequate current carrying capacity**: This is particularly important for low voltage machines as cable costs can be substantial and voltage drop to a submerged pump can reduce the overall efficiency of the system.

3.5.2 Roughness effects on wind.

In general, the more pronounced the roughness of the earth's surface, the more the wind will be slowed down. This surface roughness is characterised by a parameter known as roughness length, actually a height, (Z_o) [Lettau, 1969], and is illustrated by the following empirical relationship:

$$\mathbf{Z_o = 0.5\ hS / A_h}$$

where: h = height of the element (m)

S = cross section facing the wind (m^2)

A_h = average horizontal area of each element (m^2)

This relationship assumes that the roughness elements are solid. If they are porous, then Z_o must be reduced by an amount proportional to the porosity.

3.5.3 Vertical extrapolation of wind.

Generally, wind speed measurements are made close to the earth's surface, at approximately 10m, necessitating the extrapolation of wind with height to obtain a wind speed at hub height. One of the most widely used methods of vertical extrapolation is the 1/7th power law, which is given by:

$$U_z = U_{ref} (Z / Z_{ref})^p$$

where: U_z = wind speed at height Z (m/s)

U_{ref} = wind speed at the reference height (normally 10 m) (m/s)

P = power law exponent (assuming a value of 1/7 yields a conservative yet realistic estimate of wind speed [Diab, 1995])

Z = Height where wind speed is required (usually 10 m hub height)(m)

Z_{ref} = Wind speed specific height (usually 10 m)(m)

3.6 System design: Calculating water requirements.

Water demand can be based on a variety of factors, including type of use, economic empowerment and property size. However, this study will only be considering the provision of basic water services to local communities according to the White Paper on Water Supply and Sanitation Policy 1994, which indicates that 25 l/p/d is the minimum requirement.

As with other water supply systems, all raw water is accommodated in a reservoir prior to distribution. With wind powered supply, however, not only are peak demands to be included in the calculation of the storage capacity, but variations in wind speed and therefore delivery rates of water, must also be accommodated. Care must also be exercised during the assessment of wind in the area as hourly, daily and seasonal fluctuations must be accommodated.

3.6.1 Supply system.

Water supply should be via a single 15 mm yard tap which should have a minimum flow rate of 10 l/min and must be available for at least 51 weeks of the year [WPWSSP,1994]. Users should also be able to exercise the option of the tap being positioned inside the dwelling. However, should this be the case, suitable drainage and sanitation facilities must also be included. Peak demands as well as fire fighting demands have not been included as the areas under consideration fall under Low Risk Group 4 *'Residential areas where the gross floor area of the dwelling including outbuildings is generally not more than 55m^{2}'* [CSIR, 1994].

3.6.2 System analysis.

In order to analyse and subsequently size a system, the required end result must be known and then work backwards.

The following factors must be considered:

- Headloss due to friction.

$$\mathbf{Hf = 4\ f\ l\ v^{2} / 2\ g\ d} \qquad \text{(Darcy Weibach)}$$

Where : f = frictional coefficient of the pipe being used
l = length of pipe under consideration (m)
v = velocity of water in pipeline (m/s)
g = gravitational acceleration (m/s^{2})

d = diameter of pipe under consideration (m)

- Elevation difference.

Elevation difference must be either negative, if the supply is downhill or positive if the supply is uphill.

- Discharge.

To facilitate the calculations, the end discharge must be assumed. For this example an assumption of 10 l/min [WPWSSP, 1994] will be adopted per outlet. Once the previous factors have been calculated, from the headloss and elevation difference, a total head required, expressed as metres, can be identified for each connection into the water main. This head requirement can then be compared with the head available at that point in the water main. The total discharge, expressed on m^3/s must also satisfy the following:

- Reservoir sizing and siting.

Once the total discharge has been calculated, i.e. a total demand, the sizing and siting of the reservoir can commence. The following factors must be taken into consideration when sizing a reservoir:

- Total demand: This is to include all end users as well as an estimate of increase in supply due to the water being more freely available. Daily as well as seasonal fluctuations should also be considered.

- Total headloss for the system: This must include headloss due to friction of the reticulation pipework as well as any typical or unique fittings which may have an effect on discharge.
- Wind power available: Preferably from a detailed wind power analysis, using specific wind measuring equipment.
- Pump capabilities: This data will be calculated in conjunction with the expected wind power in the area. Manufacturers will often have this data available.
- Assurance of supply: The White Paper on Supply and Water Sanitation 1994, clearly indicates that water supply systems should have a functional reliability of 51 out of 52 weeks per year.

3.7 Calculating wind turbine size.

3.7.1 Power calculations.

Because air has mass and moves to form wind, it has kinetic energy. This kinetic energy can be converted into power which in turn can be used to drive the turbine. Power can thus be expressed as :

$$\mathbf{P = 0.5\ rho \times A \times V^3}$$

where: P = power in watts per m^2
rho = air density (1.225 kg/m^3 at sea level)
A = rotor swept area, exposed to the wind (m^2)

V = wind speed (m/s)

It also follows from the above expression that P is proportional to the cube of wind speed.

This yields the power in a free flowing stream of wind, however, it is impossible to extract all the power from the wind, (Betz Law proves that the maximum value for the power extracted from the wind is 0.59 of the total power of the wind -see proof Appendix C), and inefficiencies within the turbine contribute to a further reduction in possible power extraction.

Therefore: **P = 0.5 rho x A x V^3 x Cp x Ng x Nb**

where : Cp = Coefficient of performance (0.59 maximum possible and 0.35 representing an efficient design)
Ng = generator efficiency (%)
Nb = Gearbox & bearing efficiency (%)

Energy output is also greatly influenced by more subtle features of wind turbine design, including:

- cut in speed, or the wind speed at which the turbine begins to produce power.
- power it produces at moderate wind speeds, determined largely by aerofoil design.
- cut-out speed, the wind speed at which a turbine may shut down to protect itself from damage caused by over-speeding.
- operating characteristics, such as low speed on/off cycling, shut-down behaviour, and overall reliability, all of which determine

the turbines ability to produce power within the wind speed operating range.

- the efficiency of the drive train components, such as the generator and gearbox.

Once the power has been obtained, output can then be calculated by utilizing pump manufacturer's specifications. An expected water supply can then be identified.

3.7.2 Wind power potential.

One of the most misunderstood interpretations is that of wind power, as opposed to wind speed. All too often an average wind speed is used to calculate the power output of a wind turbine. This, however, is a gross underestimate of the wind power potential, of almost 100 percent.

As indicated in section 3.7.1 (Power calculations), the power in the wind increases with the cube of the wind speed. Therefore it follows that the average wind speed does not reflect the true power in the wind as it has assumed a linear relationship between wind speed and power.

In order to obtain a true reflection of the wind power, each wind speed probability must be weighted with the corresponding amount of power. It follows that although the higher wind speeds are less frequent, they possess the most power and therefore should be weighted higher than more frequent winds of lesser velocity.

3.7.3 Wind resource evaluation.

Wind resource evaluation is a critical element in projecting turbine performance on a given site. The power available in a wind stream is proportional to the cube of its speed, which means that doubling the wind speed increases the available power by a factor of eight. Furthermore the wind resource itself is seldom a steady, consistent flow. Time of day, season, height above the ground and its location away from large obstructions, enhances a wind turbine's performance. If wind speeds are recorded throughout the year, it will be evident that gale force winds are rare and that moderate and fresh winds are common. The wind distribution for a site is usually described using the so called Weibull Distribution as indicated in Figure 12.

Typically the Weibull distribution, or speed distribution, is a histogram detailing the amount of time the wind spent blowing at different speeds, in any direction. The results are depicted in a graphical format for ease of understanding, and the user can get a 'feel' of how the wind behaves. The fit of the graph is based on the equation of the Weibull or Probability Density Function (PDF):

$$\mathbf{f(x) = k \cdot c^{-k} \cdot x^{k-1} \cdot e^{-(x/c)k}}$$

Where : k = shape parameter, specifies the shape of the curve
c = weighted average speed (m/s)

Both k and c are derived by computing statistics about the wind data.

Probability Density Functions are intended to reflect the probability that an event will occur between two points. The area under the curve between any two speeds, greater than zero, will equal the probability that the wind will blow somewhere between these two speeds.

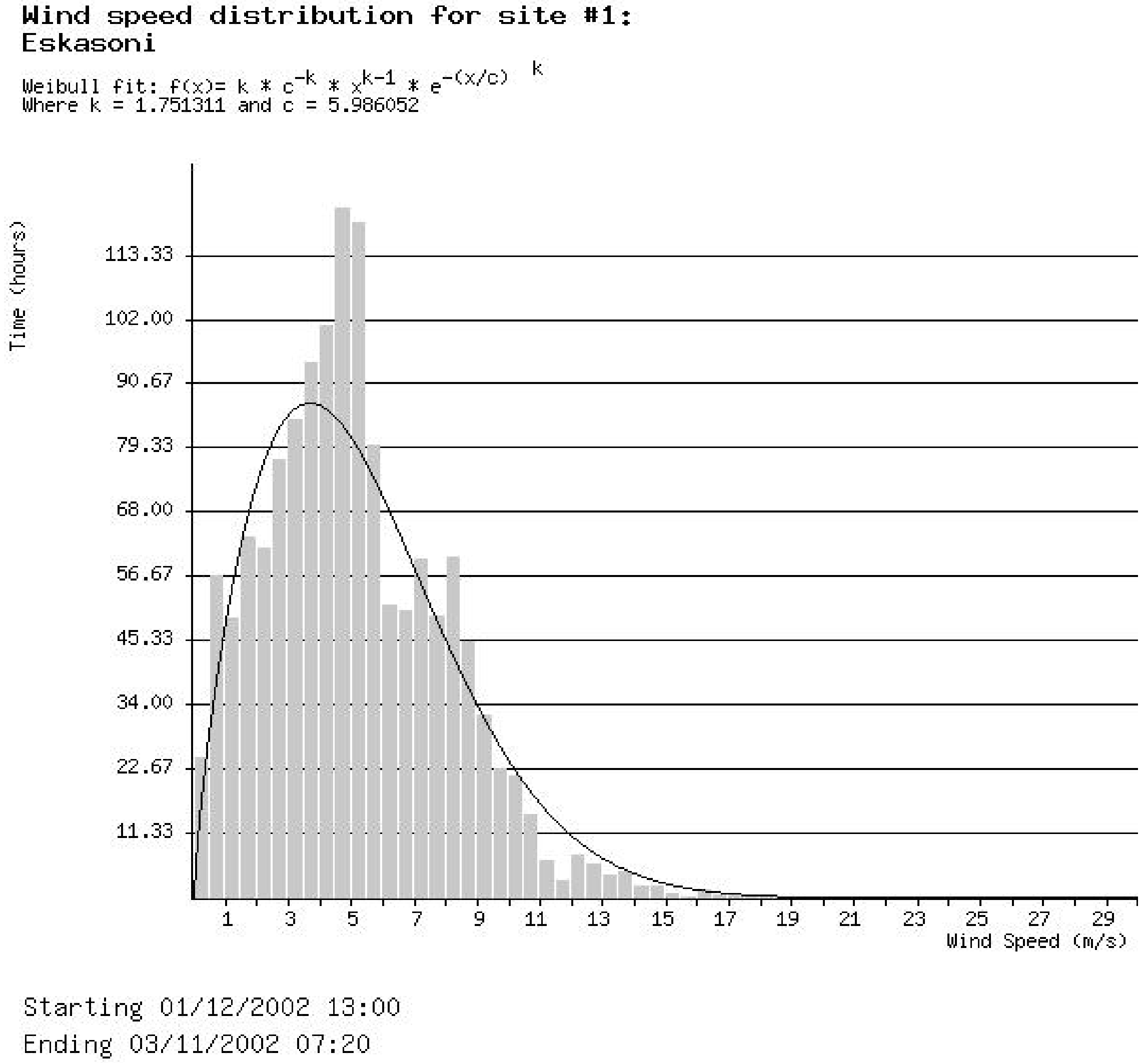


Figure 12 : Weibull Distribution.

(Source: Nova Scotia Wind Energy Project, 2001)

For example, if the k and c values are adopted from the distribution in Figure 12, (k = 1.751311: c = 5.986052), the area under the curve can be calculated from:

$$\mathbf{F(x) = 1 - e^{-(x/c)^{k}}}$$

Therefore if wind speeds of 3 m/s and 4 m/s were adopted , then the probability that the wind will blow will be: F(4) - F(3) = 0.38958 - 0.25788 or 13.17%

Wind power density is a useful way to evaluate the wind resource available at a potential site. Average wind speed, however, is not enough for the evaluation of a site's wind power potential. As wind speed increases, the power increase is cubed. Wind speed data therefore has to be weighted with the corresponding amount of power available, and this power distribution is then to be analysed and a weighted power average should be used (Figure 13).

Power density = Power of wind at 'n' speed(P) x probability of each wind speed

The area under the grey curve depicts the amount of wind power per square metre, wind flow may be expected at a particular site. The blue area indicates the theoretical maximum amount of power that can be converted to mechanical power (observing Betz law). The red section indicates the maximum energy a wind turbine can produce for this given site. It must be noted, however, that the bulk of wind energy is found at wind speeds above the average wind speed.

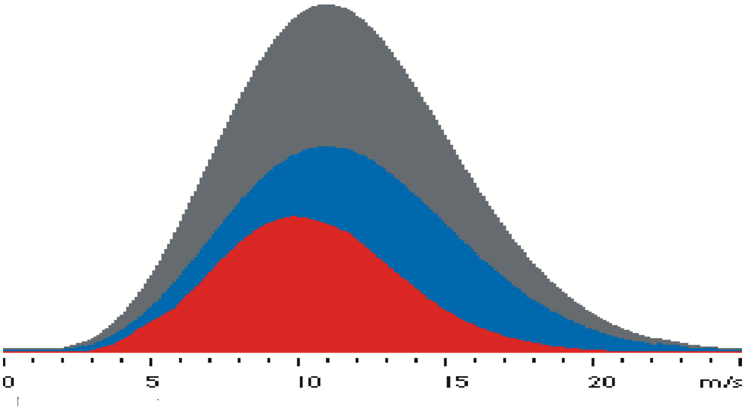


Figure 13 : Typical power density curve.

(Source: DEA, 2004)

3.7.4 Wind rose.

Strong prevailing winds, as the name implies, generally come from one direction, and in order to show the information about the distribution of wind speeds, and the varying wind directions, a wind rose is developed on the basis of meteorological observations of wind speeds and wind directions. As indicated in Figure 14, a circle has been divided up into 12 sectors of 30^o each. This can be related to the imaginary division of sectors of 30^o each around the measurement location. This division of 12 sectors may be increased or decreased depending on the end users' requirements. The radius of the 12 outermost wedges gives the relative frequency of each of the 12 wind directions, ie: what percentage of the time the wind is blowing from that direction. The second wedge gives the same information but multiplied by the average wind speed in each particular direction. The result is then normalised to add up to 100 percent. This indicates how much each sector contributes to the average wind speed at the particular location. The innermost red wedges give the same information as the first, but multiplied by the cube of the wind speed in each particular location. The result is then normalised to add up to 100 percent.

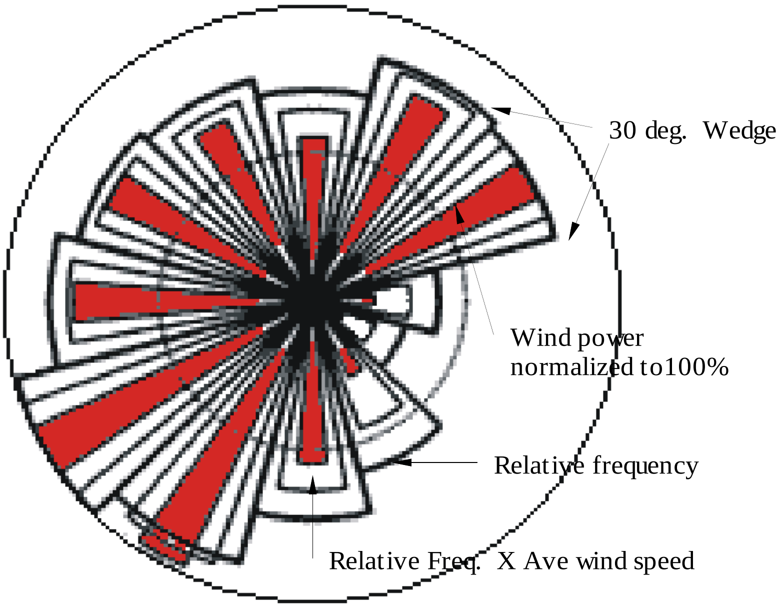


Figure 14 : Example of wind rose.
(Source: DEA, 2004).

Figure 14 indicates how much each sector contributes to the energy content of the wind at that particular location. The wind rose, therefore, can be used to compare the relative distribution of wind directions, not the actual level of the mean wind speed. Wind roses from neighbouring areas are often fairly similar, so it may be safe to interpolate between wind roses of surrounding observations. However, if the terrain is complex, mountains, valleys and coastlines running in different directions, it would be unwise to do so. Sighting of a wind turbine would be affected by a wind rose, as the landscape approaching the turbine from the direction of the prevailing wind should be relatively clear and smooth, as discussed in section 3.6.1 (Basic requirements).

3.7.5 Energy in the wind.

A wind turbine obtains its power input by converting the force of the wind into a turning force or torque, acting on the rotor blades. The amount of energy which the wind transfers to the rotor depends on the density of the air, the rotor area and the wind speed.

3.7.6 Density of the air.

As the kinetic energy of a moving body is proportional to its mass, it therefore follows that the kinetic energy in the wind depends on the density of the air. At normal atmospheric pressure and 15°C, air has a mass of 1.225 kg/m^3, but this density decreases with humidity and altitude (see Appendix D).

3.7.7 Wind turbine types.

The two types of turbine available for wind power are the multiblade, more commonly referred to as the farm windmill, and the more modern 2 or 3 blade types. Each type has its own advantages and disadvantages. In Table 4, a comparison is made between the two.

3.8 Summary.

With the ever increasing awareness of the potential damage which so called traditional energies cause to human health, as well as to the environment, governments are having to broaden their minds and start to look at the previously marginalised forms of energy generation. Of the major renewable energies (wind, solar, hydro), wind is the one which is showing the most growth potential, with most

Multi blade	2 or 3 blade
Can be used in areas of very low wind potential. Cut in speed of 1.2 m/s.	Can only be used in areas of high wind potential. Cut in wind speed of 3 to 4 m/s.
Can be used to drive a mechanical pump as well as generate electricity. High torque, low speed.	Can only generate electricity. High speed, low torque.
Less efficient (CP = 0.25 to 0.35.)	More efficient (CP = 0.45 to 0.50)
Blade design very simple, repairs can be undertaken with little training and steel blades are easily manufactured.	Blade design highly evolved, replacement blades can only be supplied by original manufacturer.
As there are in excess of 48 blades, one broken blade does not significantly hamper operation. Low rotational speed means balance is not critical.	One broken blade, renders the system almost inoperable, and if not replaced timeously, can destroy the turbine.
Less noisy due to lower speed.	More noisy as the turbines need to rotate at high operating speeds.

Table 4 : Comparison between multi blade and 2 or 3 blade turbines.

developed countries encouraging the installation of wind generators to supplement their energy requirements. In South Africa, wind has been used to supply drinking water for a number of years which means that the technology is not foreign and therefore more easily understood.

South Africa’s wind resource, although not evenly distributed, has the potential to provide adequate energy for water extraction and subsequent distribution. As mentioned previously most wind measurements in South Africa have been accumulated from weather stations, and even though these underestimate the wind speed they show that there is huge potential along the entire coastal belt.

It has further been established that direct drive, multi-blade, low speed wind machines are the most cost effective. Although less efficient, multiblade wind machines utilise the lower end of the wind spectrum and in so doing can utilise more available wind. They are also simpler to repair and not easily damaged if blades brake.

The siting of the turbine, as well as the system design, rely heavily on a multitude of factors which all need to be investigated thoroughly if the system is to function efficiently. Sufficient emphasis cannot be placed on the importance of accurate wind data. Meteorological stations are not good enough and wind measurements should be taken as close to the actual hub height as possible, for as long as possible with one year being the absolute minimum. As with most forms of renewable energy, supply is intermittent, and therefore sufficient reserves, in both water and wind, must be allowed for in the system design. During the design phase it should be emphasised that the average wind speed must not be confused with wind power potential of a particular site, and although the average wind speed is conservative, the use of it in energy calculations is incorrect.

Chapter 4: Case study

4.0 Introduction.

In order to verify the design methodology as outlined in chapter 3, an existing wind turbine was identified. It was decided to conduct a second independent design for the purposes of this study. These design results would then be compared to the actual results measured on site, as they became available.

4.1 Background.

Based on the strategic objectives, as highlighted in the WPWSSP, with regard to alleviating the chronic potable water shortages in SA, submissions were called wherein needy community organisations made representation to local government as to the level of services or lack thereof. Through Umgeni Water, who were the financiers, Glendale Heights Primary School was identified as a site in need of a more reliable water source. This nine year old rural school is situated approximately 300 metres above the surrounding area overlooking Glendale (Appendix A).

Approximately 200 students are accommodated in the school, with their only source of fresh water being one 5000 litre rainwater tank. However, in times of good rainfall this tank could only provide a limited amount of water for only eight months of the year. The only alternative source of water was from an unprotected spring a little over one kilometre away. In times of water shortage, the pupils were required to fetch water from this spring on the way to school. This however had a negative effect on school attendance, as according to the headmistress, when the water from the tank ran out student absenteeism increased [Marais and Allopi, 2003].

Connection from the national grid was ruled out due to excessively high installation costs and the associated low return on investment. Therefore an alternative stand alone system was installed. Detailed design of the system was not conducted prior to procurement, and therefore it would form a good basis from which to check this proposed design procedure.

4.2 System identification.

Various investigations followed in an attempt to identify the most appropriate and cost effective method of water supply. Most schools in the area are served by hand pumps. The only available source of potable water is a newly drilled borehole, located 100m from the school and approximately 150 metres deep with a very low yield of 250 litres/hour. Typically, a borehole with such a low yield would be ignored, however in this case no other water source was available. Standard hand pumping equipment could not draw water easily from these depths, without considerable physical exertion, and therefore the only other option was a mechanical or electrical submersible pump [Hazelton, 2000].

The power required for this installation could be provided by both wind and photovoltaics (solar), however past experience had shown that photovoltaics were extremely susceptible to theft. This factor together with the added advantage that this area had a good wind resource [Diab, 1995], resulted in wind

being the preferred power source.

The borehole was located inside a Saligna plantation, thereby necessitating the use of a 30 m turbine tower to keep the turbine beyond the effects of the wind shadow caused by the trees. Removal of the trees was considered but the owner was not in favour of any interference with them so it was subsequently decided, in order to reduce costs, that the turbine should be located away from the borehole (Figure 15), thereby enabling the use of a small 9 m high tower.

Figure 15 : Layout of turbine with respect to Saligna trees.

A further factor to consider was that the submersible water pump should be able to run dry without damage, due to the borehole yield being lower than the pumping rate. With this list of diverse parameters local suppliers were identified, and a locally manufactured multi-blade turbine and direct current submersible pump were adopted.

4.3 Siting and installation of wind turbine.

The wind turbine was sited 160m away from the borehole, clear from any wind shadow which may be caused by the trees, and on a crest in front of a 150m drop. Assessment of the surrounding area indicated that this was the most appropriate position, with the turbine not being adversely affected by turbulent updrafts (Figure 11). Due to the urgent nature of most capital projects, there was not enough time to accurately measure the site's wind potential, and therefore wind data was extrapolated from wind records. These records showed an available average wind speed of 4.0 m/s [Diab, 1995]. As this was only the available average and not the power potential, findings in chapter 3.7.2 indicate that the average wind speed underestimates the available power by approximately 100% [DEA, 2004]. A wind speed of 8 m/s was therefore adopted. In order to store excess water as well as to provide backup for any windless days, an additional 5000 litre reservoir was installed on a 3 m high steel platform, with an overflow pipe being directed into the existing 5000 litre rainwater tank behind the school (Figure 16).

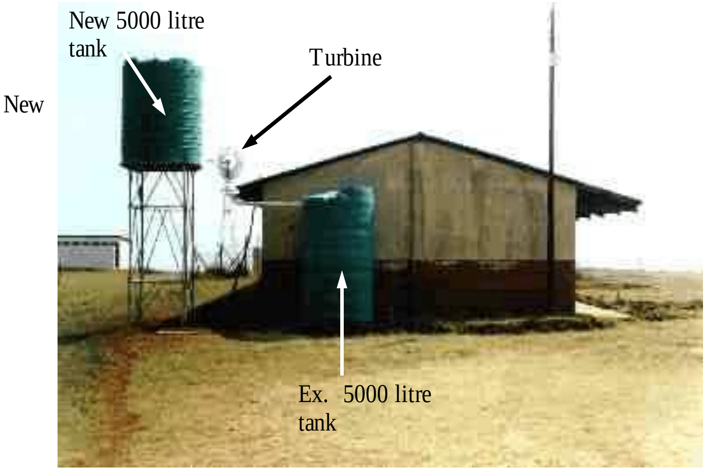


Figure 16 : Layout of tanks.

4.4 Determination of consumption.

The primary objective was to supply the school with sufficient potable water, and if there was any surplus, this could then be distributed to the surrounding community. The limiting factor for this exercise was the recharge rate or yield of the borehole.

4.5 Sizing of system.

Requirements:

- Water = 1000 litres/day (Minimum of 5 days per week)
- Depth of borehole = 150m (average depth to water)
- Total length of pipeline = 350m

4.5.1 Calculation of total head loss due to friction.

All minor losses are ignored.

Head loss (hf) = $4f\,l\,V^2 / 2\,g\,D$ (Darcy Weibach)

where: f = coefficient of friction of the pipe (0.007 as indicated by supplier)
l = length of the pipe (m)
V = velocity of the water (m/s)
g = gravitational acceleration (m/s^2)
D = internal diameter of the pipe (m)

- In order to calculate the velocity (V) we need to adopt a discharge (Q). Discharge will be the lesser of the following two values:
  1)The recharge rate of the reservoir (250 litres/hour) and,
  2) the maximum discharge rate of the pump as supplied by the manufacturer (400 litres/hour).

- Q_{max} = 250 litres/hour = 69.44 x 10^{-6} m^3/sec
- A = 490.9 x 10^{-6} m^2 (discharge is through a 25 mm nominal bore, HDPE pipe)
- Which translates into V = 141x10^{-3} m/sec = 0.141 m/sec (V=Q/A)

- hf = 4 x 0.007 x 350 x 0.1412/2 x 9.81 x 0.025
  = 0.4 m

Therefore total head = borehole depth + reservoir height + headloss
= 150 + 3 + 0.4 = 153.4 m

4.5.2 Energy required to lift the water.

$$\textbf{Power} = \delta \, g \, H \, Q \, / \, \eta$$

where:- δ = density of water (1000 kg/m^3)
g = gravitational acceleration (9.81 m/s^2)
H = height water is to be pumped (m)
Q = volume required (m^3)
η = pump efficiency

$\Rightarrow 1000 \times 9.81 \times 153.4 \times 69.44\times10^{-6} / 0.65$

$\Rightarrow$ 160.77 Watts

160.77 Watts is required for a discharge of 0.069 litres/sec or 1000 litres per 4.03 hr, therefore to pump 1000 litres we will need 4.03 x 60 x 60 x 160.77 = 2.33 MJ.

4.5.3 Energy loss between generator and pump.

All other losses due to electronic components and electrical cable will be assumed to be in the region of 20% $\therefore$ 2.33 x 1.2 = **2.796 MJ.**
This figure represents the required output from the wind turbine.

4.5.4 Turbine output.

$$\mathbf{Power = 0.5\ \xi\ A\ V^3\ Cp\ Ng\ Nb}$$

where :
ξ = Density of air (1.225 kg/m^3 at sea level at 15^oC)
A = Area covered by the turbine blades (3.3m dia. for this example)(m^2)
V = Wind speed (8m/s for this example)
Cp = Turbine efficiency coefficient (0.2 as supplied by manufacturer)
Ng = Efficiency of the gearbox (0.7 as supplied by the manufacturer)
Nb = Efficiency of the bearings (0.9 as supplied by the manufacturer)

$\Rightarrow 0.5 \times 1.225 \times 8.55 \times 8.0^3 \times 0.2 \times 0.7 \times 0.9$
= 337.84 Watts

In order to get the total output per day, we must assume how many hours the wind will be available per day. In this case we will assume it to be for eight hours per day.

This translates to: Total output per day = 337.84 x 8 x 3600 = 9729792 J $\simeq$9.7 MJ

Therefore the system can provide enough energy as the energy required to lift the water is 2.796 MJ.

Based on the above calculations, the locally manufactured wind generator which had been already installed seemed to have the potential to provide enough power.

4.6 Water delivery.

Water delivery began 36 hours after commissioning with a steady flow of clean potable water, resulting in almost immediate consumption by the local inhabitants. The zone of influence did not only include the school but grew to include the surrounding community as well. This new water source not only provided water out of a tap but also provided water that tasted better and was a lot cleaner than that from the surrounding springs. Due to the construction of the tank and stand, water delivery was via a tap 800 mm off the ground. This enabled the various plastic containers to be positioned with ease under the outflow thereby minimising contamination of the water.

4.7 Results.

Once the contractors had completed their task, monitoring of the system began with a flow meter being installed on the incoming line and weekly readings taken

(Figure 17). As can be seen from the results, water supply was in line with the expected production as calculated. Average supply for the period was 6414 litres which translates into 916 litres per day for a 7 day week, and 1228 litres per day for a 5 day week. With school only being from Monday to Friday, two days of water production was available for the surrounding area. Supply during the week was closely watched by the headmistress, who took personal control over all who used the water. Overflow from the primary tank was accommodated in the existing rainwater tank with ease, however, when the school closes for any length of time, due to school holidays etc., excess water will have to be stored elsewhere in order to minimise any erosion which may take place.

Unfortunately, due to a collapse in the borehole and subsequent blockage of the delivery pipe, all data capture stopped 7 weeks after commissioning. Numerous unsuccessful attempts were made to dislodge and retrieve the pump. It took a further seven months before a compressor was made available to clean the borehole out (funding, as well as the various stakeholders not accepting responsibility, contributed to the delay). The pump was eventually retrieved, but the blockage had caused it to overheat and burn out, resulting in costly repairs . The recommissioning of the system was then further delayed by budget constraints within the local authority, and to date the system has remained inoperative.

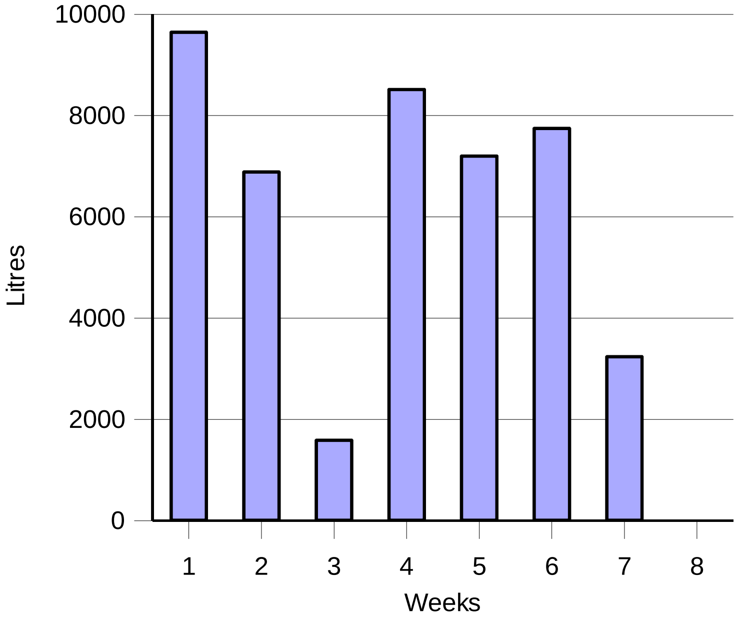


Figure17 :

Water delivery.

4.8 Problems experienced.

Further to the problem of borehole collapse, numerous other logistical problems were identified from the test case. Although not insurmountable, these factors need to be considered when similar systems are installed.

- **Battery maintenance:** As this system used a bank of four 12 V batteries to run the pump, continuous maintenance was needed. A suitable supply of distilled water was not always available, and subsequently topping up of the batteries was either not done or was done with non-distilled water.
- **Battery theft:** Although the batteries were housed in a reinforced concrete chamber with a suitable heavy duty locking device, the batteries were stolen during the 8th week.

- **Supply cable severance**: The supply cable which ran from the turbine to the battery bank was accidentally cut in two places by the contractor who installed a fence around the school. This supply interruption could clearly be seen during week 3.
- **Damage to the turbine:** Whilst the pump was not operating, prior to its extraction and repair, the manual braking system, used on the turbine to immobilise the blades, was accidentally released. This allowed the turbine to run without a load on the generator. Power generated by the turbine was then too great for the electronic components to withstand. They overheated and burned out.

4.9 Summary.

Based on the findings of the test case, it is shown that the design methodology correlates very closely with actual measured results. Water supply was more than adequate for the schools requirements, with excess being diverted into another reservoir for use by the local community.

The two main areas where the system needed attention was the one of theft of the batteries and the other of contractual responsibility.It must be noted that the long term sustainability of this project could only be tested once it had run for a number of years.

Chapter 5: Conclusion

5.0 Introduction.

One hundred years of experience with regards to wind pumps and wind driven machines in SA shows that wind power has a place in rural service provision. In the past, however, wind driven pumps were used primarily for the watering of livestock. This has possibly lead to a misconception with regards to its usefulness today, as a primary provider of potable water for human consumption.

It has now, more than ever before, become vitally important that alternatives to coal and oil be found to produce energy. Increases in the price of oil and associated impact on the SA economy, bears testimony to the fact that SA relies too heavily on fossil fuels. Our rural poor, the ones who need assistance the most, are the ones who are most affected by the high cost of these, and other forms of traditional fuels. Renewable energy, in the form of wind energy, is the fastest growing alternative energy source world wide [WWEC, 2003]. Robustness, theft resistance and vast areas of useful wind potential in SA make this form of energy source extremely feasible, with the additional benefit that the energy costs nothing.

The spectacular beauty of SA's open spaces, high mountains and deep valleys, poses a tremendous strain on infrastructure provision, and subsequently makes the fulfilment of the objectives of the RDP difficult. The provision of basic water service provision, as outlined by the WPWSSP, suggests very specific delivery criteria, however with government's limited financial reserves this may not be achievable. Water service provision will need to incorporate alternatives to normal or existing forms of infrastructure.

This case study has shown that a well designed, stand alone, wind driven system, is an alternative solution to providing SA's isolated rural communities with water. The implementation of such systems will support the government's objectives in terms of the RDP, with specific reference to water provision along the lines of the WPWSSP.

A set of best practice guidelines needs to be developed and followed, prior to any large scale adoption of this type of wind powered system. These guidelines can only be developed once a comprehensive analysis has been made of all the lessons learned from previous developments of a similar nature. These best practice guidelines could possibly form a part of a future study.

The need for a design methodology which forms a basis from which to work, is the only way to improve and streamline this technology. This technology, although old, has not been thrust into mainstream engineering, partly because of perception and partly because of a lack of knowledge.

By promoting renewable energy, a meaningful solution can be found for providing sustainable potable water to rural communities. The South African government needs to formulate policy guidelines on the adoption of wind energy for rural development, and by so doing will be following in the footsteps of first world countries, which have already identified the huge potential and advantages of utilizing wind energy.

5.1 Free basic water.

Although water supply systems must be demand driven, poverty and unemployment remain an obstacle to the payment of water tariffs. Non-payment and subsequent water supply interruptions would simply exaggerate an already volatile situation. In many cases once the supply has been interrupted the people simply switch to their previous forms of collection. It is therefore suggested that a more creative situation is needed, possibly where at basic supply levels, consumers should only pay if the water supply was used to generate a sustainable income. Otherwise society has a duty to support all of its members.

5.2 Provide for local economic development.

Lessons learned from both local and overseas developments indicate that in order for a water supply system to be sustainable, especially in terms of operation and maintenance, they must be linked to some form of economic development [WWEC, 2003]. The system has to be economically sustainable by generating income via secondary industry stimulated by the water supply, as with a free basic water supply no income will be generated if demand is below this threshold level. The system will have to generate its own capital and, in so doing, stimulate not only a cash inflow, but a sense of pride and worth amongst the community. Maintenance will then be a necessity rather than a “misunderstood” waste of money. Water committees will also have more say amongst the community if a direct correlation can be made between the supply system and their social and economical upliftment. It is also suggested that water service committees be paid for their services, thereby adding a new dimension to their accountability.

5.3 Service to be upgradable.

A system supplied through a demand driven approach must have capacity for upgrading. As the customers economic status improves so must the supply system. Customers must have the option to upgrade from community water points to metered yard or house connections. It has also been proved that the distance to the water source is of utmost importance in curtailing water-washed transmission of disease [Sanders and Groenewalt, 1996].

5.4 Renewable energy and alternative technologies.

Educating the communities and having supply systems in place that work, will not only help in providing water to the most rural areas but will enable the efficiencies of renewable energy to be put to use. Apart from water pumping, wind turbines can be used to generate electricity. Surplus electricity produced from these utilities can be used in social upliftment schemes, with the formation of cottage industries. Time saved by not having to collect water can be put to better use and used to generate extra income and thus boost employment and raise the standard of living. Furthermore, energy systems which convert natures free energy sources, such as sun and wind, into useable energy can be very cost effective and cheap to run. This in turn will stretch the government’s available financial resources even further.

5.5 Multi-sector partnerships.

In any walk of life, some people do things better than others and some people are better suited to specific jobs than others. This is very true when it comes to rural service provision. The public sector strengths lie in the monitoring and evaluation of projects as well as the development of regulations and policies. The private sector, because of the financial reward, is best suited to the implementation and design of appropriate systems as requested by the relevant parties. Efficiencies will be inherent in the capital works, and planning and design times will be kept to a minimum. However, when it comes to grass roots relations, negotiations and skills development, the various NGOs will be ideally suited. They will be able to relay all necessary information at the right speed, and pitch it at the correct level so that once the system is installed the community will not only know what to expect, but will understand how it works and what it is capable of doing, thus removing the need for expensive remedial work through vandalism and illegal usage. This would also go a long way to protecting the only items which are still susceptible to theft, the batteries.

Chapter 6: Recommendations

6.0 Input data.

As with any design the input data must be as accurate as possible. The single most important factor in this wind supply system is the available wind potential. Although not always possible, the most recent comprehensive wind data should be used, and at no time should the average wind speed be used for power calculations. As this is likely to result in a gross underestimate of the wind potential.

6.1 Storage capacity.

Renewable energies, although free, do have one major drawback is that they are intermittent and not regular. The designer must bear this in mind when designing a system. Enough storage capacity must be included, so that in times of zero wind speeds, there is enough stored water for the community.

6.2 Hybrid systems.

Although not covered by this study, combination systems, known as hybrid systems could be used to smoothen the energy supply to the system. Wind/gas, wind/solar or wind/hydro are all hybrids which complement each other (Energy Saving Trust, 2005).

6.3 Sustainability: an obtainable objective.

Research conducted within the community, indicated that although the water service was greatly appreciated, there would be very limited contributions to a maintenance fund or payment of the services received. This was partly due to the very limited income of most households, with the only income being from government grants. There is also the fact that all consumers qualify for a water allowance. This allowance equates to the first 6000 litres free, per household per month.

If one considers this allowance, it can be shown that the surrounding households would find it extremely difficult to transport 6000 litres. Approximately 240 trips with the standard 25 litre plastic container, which when further reduced, works out to 8 trips per day for 30 days. This type of consumption would be highly unlikely, and therefore with consumption less than 6000 litres, why should they pay? Their urban counterparts are not charged for this water.

With this in mind, a more creative method of sustaining the system will have to be developed. One option is that ongoing maintenance of the system would be conducted by an outside organization. This, however, goes against the white paper's suggestion that the local community accept responsibility for maintenance. It was also noted, in the test case, that the school teachers themselves were reluctant to take responsibility. Although the installation contractor left his cell phone number with the headmistress, he was only advised of interruptions in the water flow by the project managers, who were notified via the local authority. This delay in communication resulted in there being long periods without water, often caused by minor system problems.

6.4 Theft protection.

Theft protection is an iterative process, with improvements being made only once there has been a breach of security. The batteries in the test case were housed in a concrete chamber with a suitable heavy duty locking device on the lid. The only accessible part being the lock. The lock was compromised due to its ease of access and therefore it is recommended that the lock be housed in a galvanised steel frame to limit access.

6.5 Maintenance contracts.

Because of the uniqueness of the situation regarding the upkeep of the water supply systems, especially small systems lacking the financial resources to support dedicated personnel, it is suggested that the most cost effective method of sustainable water supply would be the combination of a complete system installation and subsequent maintenance contract. This maintenance contract should include a total package, whereby the recipient is guaranteed that for a specific period of time they will incur no additional maintenance costs. Repairs which fall outside the scope of the contract, for example theft and vandalism, should obviously be excluded.

The maintenance contract could be purchased along with the system, and would be for a specified period of time. As this contract would form a part of the initial capital cost, no further sourcing of finance for the project would be needed.

6.5.1 Outline of typical maintenance contract.

The following section will highlight some of the more important clauses to be included in a maintenance contract. As each contract will have its own set of peculiarities, only generic items will be included.

- Parties to the agreement.

  It is imperative to establish who the responsible parties are to an agreement, with contact persons, their position and contact numbers. Within a company it must be established who will take responsibility and whether or not that person can take responsibility. The test case highlighted this as there was no clear definition as to who was responsible to whom, and to what degree.

- Address or location and extent of the site.

  The site must be co-ordinated and a borehole reference number allocated. The zone of influence must also be precisely determined. This may necessitate a detailed survey of the area, coordinates plotted on an aerial photograph or simply a set of GPS coordinates. If there is a map of the area indicating the extent of the works, this should be included in the maintenance agreement.

- Effective date.

  The date from which the maintenance period starts, duration of the maintenance period and finish date. The start of the maintenance period could be indicated by the issuing of a completion certificate, or in the case of large works, a hand over certificate for a particular stage.

- What is covered by the contract and what is exempt.

  Here the contractor must have studied the system and have a thorough understanding on what needs to be done and when. Major breakdowns due to lack of maintenance will have severe financial implications and should be avoided. Furthermore if charges are to be levied for items outside the scope of the contract, who will be responsible for the payment?

- Payment conditions.

  As this contract falls outside the scope of the initial works, payment conditions should be identified so that there are no undue delays, which if unacceptable, could adversely affect the performance of the contract.

- Changes to the agreement terms.

  In order to maintain a degree of flexibility in the relationship, there should always be a clause which enables both parties to change certain items upon agreement. This agreement must always be in writing and signed by both parties. This clause will be effective in the ongoing development of this type of agreement, especially if both client and contractor are using new technology.

- Limitation of liability.

Claims in respect of payment for damages to persons or property arising out of the malfunction or failure of the products is always a possibility. It is advisable that the contractor indemnify himself against such claims. Keep the contractor's liability to the equipment supplied, and allow the contractor to decide whether or not to repair or replace.

- Agreement termination.

  An escape clause must be included. This is to protect both parties. In a case where one of the parties default, there should be an efficient way of terminating the contract, without the need for expensive litigation. The need for termination must be spelt out with the relevant time frames for correspondence and discussion, and should include a mutually acceptable, independent person, who is capable of mediating or arbitrating as the case may be.

- Dispute resolution.

  A flow chart as to the process to be followed for dispute resolution should be included. This will not only give credibility to the contract as an agreement, but will also necessitate both parties to investigate thoroughly their own agendas and interests.

- Geographic scope and jurisdiction.

  It would be in the interests of both parties to stipulate the area of jurisdiction, so that in the unlikely event of a dispute, there can be no advantage to either party as to the location of the legal jurisdiction.

- Further renewal of contract.

  If the situation arises whereby a further maintenance period could be required, a negotiating framework should be included so that both parties may re-negotiate rates and costs based on previous history, thereby ensuring a balanced agreement.

If a maintenance contract is purchased, it would also be advisable that proof of the actual maintenance, as outlined in the contract, is actually done (Table 5).

Item	**Inspection cycle**	**Oil and grease cycle**	**Replacement Cycle**
Wheel bolts and nuts	Initially		
Tower bolts and nuts	Initially		

Drive shaft support bearings	Initially	2 months	
Quick release coupling	Initially	2 months	
Turn table bearing		2 months	
Mast pipe support bearing		2 months	
Break chain	Initially	2 months	
Break chain pulleys		2 months	
Brake slide		2 months	
Brake winch		2 months	
Tail hinge		2 months	
Main shaft front bearing		2 months	
Main shaft back bearing		2 months	5 years
Pinion bearings			5 years
Gearbox oil			24 months
Generator drive chain	Initially		24 months
Generator bearings			5 years
Drive shafts			5 years
Submersible pump			2 years
Generator drive shaft bearings			5 years

Table 5: Typical breakdown of maintenance contract for wind turbine.

(Source: Turbex Wind Turbines, 2004)

6.6 Education.

As with any technology, education plays a vital role in its success. Community involvement and buy-in is absolutely essential if the system is to work and to remain working. Perceptions can be changed, and what is perceived to be second rate, can be shown as the only viable sustainable option.

6.7 Design flow chart.

The following flow chart is suggested for off grid, wind powered water supply schemes.

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Location of Glendale school

Appendix A

<u>Locality map.</u>

Appendix B

Wind turbine terminology.

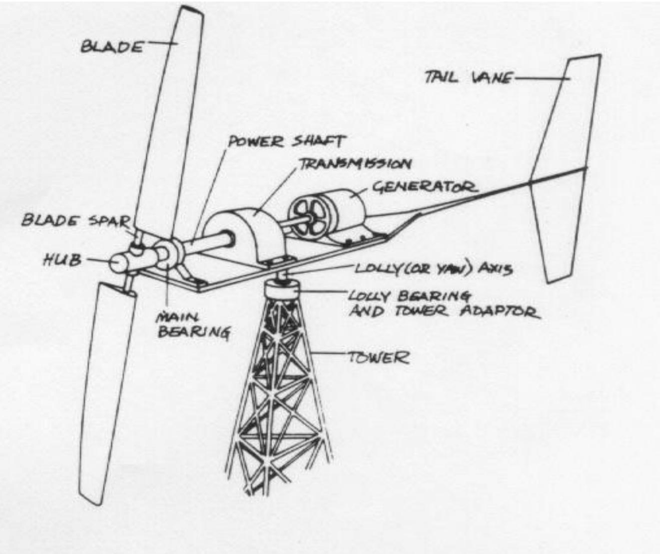


Figure 2 An electricity producing wind generator

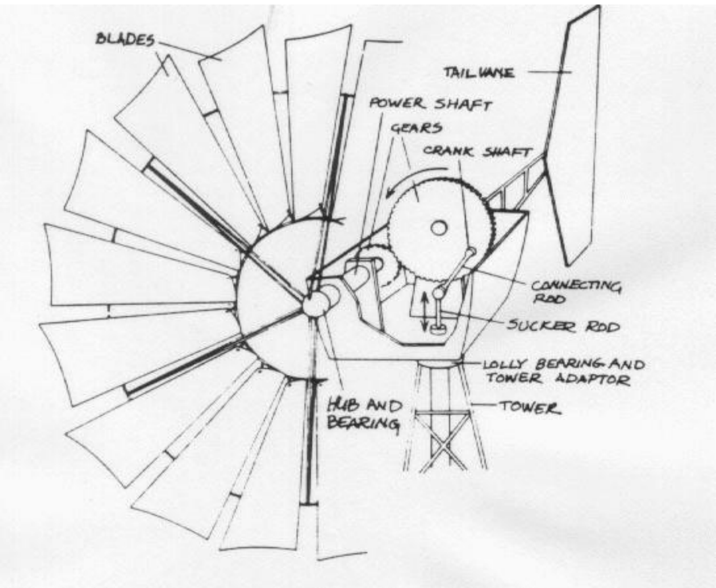


Figure 1. Components of an American Farm windmill

Typical high speed wind turbine. (Source: US Government printing office)

Typical low speed wind turbine.

(Source: US Government printing office)

Appendix C

Proof of Betz' Law.

(Source: DEA, 2004)

This page gives a proof of Betz' law, which uses Betz' own reasoning from his book Wind-Energie from 1926 to explain the law.

Proof of Betz' Theorem

Let us make the reasonable assumption that the average wind speed through the rotor area is the average of the undisturbed wind speed before the wind turbine, v1, and the wind speed after the passage through the rotor plane, v2 , i.e.
$(v_1 + v_2)/2$. (Betz offers a proof of this).

The mass of the air streaming through the rotor during one second is

$$m = \rho F (v_1 + v_2)/2$$

where : m is the mass per second,
ρ is the density of air,
F is the swept rotor area and $[(v_1 + v_2)/2]$ is the average wind speed through the rotor area.

The power extracted from the wind by the rotor is equal to the mass times the drop in the wind speed squared (according to Newton's second law):

$$P = 0.5\ m\ (v_1^2 - v_2^2)$$

Substituting m into this expression from the first equation we get the following expression for the power extracted from the wind:

$$P = (\rho/4)\ (v_1^2 - v_2^2)\ (v_1 + v_2)\ F$$

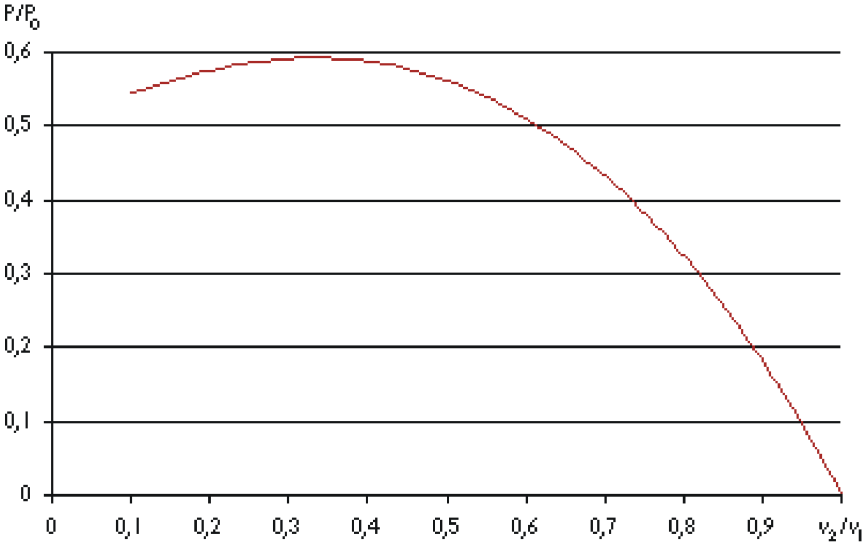
Now, let us compare our result with the total power in the undisturbed wind streaming through exactly the same area F, with no rotor blocking the wind. We call this power P 0 :

$$P_0 = (\rho/2)\ v_1^3\ F$$

The ratio between the power we extract from the wind and the power in the undisturbed wind is then:

$$(P/P_0) = (1/2)\ (1 - (v_2 / v_1)^2)\ (1 + (v_2 / v_1))$$

We may plot P/P_0 as a function of v_2/v_1



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We can see that the function reaches its maximum for $v_2/v_1 = 1/3$, and that the maximum value for the power extracted from the wind is 0,59 or 16/27 of the total power in the wind.

Appendix D

Density of air at standard atmospheric pressure

Temperature: Degree Celsius	Temperature: Degree Fahrenheit	Density; Mass of dry air kg/m3	Maximum water content
-25	-13	1.423	
-20	-4	1.395	

-15	5	1.368	
-10	14	1.342	
-5	23	1.317	
0	32	1.292	0.005
5	41	1.269	0.007

10	5	1.247	0.009
15	59	1.225	0.013
20	68	1.204	0.017
25	77	1.184	0.023
30	86	1.165	0.03

35	95	1.146	0.039
40	104	1.127	0.051

Appendix E

Conference Presentations and publications based on this study

1. Marais B, Allopi D, Supply of sustainable subterranean water through the use of wind turbines: A case study. Paper presented at the International Conference on Engineering Technology Research. Johannesburg, South Africa, 2002.
2. Marais B, Allopi D, Wind power for unserved areas of rural development. Faculty research day, Faculty of Engineering, Science and the Built Environment, Durban Institute of Technology, South Africa, 25 September 2002.
3. Marais B, Allopi D, Water is Life. Poster presentation at the World Wind Energy Conference, Cape Town, South Africa, 24-26 November 2003. (See attached poster)

Appendix F

Groundwater Harvest Potential of the Republic of South Africa

(Scource: DWAF, 2004)

GROUNDWATER HARVEST POTENTIAL OF THE REPUBLIC OF SOUTH AFRICA

Map Authors - Alan Seymour and Paul Seward
Cartography and GIS Support - Elretha Louw

In a water-scarce country such as South Africa it is imperative that every drop of water be used judiciously. To aid the wise use of groundwater a National Groundwater Harvest Potential Map has been compiled. This map gives the first nationwide, quantitative depiction of sustainable rates of groundwater potentially available for abstraction.

The aim of this map is to provide a very general picture of Harvest Potential to guide national and regional planning of groundwater development, and to create an awareness of sustainable yield issues. The map is not suitable for local planning, development and management of groundwater.

This first attempt at a quantitative national picture relies heavily on a limited borehole data set, and computerized statistical procedures. Thus there are obviously local cases where better data, more advanced procedures, or local expertise, would provide a more accurate picture. Any additional groundwater-related data received by the Directorate: Geohydrology will improve the accuracy of further generations of this map.