LOW-COST AIR-LIFT GROUNDWATER PUMP DEVELOPED FOR USE IN RURAL SETTLEMENTS

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REPORT TO THE WATER RESEARCH COMMISSION

by

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EXECUTIVE SUMMARY

INTRODUCTION

A large portion of the South African community lives in areas where power is not easily accessible. This refers to both electrical power supply and to fossil fuel supply such as coal, diesel or petrol. The groundwater pump which was the main development objective of this project utilises human resource for abstraction of groundwater which can be supplemented with wind power stored as compressed air.

The primary objectives of the project were to:

i. Develop an inexpensive and reliable groundwater abstraction tool of simple construction and test the functionality of the equipment..

ii. The maintenance of this groundwater abstraction tool would have to be simple and it should be possible for a one, non-specialist, person with tools easily available in rural areas, to remove the pump from a borehole and to repair it should it become necessary.

iii. The operation of the pump should not be complicated. Any air compression equipment including hand or foot (tyre) pumps should be capable of running the groundwater abstraction pump at reasonable (10 to 30 m) groundwater depths.

iv. Any parts which may be necessary in maintaining and repairing the equipment should be available in most hardware shops even in small rural towns.

v. Manufacture of the pump should be possible in rural areas without specialised equipment. Light, non-corrosive material would be preferable in construction of the pump.

vi. A windpack compressor capable of storing wind energy as compressed air should be developed and tested as a means of providing supplementary power to the groundwater pump.

The report is structured to firstly provide information on the development of the groundwater pump and the wind pack compressor, followed by sections on performance testing of the equipment and finally the conclusions from the study.

FINDINGS

Storage of wind energy as available air pressure in a receiver tank as opposed to direct storage as water in a water tank has the following advantages:

- The quality of the water obtained by the community will not be affected by insects, vandalism or vermin
- Water is not lost from the system by evaporation
- Water is only used as required (no running taps draining the storage), thus resulting in reduced energy wastage.
- Due to the improved sanitation perspective, risk of rural communities contracting diseases from usage of water from open water tanks is avoided. The need for boiling all water is reduced.
- The windwheel can be positioned in a location optimal for the capture of wind (e.g. top of a hill), whereas the borehole can be installed at a point most advantageous from the point of view of shallow placed and easily available groundwater (e.g. at the base of the hill). This breaks from the old system where the windwheel had to be positioned directly above the borehole and often resulted in either disadvantageous position for wind capture or unnecessary depth of borehole when positioned on high topographical points.

Primary disadvantages compared to conventional systems can be considered as:

- A new system not known to rural communities, which still needs to find community acceptance.
- Air pressure leaks are more difficult to control than water leaks.
- Air storage tanks are more expensive to manufacture than water tanks.

FUNCTION OF THE PUMP

Briefly, the Air-Lift Groundwater Pump system operates in the following way (refer to the Figure):

- Air pressure is applied to the surface of the water in the Pressure Cylinder
- The air pressure forces water up the Water Delivery Pipe to the surface
- When the water reaches the level of the Float at the Ballcock valve, the valve is shut preventing further water flow to the surface.
- The Air Valve on the surface is then opened equalising the pressure in the Pressure Cylinder.
- Air Pressure is again applied and the procedure is repeated.

CONTRACT OBJECTIVES

The results of the project have fulfilled the aims stated in the original proposal.

A practical, novel and appropriately cost effective groundwater abstraction system has been developed and has been shown to function satisfactorily.

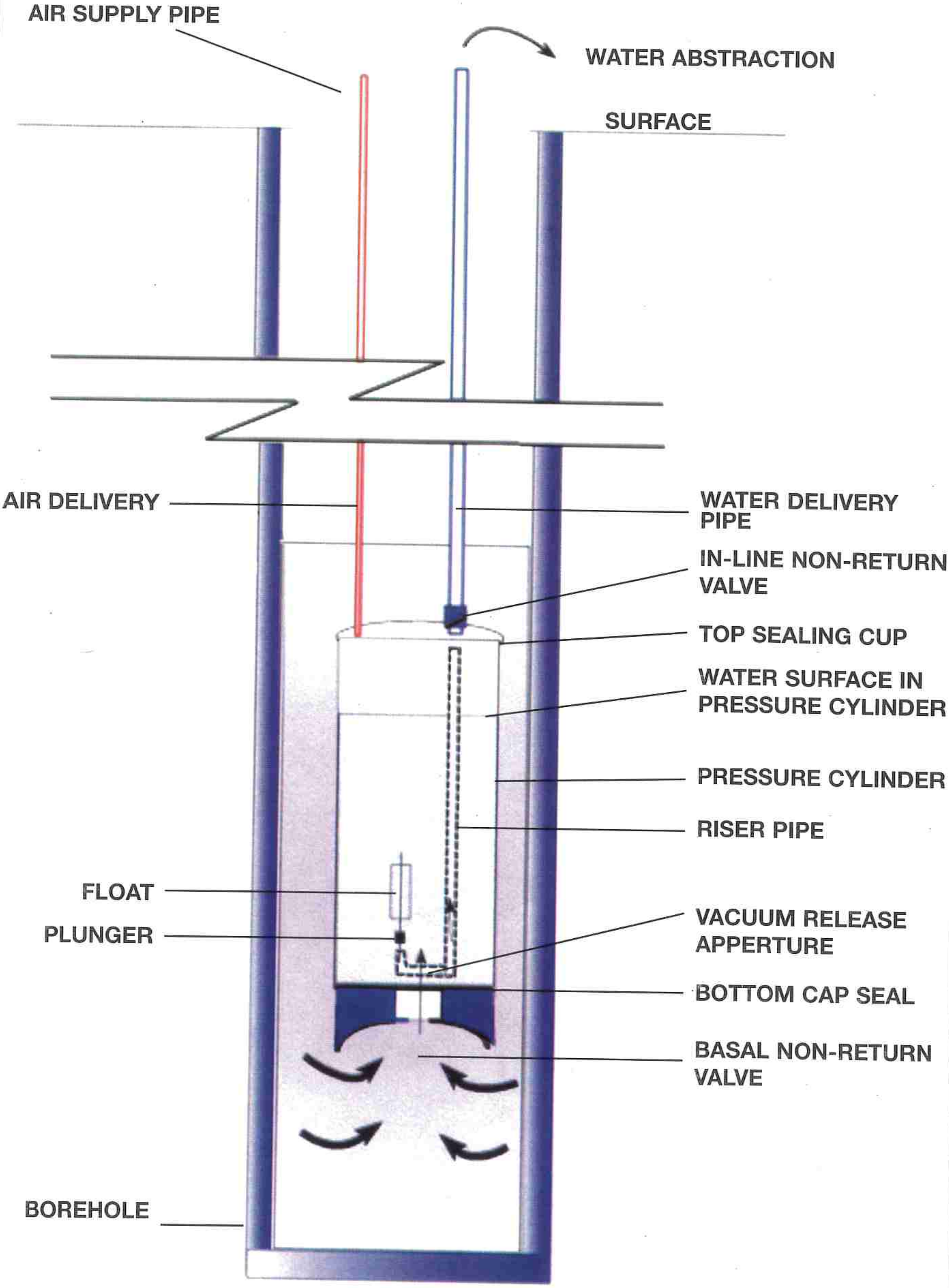

Fig 2.1	Schematic of the Groundwater Pump	WRC K5/876

The system can be applied to rural water supply where above groundwater storage is not properly satisfactory, or where the windmill and borehole locations have to be separated.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are reached:

i. The groundwater pump developed in the course of this project functions fully satisfactorily when installed in boreholes at water depths lower than 40 m.

ii. A regular, low-cost, tyre pump is all that is required to operate the pump satisfactorily.

iii. Modifications incorporated to the initial design - addition of a check valve to maintain the water head in the riser pipe and a float valve to control pressure discharge in the riser pipe function satisfactorily.

iv. The windpack compressor allows for storage of wind energy which is then easily available for acquiring of groundwater.

v. Larger air pressure receiver tanks will have to be produced in future to enable greater energy storage and thus larger availability of water, even during low wind conditions.

vi. The system operation needs to be fully tested under rural conditions setting to ensure equipment robustness and potential for wide spread use.

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"Development of a Low-Cost Air-Lift Ground Water Pump for Use in Rural Settlements"

The Steering Committee responsible for this project, consisted of the following persons:

Mr D van der Merwe	Water Research Commission (Chairman)
Mr H.C.Chapman	Previously of Water Research Commission
Ms U Wium	Water Research Commission (secretary)
Mr AG Reynders	Water Research Commission
Mr J Fuls	A.R.C. (Institute for Agricultural Engineering)
Dr D Banks	University of Cape Town
Mr A Stasikowski	Stass Environmental
Mr P van Rensburg	Stass Environmental
Prof CJ Rallis	University of the Witwatersrand
Mr C Chibi	The Mvula Trust

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Mr J Raymond	Geo-Graph
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LOW-COST AIR-LIFT GROUNDWATER PUMP DEVELOPMENT FOR INFORMAL AND RURAL SETTLEMENTS

1 INTRODUCTION

A large portion of the South African community lives in areas where power is not easily accessible. This refers to both electrical power supply and to fossil fuel supply such as coal, diesel or petrol. The groundwater pump, which was the main development objective of this project, utilises human resource for abstraction of groundwater which can be supplemented with wind power, stored as compressed air.

The primary objectives of the project were to:

i. Develop an inexpensive and reliable groundwater abstraction tool of simple construction.

ii. To test the developed equipment for functionality under field conditions.

iii. The maintenance of this groundwater abstraction tool would have to be simple and it should be possible for a single, non-specialist, person with tools easily available in rural areas, to remove the pump from a borehole and to repair it should it become necessary.

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vi. Manufacture of the pump should be possible in rural areas without specialised equipment. Light, non-corrosive material would be preferable in construction of the pump.

vii. A windpack compressor capable of storing wind energy as compressed air should be developed and tested as a means of providing supplementary power to the groundwater pump.

The report is structured to firstly provide information on the development of the groundwater pump and the windpack compressor, followed by sections on performance testing of the equipment and finally the conclusions from the study.

2 GROUND WATER PUMP CONSTRUCTION AND FINAL DESIGN

2.1 Literature review

The concept of using pressure to drive water from depth has been used in the 19th century by Welsh coal miners. The mines used steam to generate enough pressure to lift groundwater to the surface (CSM - 1981). A literature review and a patent search were performed to find other studies which used air pressure in a similar way , but these proved fruitless. The search only revealed that groundwater sampling devices also use gas pressure to obtain groundwater (CIRIA - 1991).

From the above, it is concluded that the equipment proposed for development in this study is a theoretical concept that needs to undergo verification as to the functionality of the design. This objective was retained as the primary goal of this investigation.

2.2 Background to the Design Concept

The use of air pressure to move liquid is not a new concept. Air lift is extensively utilised in industrial applications, and is especially common in the mining area. Air lift of water is not normally accepted as cost effective due to the high cost of compressed air. For rural applications however, where only a limited amount of water is normally required for house hold usage (20 litres per person per day is the objective set by DWAF), using air pressure for water abstraction, which is obtained from either hand operated equipment (e.g. hand held tyre pumps) or wind generated compressed air which has no running cost in rural settings, is a feasible proposal.

In general the compression of air develops heat which is an energy loss as it cannot be further utilised in the abstraction of groundwater. It must be pointed out that most other systems of hand operated groundwater abstraction pumps loose energy in one way or another. The work requirement in obtaining groundwater using a hand pump can be considered wasteful as, on average, 30-50 kgs of steel rod is lifted approximately 10 cm

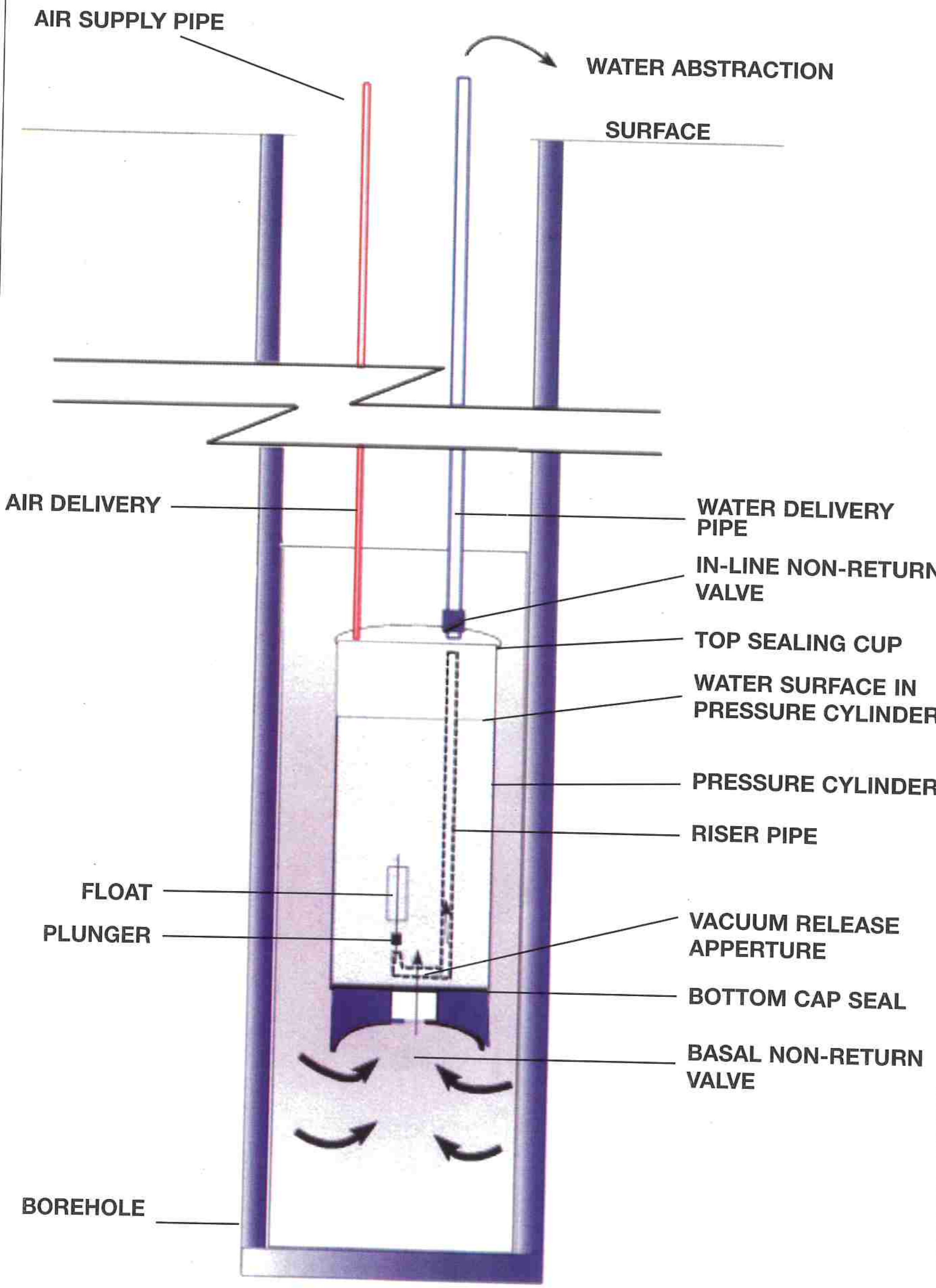


Fig 2.1	Schematic of the Groundwater Pump	WRC K5/876

to obtain 0.3 litres of water and then promptly dropped back into the borehole. Likewise, a rotary mono pump suffers from friction loses at the rubberised worm drive contacts, losing energy during operation by friction and heat loss. The author's experience from East Africa (Kenya - Voi region) on solar powered groundwater pump units, supplied by German aid organisations, though efficient in a first world setting, did not last sufficiently long to be effective (occasionally under two weeks) due to the complex operational nature of these units. Another factor which caused failure of such systems was the unfortunate loss, through theft, of the lead acid batteries used for energy storage. Ironically, these were the only parts of the system which were locally available.

The water abstraction unit developed during the course of this project is of a simple nature, requiring the presence of an underground submerged pressure vessel which is attached to the surface by an air line and a water delivery pipe. The only part visible above the ground level are the on/off valves.

The design concept rests basically on the fact that on application of air pressure to the exposed water surface in the cylinder via the air delivery pipe, water will be forced out through the water outlet pipe at a rate proportionally equivalent to the applied pressure as per Boyle's Law which states that $P_1V_1 = P_2V_2$.

Each unit is designed to provide 30 litres of water per cycle. Of necessity, the pump is of a two stroke nature, one to allow water ingress at atmospheric pressure and secondly, on application of air pressure, to extrude the water to the surface.

The pump is operated in the following way (refer to Fig. 2.1):

i. Air pressure is applied to the Air Supply Pipe by either manual means (hand pumps) or compressed air from the wind pump compressor. Typically this air pressure has to be in excess of the equivalent head at which the pump is submerged eg. 110 KPa for a 10 metre depth, 220 KPa for a 20 metre depth etc.
ii. Due to the air pressure applied to the surface of the water in the Pressure Cylinder, water is forced up the Water Deliver Pipe and out to the surface where it can be

used immediately or stored in a water tank.

iii. When the water level in the Pressure Cylinder reaches the level of the Float at the Plunger Valve, the Valve is activated shutting off further water flow to the surface. At this point the air pressure inside the pressure cylinder needs to be manually released by an Air Valve on the surface. Opening this valve reduces the air pressure in the cylinder to the point where the Bottom Non-return valve opens allowing water to refill the Pressure Cylinder once again. This completes the cycle and the procedure can be repeated

iv. On completion of the filling of the submerged pump, pressure is again applied which closes the bottom non-return valve and forces water to the surface, completing the two stroke action of the pump. The water head in the delivery water pipe is maintained by the inclusion of an in-line non-return valve at the top of the pump, positioned to allow easy access for maintenance.

Figure 2.1 shows a schematic of the pump, situated in a borehole, with the position of all piping indicated, as well as the location of the non-return valves. It should be noted that the water inlet to the pump should be located a minimum of two metres above the bottom of the borehole to prevent the ingress of sludge, grit or other material which can affect the operation of the non-return valve. Water turbulence in the borehole, caused by water entry into the pump, can be expected to affect the borehole for short periods of time on the inlet stroke of the pump operation, capable of creating sufficient force to lift debris from the borehole bottom. Care must therefore be taken during the positioning of the pump to prevent fouling of the non-return valves. Should a problem be experienced it can easily be cleared by the someone appointed locally and trained to maintain the equipment.

2.3 Construction Materials

One of the primary objectives of the project was to develop equipment which could be easily manufactured or repaired under rural conditions. This means that heavy machinery, or equipment requiring permanent electrical installations could not be used. Furthermore, the construction materials should preferably be non-corrosive and easy to handle. These self-imposed restrictions on material usage strongly suggested the use of plastics as even simple hand held tools are all one frequently needs in the shaping and assembling with plastic.

PVC piping is easily available and inexpensive in most parts of South Africa and provides ideal construction material for the groundwater pump. The only part of the pump which was not made of PVC, was the brass non-return valve at the base of the pressure cylinder. The reason for this was that there are no locally manufactured (and thus inexpensive) PVC check valves. Brass check valves, on the other hand, are widely available and normally well within the price range delineated for the groundwater pump application.

The final test equipment for the groundwater pump was developed to work under water or air pressures which do not exceed 850 KPa, thus all PVC components which were tasked with containment of pressure conformed to a minimum standard of Class 12 construction material (which allows for a maximum pressure of 1200 KPa).

Initially, pressure cylinders developed for this application were constructed of Class 6 piping as it was considered that the pump would not be used at borehole depths greater than 40 m (approximately equivalent to a pressure head of 400 KPa), but with the addition of external pressure supply from a windpack capable of generating 850 KPa, materials had to be upgraded. Standard PVC cement was used as bonding material for pump construction.

2.3.1 Construction of the Pump

The construction of the pressure cylinder requires a number of simple steps. These are:

1. **Materials**

- 6m length of PVC, 12 bar, 150mm diameter pipe
- 2 x end caps, 150mm diameter
- 2 x non-return valves, 55mm and 20mm diameter
- 1 tin of PVC cement glue
- Adjustable open-end spanner, saw and hand drill
- Various brass connectors and pipe fittings

The cost of the above materials is in the region of R 500.

2. **Procedure** (refer to Fig. 2.2)

(a) Drill a 50 mm diameter hole, centrally in the bottom end cap. A wood router can be used for this purpose.

(b) Drill two 20 mm diameter holes in the top end cap.

(c) Attach an air hose connector and a PVC pipe connector in the two 20mm diameter holes. Attach a 5,5m length of 20mm diameter PVC pipe on the inner portion of the end cap. Attach float and plunger to the base of the pipe as per diagram in Figure 2.1.

(d) Glue both end caps in place at both ends of the cylinder.

(e) Thread the bottom non-return valve into the bottom end cap hole.

(f) Fit the top non-return valve to the attachments installed in the top cap and connect the air and water pipes.

3. Rope and pulleys can be fitted to the top end cap for ease of installation and removal for maintenance.

2.4 Preliminary testing of equipment

Prior to installing the equipment in a borehole, a number of rigorous tests were performed on the equipment to ensure the ability of the pump to perform correctly underground. The objective of the surface test regimen was to:

- Ensure the equipment can withstand pressures to which it will be subjected.
- Confirm that all the joints are well cemented and do not leak either air or water.
- Demonstrate functionality of the design principles under variable pressure heads.
- Ensure that any design problems (pipe and valve sizing) are rectified prior to installation underground.
- Gather initial test data on the pump to allow for the development of test scenarios after installation of the equipment in a borehole (use of hand-operated pumps under different pressure heads etc.).

The tests were performed in a swimming pool as this was the most convenient environment available where a full scale prototype could be fully submerged, tested and observed.

As might be expected, a number of initial teething problems with optimal sizes of joints and positioning and sizing of non-return valves for optimal pump performance were encountered. These were best solved in the surface tests, where the results of various adjustments were easily visible and also allowed for easy access to all pump parts.

Final optimised design specifications and measurements of the pump are as follows:

Length of pressure cylinder	6 m
Pressure classification	Class 12
Inlet check valve	50 mm diameter (brass flap valve)
Pressure supply	Class 10 bar PVC piping *10 mm diameter
Water outlet	Class 10 bar PVC piping *25 mm diameter
Outlet check valve	25 mm diameter (brass flap valve)

* Piping size specifications refer to interior diameters.

The tests showed that the equipment was functional and performed as expected, allowing for installation of the pump in a borehole. One of the major drawbacks experienced was the expulsion of all air from the system on purging of the pump of water. As the cylinder purges an air spring develops, blowing all water out of the delivery pipe, thus necessitating the re-filling of the riser pipe before any water is obtained, which was considered a waste of air pressure. This problem was addressed under modifications and re-design, detailed in the next section.

2.5 Problems encountered, Redesign and Improvements

The two major changes which were adopted after the initial equipment tests, were the increase in the strength of the material used to construct the pump, from Class 6 to Class 12, and the incorporation of an automatic flow shutdown at the base of the unit.

The increase of the pressure carrying capacity of the pump was done in anticipation of high storage pressures which can be obtained from the windpack compressor. It was decided that rather than incorporating a regulator on the pressure inlet to the pump, it may be advantageous to use higher pressures for increase in the pump water outflow rate, when it was required. As the windpack compressor is capable of supplying pressures in excess of 800 KPa, the nearest pressure classification Class of piping was used, which was 12. This also allowed for an improved safety factor which is highly desirable when dealing with high pressures.

The water head in the riser pipe control device was developed on the principle of a simple float switch. As the water level dropped to a certain level, the outlet (riser) pipe was closed off by a plunger, thus preventing the purging of the riser pipe by air.

The main problem in the development of the float was that it had to function under pressures in excess of 800 KPa. This means that the float had to be sturdy enough to withstand high pressure without collapsing (and thus losing its buoyancy) and at the same time had to be able to exert sufficient force to maintain the plunger away from the inlet to the riser pipe during operation of the pump. Secondary problems were experienced when the acceleration of water between the upper riser check valve and the float plunger caused temporary vacuum on closing of water supply, especially at high pressure. This in turn prevented the float from releasing the plunger to allow water flow up the riser pipe on refill of the pressure vessel.

This particular problem was solved by simply installing a small diameter hole (1 mm) in the riser pipe, at the bottom of the bend (see Fig. 2.1), which then allowed vacuum release without compromising the function of the float switch.

Optimisation of the pump was primarily related to the sizing of the various pipes and inlet valves for fast operation, without compromising the robustness or cost effectiveness of the equipment.

3 WIND ENERGY PACK

3.1 Introduction

Wind energy is available as a renewable and sustainable energy source which has distinguished itself as being reliable in various different applications throughout the world.

The main applications for wind energy have generally been in the generation of electricity power by grid-connected wind turbines. However, even at the very low production cost of these units, wind generated electricity is not yet fully cost-competitive with coal- or natural-gas-produced electricity for the bulk electricity market. It is because of this cost restraint that we have approached the wind energy source from a different perspective where the free wind energy is transformed into a controllable energy source by storing energy as compressed air, which in itself is an expensive and sought after commodity. The safety and versatility of compressed air is appreciated by all the main role players in the industrial environment, where it is used extensively in various applications.

3.2 Background and Current systems

Wind energy was first utilized through the use of the normal borehole-windmill as it is generally known throughout the world. This design has stayed unchanged and unchallenged for many years where it was generally accepted as the ultimate free energy water pumping system. However, this design is mainly a one function system which can only be used for pumping water from a borehole. Maintenance of this system is an expensive drawback where repairs usually result in a time consuming exercise with rigid and very heavy piping having to be pulled to the surface before the main pump-element can be reached. This task is required even when performing minor repairs or replacing pump seals etc. which subsequently results in maintenance being a costly, time consuming and labour intensive exercise.

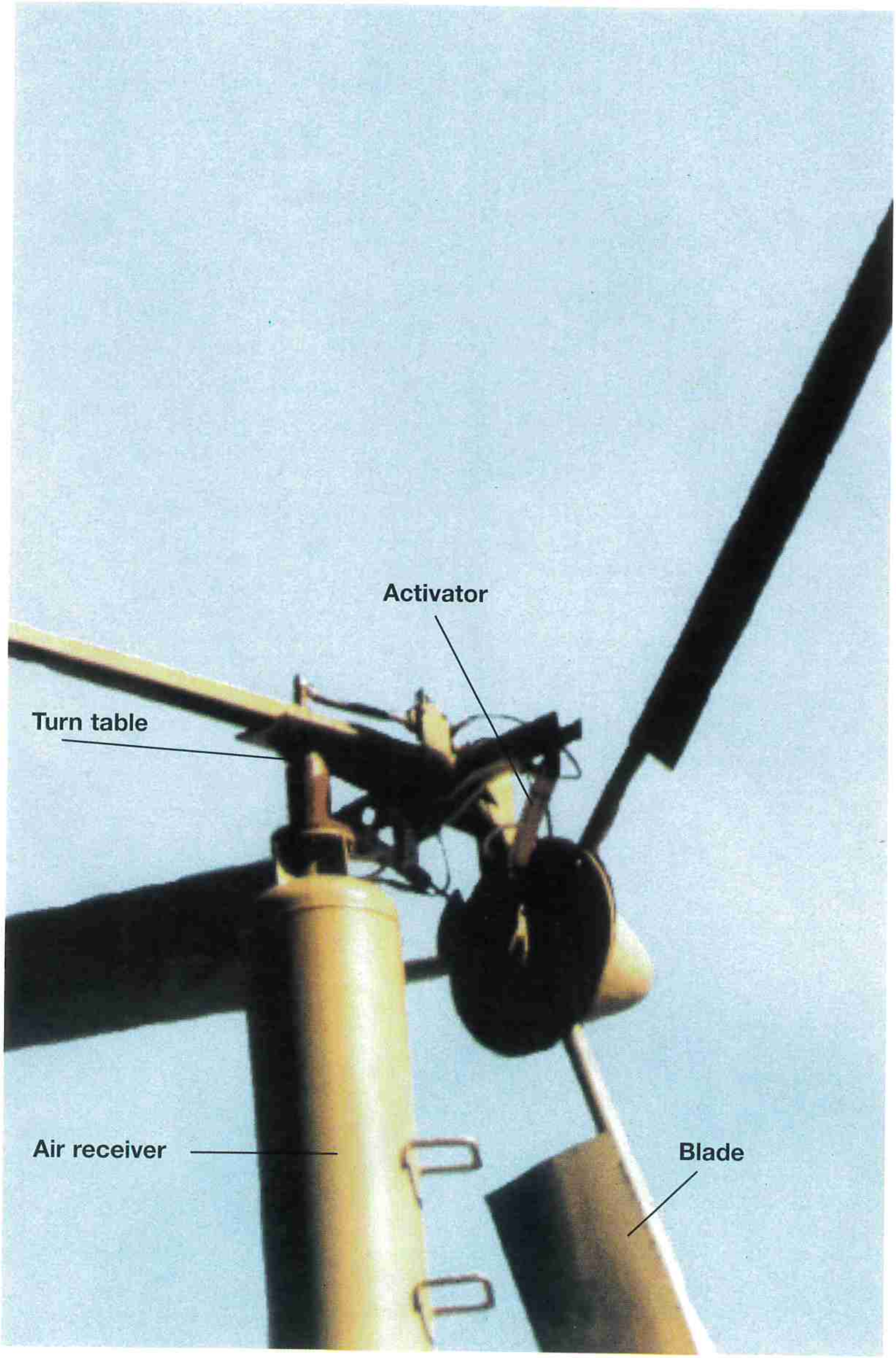


Figure 3.1	VIEW OF ACTUATOR ATTACHMENTS TO WINDWHEEL	WRC K5/876

Figure 3.2	Windpack and borehole assembly	WRC K5/876

SCHEMATIC OF WIND WHEEL DESIGN

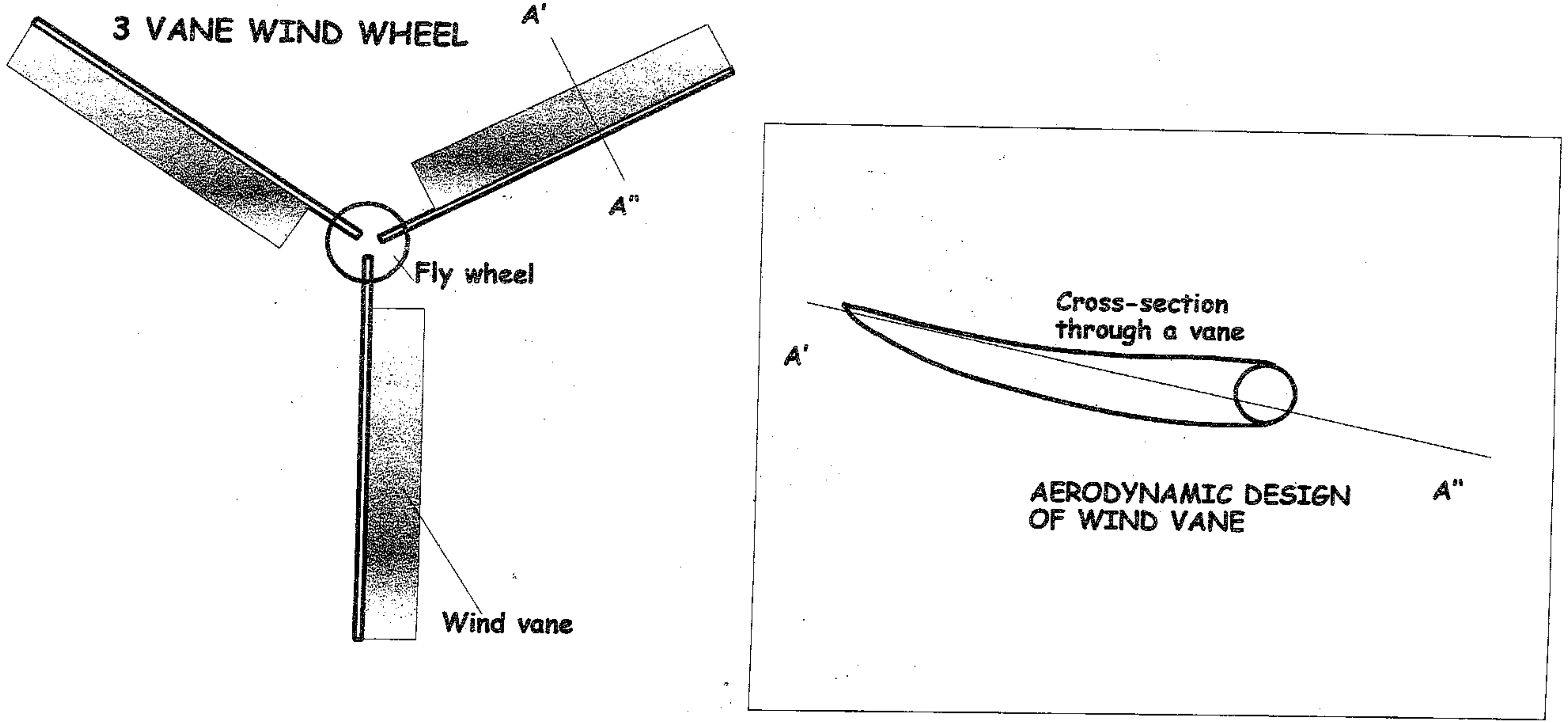


Figure 3.3	Schematic of the wind wheel design	WRC K5/876

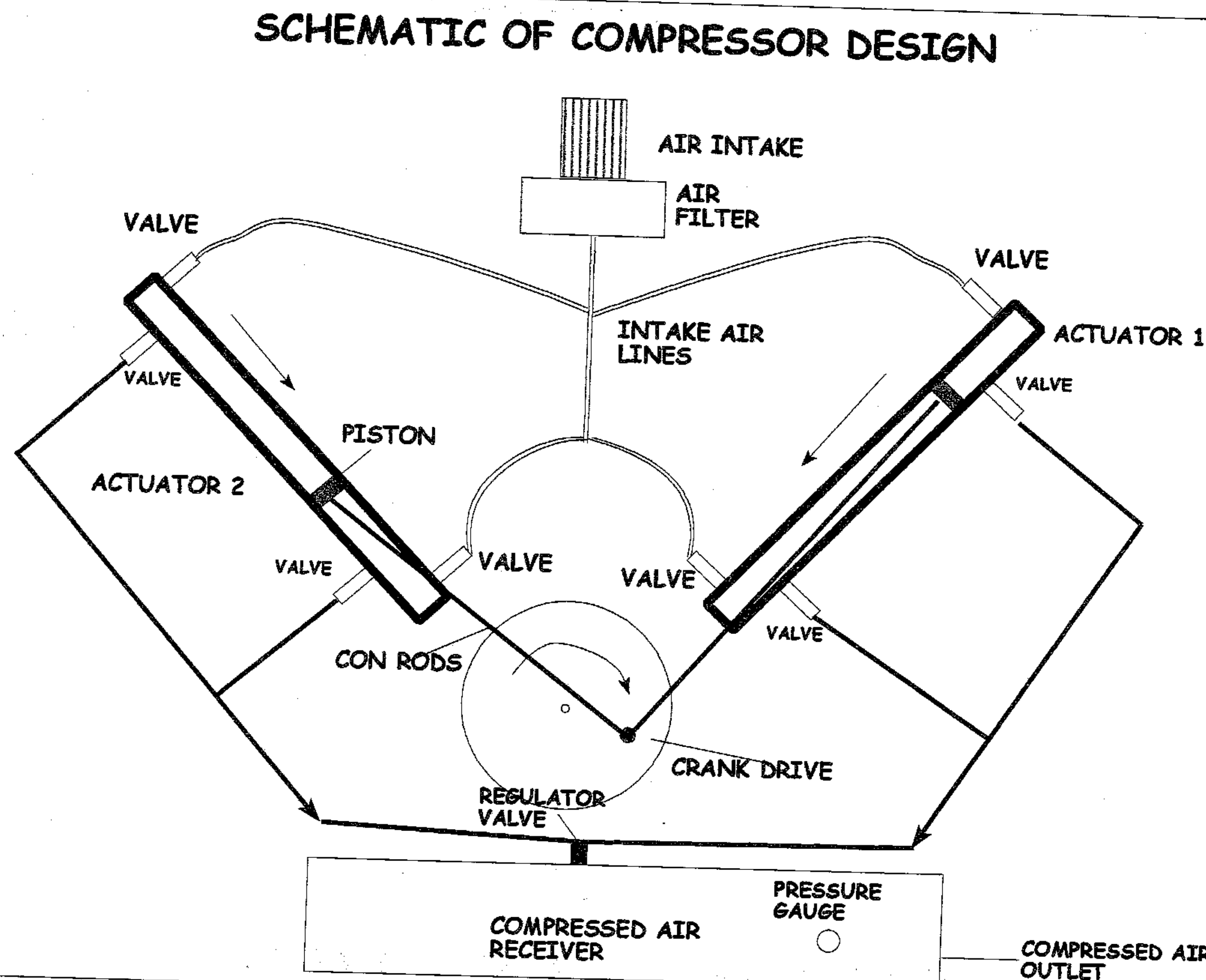


Figure 3.4	Schematic of compresssor design	WRC K5/876

To date, the main development in the field of power generation by means of wind-energy, was dominated by generating direct current which is then stored in batteries. This power is converted into alternating current by means of an electronic converter, and fed into an utility grid. These batteries need to be replaced at regular intervals, and repairs on the electronic systems can only be performed by highly skilled personnel. All these drawbacks add up to a very high operating and maintenance cost over the life cycle of such a system.

It is because of all these drawbacks on the existing systems that we have come to the conclusion that, although wind-energy in general is relatively cheap compared to other energy forms, there is definite need for improvement to the current systems in operation.

3.3 Initial Prototype ("mark 1")

The first prototype was built by converting a 1963 model 10' Climax windmill, where the gearbox was replaced with a small two cylinder industrial compressor. A belt drive was used to increase the shaft speed of the compressor for effective splash lubrication. However, this design was not effective due to the insufficient lubrication at low wind speeds. The Climax rotor which was primarily designed not to exceed 50 rpm contributed to this problem.

The mark 1 unit made use of a ground stationed reservoir of $2m^3$ capacity which could be loaded to a maximum pressure of 1000 KPa. This was normally achieved within a 24 hr period in moderate wind conditions (10 to 20 km/hr). These results initiated the development of a more advanced unit, utilizing high speed power rotors and simple compressor units.

3.4 Development of Current Prototype

One of the design criteria identified was that the final configuration must be simple and easily maintainable as these units will be for installation in rural areas.

Therefore, the design and construction of the wind energy pack is based on very simple mechanical principles and technology, with all maintenance components already available nationwide. The design consists of a wind wheel, which is mounted on top of a pressure reservoir vessel via a rotating table (see Figs. 3.1, 3.2 and 3.3). With this design the pressure vessel now acts as the mast and platform for the windmill. The rotating wind wheel drives an open-plan compressor system which in turn forces compressed air into the pressure vessel which now acts as a controllable energy source. This stored energy can now be utilized in various different applications of which the pumping of water from a bore-hole should be the most common application.

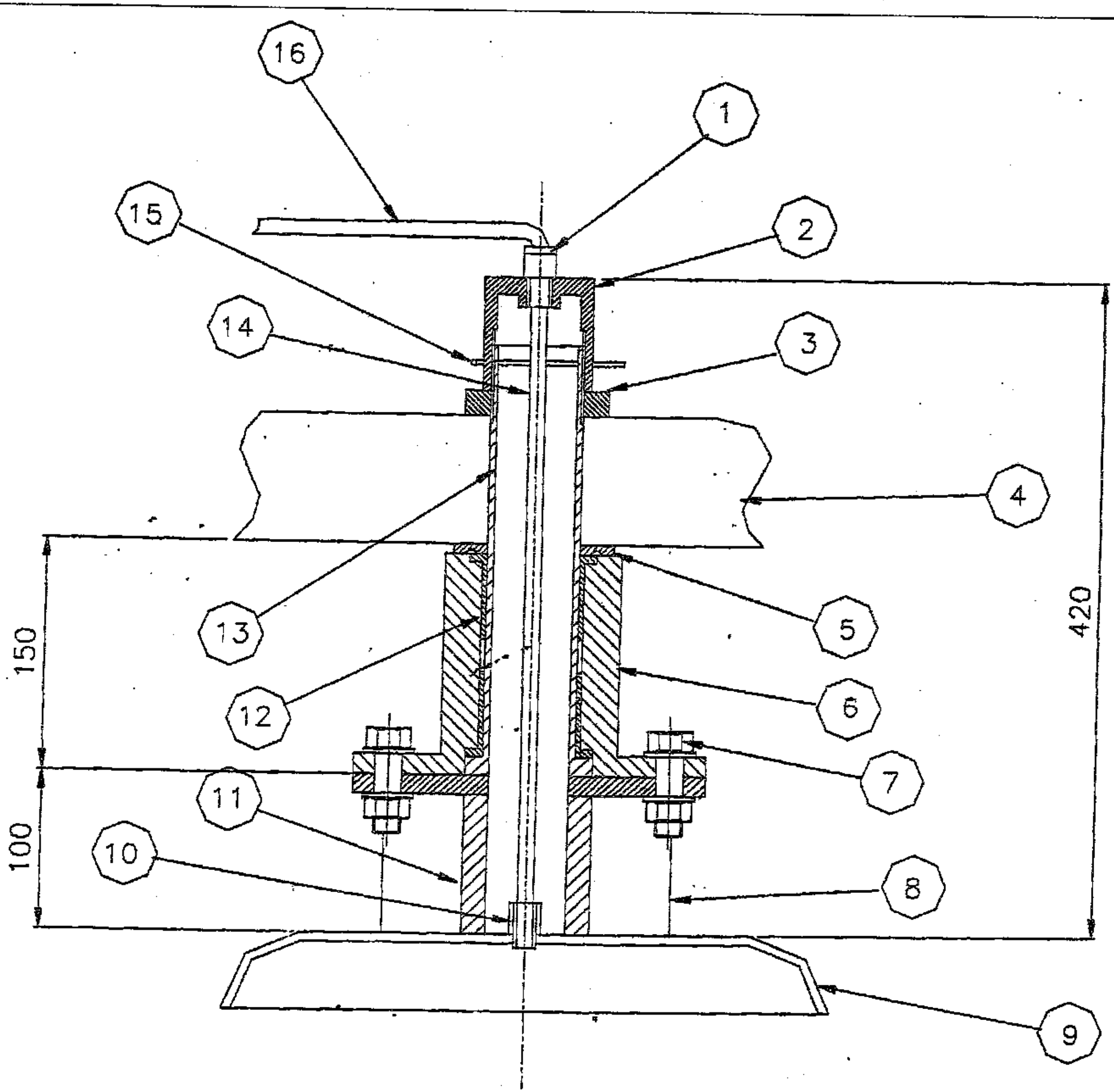
3.5 Overview to the prototype.

The prototype was a production unit where the main emphasis was to determine whether the system will function in the field. A few of the successful features of the system were incorporated in the Mark 1 design are as follows:

3.5.1 Blade design

The blade profile of the wind wheel was designed in conjunction with the Aerodynamic Division of the Faculty of Engineering of the University of Pretoria. The main emphasis of this design was to be as efficient as economically possible at a very low wind velocity.

The rotor consists of three high speed blades which were manufactured through forming lightweight wood to the designed profile and covering it with 0,8mm sheet-metal for rigidity and sturdiness (Fig. 3.3).



16	COMPRESSOR OUTLET PIPE
15	SPLIT PIN
14	THROUGH PIPE
13	ROTATING TUBE
12	VESCONITE BUSH
11	LOWER TUBE
10	PIPE CONNECTOR
9	TANK ASSY.
8	6 mm WEB
7	M16 BOLT, NUT, WASHERS
6	HOUSING
5	VESCONITE BUSH
4	BOOM ASSY.
3	LOCK NUT
2	TOP NUT
1	ROTATING PIPE JOINT

Fig 3.5 WINDPACK ROTATING UNIONWATER PUMP WRC K5/876

Where older generation windmills rely primarily on drag force to turn the rotor, these blades make use of aerodynamic lift forces.

3.5.2 Compressor system

The compressor system comprises of a twin set of double action actuators which effectively results in four compression strokes for each complete turn of the wind wheel. This open-plan compressor system lends itself to easy and relatively cheap maintenance and repairs. Should one of the actuators fail, the second unit will still be functional thereby assuring continuous operation of the system.

Effective lubrication was achieved by installing an in-line oil-vapour lubricator on the air intake side of the compressor unit.

3.5.3 Turntable

The turntable rotates on a set of visconite bushes which are capable of accommodating the lateral pressure forces which are forced onto this area of the unit (see Figures 3.1 to 3.4). This specific material is used due to the proven life expectations of similar bushes in various other strenuous applications (see Figure 3.5).

Air is fed to the reservoir by connecting the supply pipe to a hydraulic rotating coupling mounted through the centre of the turntable to the reservoir.

3.5.4 Reservoir

The reservoir, acting as the mast for the complete system, was manufactured from a 15"class 16 seamless steampipe, 6 m long and with a capacity of 0.814 m^3 (814 litre). Because the reservoir acts as the system mast it is well anchored by three (3) mounting legs and supported by three (3) steel anchor cables.

3.5.5 Safety features.

The following safety features have been designed into the system:

- A one-way valve situated in the inlet section of the reservoir allows for maintenance and repairs to be performed on the compressor or wind wheel systems without having to loose any of the already stored energy.

- A pressure release valve, currently set at maximum of 810 KPa, was installed in the air line between the compressor and the one-way valve which eliminates the possibility of developing excess pressure scenario in the reservoir.

- A water trap or bleeding point was installed at the lowest point of the reservoir tank in order to drain any moisture which may accumulate from the compressed air moisture content.

- All exterior surfaces have been painted with zinc oxide paint as protection against rust. A valve is positioned at the base of the compressed air receiver to enable the periodical removal of condensate from the receiver.

3.5.6 Cost

The material cost of a single windpack unit is in the region of R 5000.00

3.6 Improvements intended for future units.

3.6.1 Blade design

On all future test units, blades will be used which are manufactured from a moulded composite material. Different rotor variations for the advanced blade design will be available in 2,5 m and 4,5 m diameter, depending on the application, wind speed and geographical location of the installation. In addition to this, a manual or automatic mechanism to disconnect the turntable from the wind wheel during high wind is being investigated. The present study, although successful, is limited to one field unit and as such, results can not be extrapolated to potential future design adjustments.

3.6.2 Reservoir

For future units a reservoir of 21" diameter may be used. This will allow for a larger capacity to store energy, and will also give better support and strength to the complete system. The system will be set to a maximum pressure of 1000 KPa, depending on the application and requirement of each individual system. The cost of this reservoir will be directly related to the size and capacity of each unit.

3.6.3 Future Development Initiative

We are currently in the process of investigating the viability of an advanced operating system which involves the use of a smaller primary reservoir which loads up to operating pressure before storing energy in the main reservoir. With this design any system will be in operational mode within a limited period of time with the main reservoir only coming into operation when it has reached the equivalent operating pressure of the primary reservoir.

3.7 Advantages over equivalent designs

The following advantages are recognised:

- Wind energy, which would otherwise be lost, can be stored to be used as and when required. As water remains underground, there are no water losses due to contamination or evaporation.
- Once the wind energy has been stored as compressed air its use is multi-functional, i.e. it may be used in applications or situation that require a compressor.
- Able to serve a multi borehole system, i.e. more than one borehole can run off one reservoir unit.
- The storage unit does not have to be constructed on top of the borehole.
- The system will function and be of value even in situations where there is not much wind because the storage is cumulative.
- All major components are available as standard components.
- Assuming as storage capacity of 1000 Kpa the depth of the borehole does not influence functionality to a depth of 90m.
- Once correctly installed, the system requires little maintenance to function efficiently.

3.8 Conclusion

Although wind energy is not generally considered as a firm energy source due to the variable nature of the resources used, energy storage is an important technical challenge considering the fact that the earth is running out of its natural energy fuel resources at a rate where it will not have sufficient resources to fulfill the required needs for the Twenty First Century.

Wind energy is environmentally friendly and will be one of the most important, widely applied renewable energy sources during the decades to come. Of course, there are substantial challenges to be met, such as the aesthetic considerations, but they all appear to be solvable to ultimately ensure that wind energy becomes a leading role player in the field of energy availability.

4 GROUNDWATER PUMP FIELD PERFORMANCE TESTS

The pump performance tests were done under various installation depth conditions (see Fig. 4.1). The pump was installed in the borehole at various depths, and water was then poured into the borehole to the point where water was above the pump. As the pump locks the base check valve on application of pressure and does not react with the hydrostatic forces surrounding it (eg head of water above the top of the pump), these tests were deemed fully representative of the various conditions found in the field.

Tests were done at the following depths:

10 metres below the surface	(16 m effective operating depth)
15 metres below the surface	(21 m " ")
20 metres below the surface	(26 m " ")
25 metres below the surface	(31 m " ")
30 metres below the surface	(36 m " ")
40 metres below the surface	(46 m " ")
50 metres below the surface	(56 m " ")

Three basic hand (or foot) operated pumping devices were used in each of the test scenarios: hand pump 1, hand pump 2 and a foot pump. The difference between the two hand pumps was that one was of a thinner diameter (30 mm) while the other was shorter, but thicker at 40 mm diameter. The thinner pump was naturally easier to depress, though it had a longer stroke.

The operation of a standard single cylinder 1 h.p. electric motor driven compressor and a cigarette lighter operated tyre compressor were also analysed, and are presented in the Appendix.

It was important to analyse the potential for the use of hand operated pumping devises as the pump was designed for rural applications. The air pressure supply had to be obtained

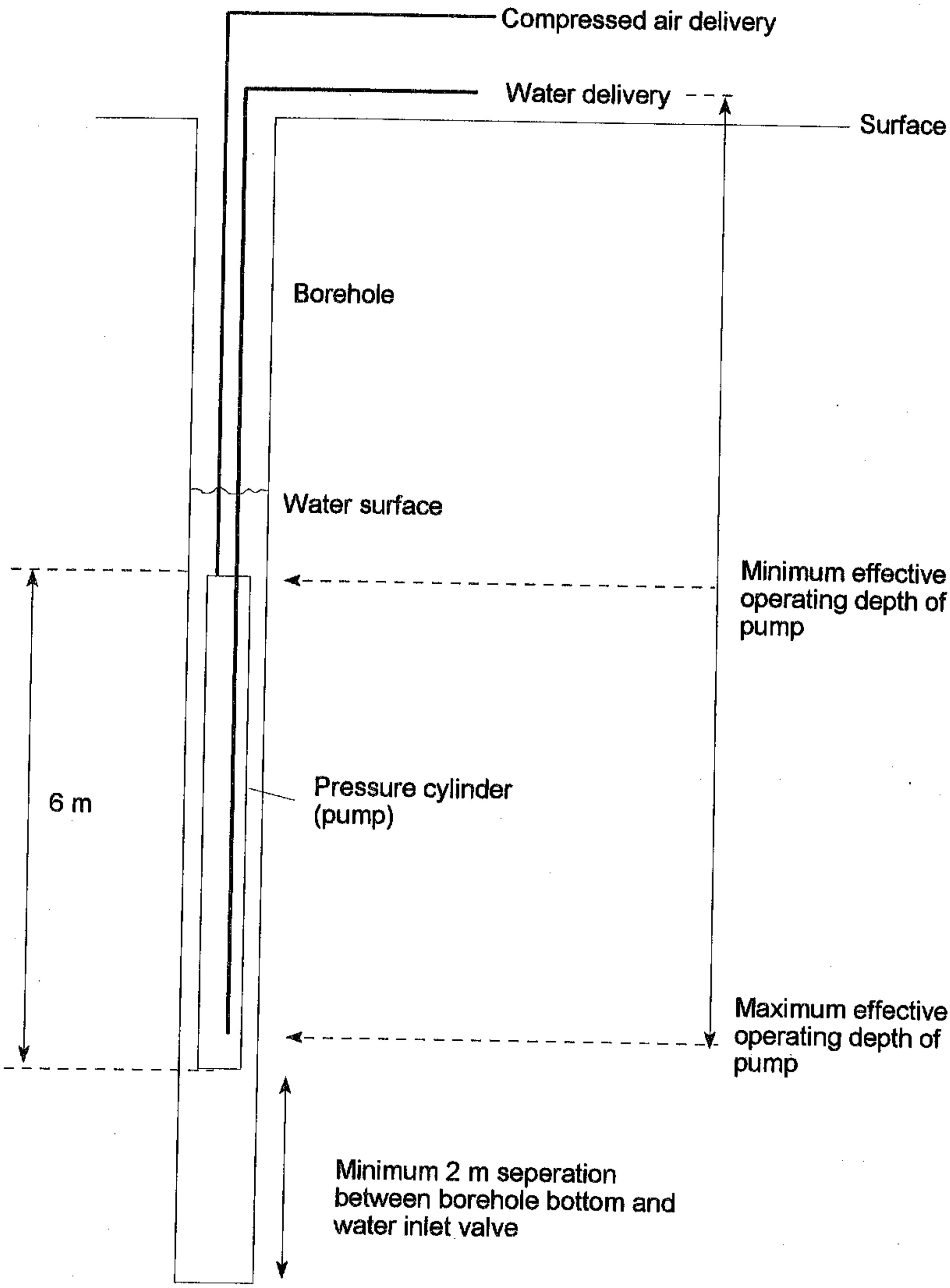


Fig 4.1	Positioning of the Ground Water Pump	**WRC K5/876**

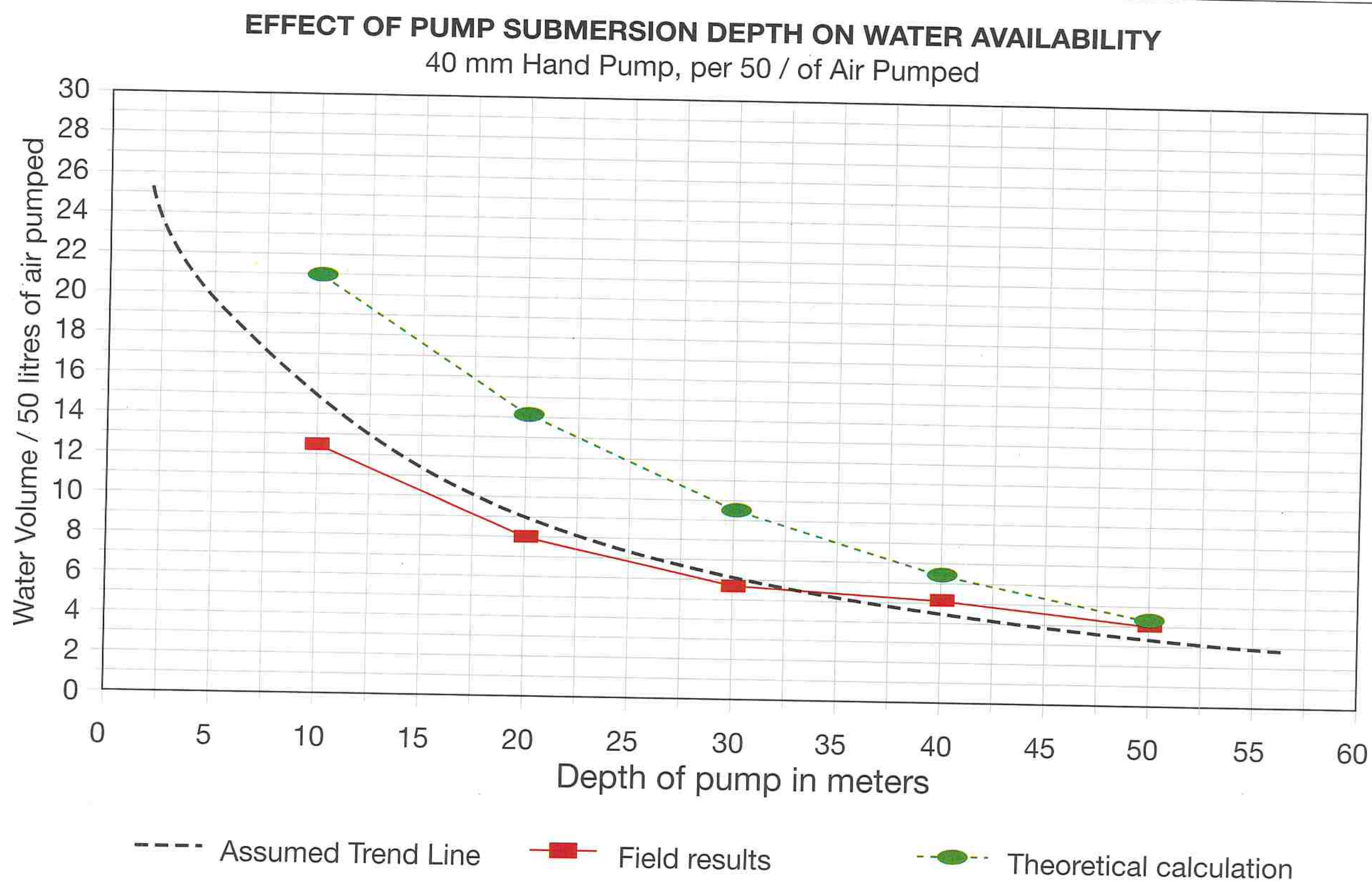


Figure 4.2	Effect of pressure head on water abstraction per unit air volume pumped	WRC K5/876

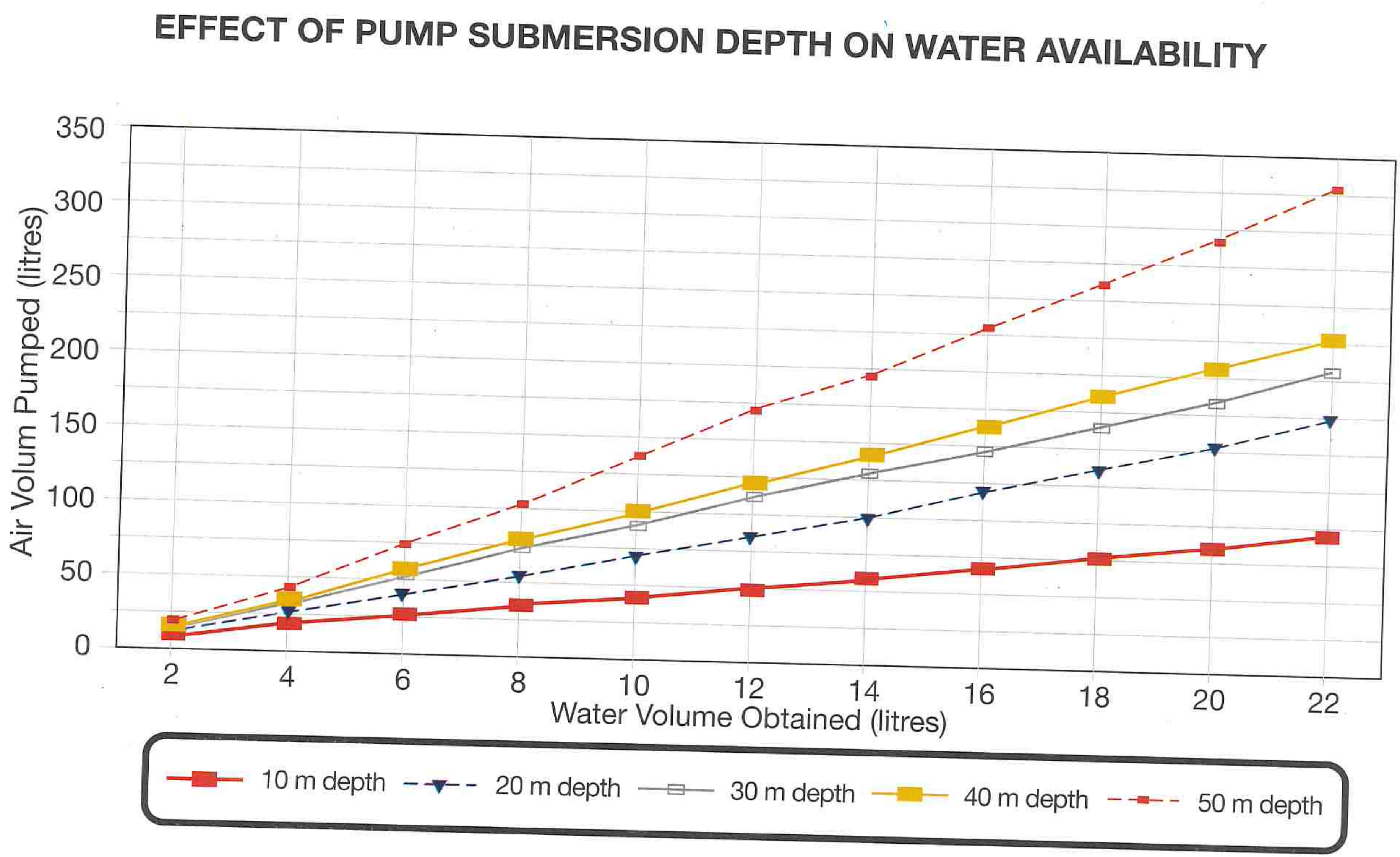


Figure 4.3	Effect of depth on abstracted volume of water	WRC K5/876

from low cost and easily available hand operated air pumps. The most common of these is the tyre pump (average cost of R 25.00 per unit), which is easily available at hardware stores, garages and some supermarkets..

The performance characteristics of the pumps are summarised in Figure 4.2 and Table 4.2 below. The performance of the 40 mm diameter plunger hand pump (referred to as hand pump 1) at various depths in the borehole is given in Figure 4.3. Table 4.1 presents the required direct force on the pump handle to cause depression against various water pressure heads.

TABLE 4.1 Calculated force requirement to depress the plunger of the hand pump 1 (40 mm diameter plunger) at various pressure heads

Depth	Pressure head	Required Force	Eq. Mass Weight
10 m	100 KPa	125 N	12.75 kg
20 m	200 KPa	250 N	25.5 kg
30 m	300 KPa	375 N	38.26 kg
40 m	400 KPa	500 N	51 kg
50 m	500 KPa	625 N	63.8 kg

The forces or equivalent weight component referred to in Table 4.1 is the directly applied force which is needed for depression of the plunger at the various pressure heads, that is no cantilever advantage from pivoted pump handles is included. The forces are calculated for the 40 mm diameter plunger, so it can be expected that lesser force will be required for the 30 mm diameter plunger hand pump. The calculation derives from the simple mathematical relationship of $F = P * A$ (where P=pressure, A=area and F= force).

This relationship ignores friction forces and heat energy losses, however, for the purpose of these calculations, these factors are assumed negligible. Attempt at calculating potential real values of friction or heat loses in a hand pump would be fictitious as these instruments vary greatly in terms of applied lubrication, wear and tear, age, material and method of use.

The plot in Figure 4.2 clearly shows that the ratio between water volume per unit of air pumped decreases with pump submerged depth, or proportional pressure head. Between 10 and 20 m depth, the ratio is 1:5 (i.e. approximately 1 litre of water obtained to every 5 litres of air pumped). This ratio falls off to 1:10 at a depth of 40 metres, which is likely to be a cut-off for useful operation of the pump. These results are empirically derived and show lower efficiency than the theoretical calculations which are shown on the plot in Fig. 4.2. This is primarily due to the losses of pressure through poorly located or leaking air seals in the pump and any of the airline connections. The connections were not touched in the 6 months of testing to allow a "real life" simulation on the working parts of the equipment.

Based on these results it can be surmised that the pump shows promise for usage in abstraction of groundwater by physical effort in situations where the water table rests at depths less than 40 m, preferably shallower.

5 WINDPACK COMPRESSOR APPLICATION

The windpack compressor allows for storage of 814 litres of air at a pressure of 810 KPa. The energy storage in the air receiver is equivalent to a stored water volume of :

4) pump at 10 m depth = 2 200 litres of water
5) pump at 20 m depth = 1650 litres of water
6) pump at 30 m depth = 1105 litres of water
7) pump at 40 m depth = 660 litres of water

The above measurements are derived from field calculations based on real abstracted volumes (Fig. 4.2). Again, theoretical calculations show better performance but are not representative of projected field working conditions.

The windpack compressor pumped air at the following rates for various wind speeds, which were measured in the field by timing the flight of tissue paper over a distance of 10 and 20 metres. Although not ideal, this test was cost effective and illustrated the point adequately.

The table 4.2 below illustrates the effect of various wind speeds on the rotating speed of the windwheel and the resultant volume of air pumped by the actuators. The volumes pumped are calculated from the relationship of the actuator swept volume derived from measured stroke and plunger area.

TABLE 4.2 Windpack performance

Wind Speed	***Wind Wheel Speed rev/sec***	***Theoretical Air volume pumped***
10 km/h	0.5 rev/sec	1.1 m^3/hr
15 km/h	1.0 rev/sec	2.2 m^3/hr
20 km/h	1.5 rev/sec	3.3 m^3/hr
30 km/h	2.0 rev/sec	4.4 m^3/hr

The above relationship is relatively linear, but can be expected to taper off at higher wind speeds due to energy losses derived from friction on bearing surfaces, air turbulence around the vanes and increased friction and heat at actuator plunger surfaces. The inclusion of compressibility may improve the calculated volumes. The windwheel is capable of angular velocities in excess of the ones presented above, but no reliable measurements were taken during high wind speed conditions.

Storage of wind energy as available air pressure in a receiver tank as opposed to direct storage as water in a water tank has the following advantages:

- Water quality is unaffected by insects, vandalism or vermin
- Water is not lost from the system by evaporation
- Damage to the aquifer from frequent groundwater drawdown is reduced due to the inherent principle of the system of water storage underground (energy storage as compressed air and not as above surface water)
- Water is only used as required (no running taps draining the storage), thus resulting in reduced energy wastage.
- Due to the improved sanitation perspective, risk of rural communities contracting diseases from usage of water from open water tanks is avoided. The need for boiling all water is reduced.
- The windwheel can be positioned in a location optimal for the capture of wind (e.g. top of a hill), whereas the borehole can be installed at a point most advantageous from the point of view of shallow placed and easily available groundwater (e.g. at the base of the hill). This breaks from the old system where the windwheel had to be positioned directly above the borehole and resulted often from either disadvantageous position for wind capture or unnecessary depth of borehole when positioned on high topographical points.

Primary disadvantages compared to conventional systems can be considered as:

- A new system not known to rural communities, which still needs to find community acceptance.

- Air pressure leaks are more difficult to control than water leaks.
- Air storage tanks are more expensive to manufacture than water tanks.
- Vandalism of the air supply pipes.

6 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are reached:

i. The airlift groundwater pump developed in the course of this project functioned according to the engineering principles along which it was designed. Its performance was confirmed in boreholes at water depths lower than 40 m.

ii. A regular, low cost, tyre pump is all that is required to operate the pump and deliver water to surface from depths of up to 40 m.

iii. Modifications incorporated to the initial design, i.e. addition of a check valve to maintain the water head in the riser pipe, and a float valve to control pressure discharge in the riser pipe, improved the function of the pump.

iv. The windpack compressor allows for storage of wind energy which is then easily available for acquiring of groundwater.

The following recommendations are made:

i. Larger air pressure receiver tanks will have to be produced in future to enable greater energy storage and thus larger availability of water, even during low wind conditions.

ii. The system operation needs to be fully tested under rural conditions setting to ensure equipment robustness and potential for wide spread use.

iii. The economic viability of the system needs to be addressed.

APPENDIX

TABLE 4.2 PERFORMANCE CURVES FORTHE GROUND WATER PUMP

10 m depth	hand pump 1 Water volume (ERR)	pump strokes	pumped air vol. (ERR)	cummul. air vol. (ERR)	time sec
	2	21	9.24	9.24	16
	4	20	8.8	18.04	15
	6	18	7.92	25.96	12
	8	18	7.92	33.88	13
	10	15	6.6	40.48	12
	12	17	7.48	47.96	7
	14	19	8.36	56.32	14
	16	20	8.8	65.12	14
	18	21	9.24	74.36	16
	20	18	7.92	82.28	16
	22	23	10.12	92.4	19
	total	***210***	***92***		***154***

hand pump 2 pump strokes	pumped air vol. (ERR)	cummul. air vol. (ERR)	time sec
36	11.52	11.5	12
30	9.6	21.1	10
34	10.88	32.0	14
35	11.2	43.2	12
33	10.56	53.8	11
39	12.48	66.2	14
40	12.8	79.0	15
37	11.84	90.9	13
38	12.16	103.0	17
39	12.48	115.5	19
38	12.16	127.7	18
399	***128***		***155***

foot pump pump strokes	pumped air vol. (ERR)	cummul. air vol. (ERR)	time sec
39	11.5	11.5	17
40	11.8	23.3	16
39	11.5	34.8	16
39	11.5	46.2	20
27	8.0	54.2	14
29	8.5	62.7	15
33	9.7	72.5	17
36	10.6	83.1	15
43	12.7	95.7	27
44	13.0	108.7	30
46	13.5	122.2	34
415	***122.2***		***221***

15 m depth	hand pump 1 Water volume (ERR)	pump strokes	pumped air vol. (ERR)	cummul. air vol. (ERR)	time sec
	2	21	9.24	9.24	16
	4	20	8.8	18.04	15
	6	18	7.92	25.96	12
	8	18	7.92	33.88	13
	10	15	6.6	40.48	12
	12	17	7.48	47.96	7
	14	19	8.36	56.32	14
	16	20	8.8	65.12	14
	18	21	9.24	74.36	16
	20	18	7.92	82.28	16
	22	23	10.12	92.4	19
	total		***92***		

hand pump 2 pump strokes	pumped air vol. (ERR)	cummul. air vol. (ERR)	time sec
54	17.28	17.3	30
63	20.16	37.4	37.0
79	25.28	62.7	48.0
84	26.88	89.6	55.0
97	31.04	120.6	75.0
46	14.72	135.4	26.0
self pump	0	135.4	
	0	135.4	
	0	135.4	
	0	135.4	
	0	135.4	
	135		

foot pump pump strokes	pumped air vol. (ERR)	cummul. air vol. (ERR)	time sec
43	12.7	12.7	36
53	15.6	28.3	38
34	10.0	38.3	34
36	10.6	48.9	37
39	11.5	60.4	34
37	10.9	71.3	32
49	14.4	85.7	33
43	12.7	98.4	25
47	13.8	112.2	
49	14.4	126.6	
50	14.7	141.4	
	141.4		

20 m		hand pump 1				hand pump 2				foot pump			
depth	Water volume (ERR)	pump strokes	pumped air vol. (ERR)	cummul. air vol. (ERR)	time sec	pump strokes	pumped air vol. (ERR)	cummul. air vol. (ERR)	time sec	pump strokes	pumped air vol. (ERR)	cummul. air vol. (ERR)	time sec
	2	29	12.76	12.76	16	60	19.2	19.2	45		0.0	0.0	
	4	30	13.2	25.96	15	57	18.24	37.4	39.0		0.0	0.0	
	6	31	13.64	39.6	12	59	18.88	56.3	37.0		0.0	0.0	
	8	32	14.08	53.68	13	53	16.96	73.3	29.0		0.0	0.0	
	10	34	14.96	68.64	12	52	16.64	89.9	30.0		0.0	0.0	
	12	33	14.52	83.16	7	47	15.04	105.0	27.0		0.0	0.0	
	14	36	15.84	99	14	50	16	121.0	29.0		0.0	0.0	
	16	42	18.48	117.48	14	52	16.64	137.6	32.0		0.0	0.0	
	18	37	16.28	133.76	16	46	14.72	152.3	25.0		0.0	0.0	
	20	41	18.04	151.8	16	48	15.36	167.7	29.0		0.0	0.0	
	22	43	18.92	170.72	19	56	17.92	185.6	30.0		0.0	0.0	
	total		***171***				***186***				***0.0***		

30 m		hand pump 1				hand pump 2				foot pump			
depth	Water volume (ERR)	pump strokes	pumped air vol. (ERR)	cummul. air vol. (ERR)	time sec	pump strokes	pumped air vol. (ERR)	cummul. air vol. (ERR)	time sec	pump strokes	pumped air vol. (ERR)	cummul. air vol. (ERR)	time sec
	2	35	15.4	15.4	18	54	23.76	23.76	41		0.0	0.0	
	4	40	17.6	33	31	51	22.44	46.2	37.0		0.0	0.0	
	6	43	18.92	51.92	36	52	22.88	69.08	39.0		0.0	0.0	
	8	44	19.36	71.28	25	49	21.56	90.64	31.0		0.0	0.0	
	10	41	18.04	89.32	22	55	24.2	114.84	38.0		0.0	0.0	
	12	47	20.68	110	29	45	19.8	134.64	32.0		0.0	0.0	
	14	38	16.72	126.72	31	32	14.08	148.72	23.0		0.0	0.0	
	16	39	17.16	143.88	20	34	14.96	163.68	25.0		0.0	0.0	
	18	42	18.48	162.36	27	41	18.04	181.72	33.0		0.0	0.0	
	20	43	18.92	181.28	37	44	19.36	201.08	36.0		0.0	0.0	
	22	49	21.56	202.84	34	39	17.16	218.24	30.0		0.0	0.0	
	total		***203***		***310***		***218***		***365***		***0.0***		

40 m		hand pump 1				hand pump 2				foot pump			
depth	Water volume (ERR)	pump strokes	pumped air vol. (ERR)	cummul. air vol. (ERR)	time sec	pump strokes	pumped air vol. (ERR)	cummul. air vol. (ERR)	time sec	pump strokes	pumped air vol. (ERR)	cummul. air vol. (ERR)	time sec
	2	34	14.96	14.96	19	60		0.0			0.0	0.0	
	4	47	20.68	35.64	20	57		0.0			0.0	0.0	
	6	47	20.68	56.32	19	59		0.0			0.0	0.0	
	8	49	21.56	77.88	24	53		0.0			0.0	0.0	
	10	44	19.36	97.24	26	52		0.0			0.0	0.0	
	12	51	22.44	119.68	23	47		0.0			0.0	0.0	
	14	47	20.68	140.36	21	50		0.0			0.0	0.0	
	16	49	21.56	161.92	28	52		0.0			0.0	0.0	
	18	52	22.88	184.8	31	46		0.0			0.0	0.0	
	20	48	21.12	205.92	20	48		0.0			0.0	0.0	
	22	46	20.24	226.16	19	56		0.0			0.0	0.0	
	total		***226***				***0***				***0.0***		

50 m		hand pump 1				hand pump 2				foot pump			
depth	Water volume (ERR)	pump strokes	pumped air vol. (ERR)	cummul. air vol. (ERR)	time sec	pump strokes	pumped air vol. (ERR)	cummul. air vol. (ERR)	time sec	pump strokes	pumped air vol. (ERR)	cummul. air vol. (ERR)	time sec
	2	40	17.6	17.6	29		0	0.0			0.0	0.0	
	4	56	24.64	42.24	30		0	0.0			0.0	0.0	
	6	71	31.24	73.48	32		0	0.0			0.0	0.0	
	8	66	29.04	102.52	47		0	0.0			0.0	0.0	
	10	77	33.88	136.4	65		0	0.0			0.0	0.0	
	12	75	33	169.4	60		0	0.0			0.0	0.0	
	14	56	24.64	194.04	37		0	0.0			0.0	0.0	
	16	78	34.32	228.36	71		0	0.0			0.0	0.0	
	18	71	31.24	259.6	45		0	0.0			0.0	0.0	
	20	75	33	292.6	49		0	0.0			0.0	0.0	
	22	79	34.76	327.36	52		0	0.0			0.0	0.0	
	total		***327***				***0***				***0.0***		