THE DEVELOPMENT OF THE ROPE AND WASHER PUMP FOR USE WITH TUBEWELLS IN MAPUTALAND, SOUTH AFRICA

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THE DEVELOPMENT OF THE ROPE AND WASHER PUMP FOR USE WITH TUBEWELLS IN MAPUTALAND, SOUTH AFRICA

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SUMMARY

The Ubombo Family Wells Programme (UFWP) is currently being implemented in the Maputaland area of northern KwaZulu Natal province, South Africa. Managed by Partners in Development (PID), the UFWP focuses on the provision of low-cost water supplies for rural families in this area. This provision is accomplished using appropriate technologies in water supply, construction, and operation. Water supplies are obtained through the manual drilling of tubewells (small-diameter boreholes), which are lined and equipped with pumps. Bucket Pumps, as are currently used, have proven to be very reliable but have low pumping rates and have not been readily accepted by some local officials. An improved pumping system is desirable to the UFWP.

The Rope and Washer Pump (R & W Pump), an appropriate technology water-lifting device, has been implemented successfully in a number of developing countries around the world. The advantages of the R & W Pump include its low cost, durability, simple operation, and relatively high pumping rate, which make it possible for this pump to be built and maintained at the small village level. This research project focuses on the development of the Rope and Washer Pump for use with tubewells in Maputaland.

Fieldwork was undertaken in Maputaland from July 2003 to January 2004. Extensive monitoring of several reference R & W Pumps led to a final project pump design, which includes a new, original design of a hygienic pump cover. The final R & W Pump design was analysed for economic feasibility, pumping performance and efficiency, and microbiological water quality. The potential sustainability of the R & W Pump is analysed for the UFWP, based upon the monitoring of the reference pumps. The evaluation of sustainability considers the durability of the R & W pump, as well as the ability and willingness of the users to maintain and repair them.

The outcome of this project is the design and construction of an effective Rope and Washer Pump for the Ubombo Family Wells Programme. This pump provides a considerably higher rate of flow than that produced by the Bucket Pump, and leads to a significant upgrade in the level of service provided. The R & W Pump may be produced locally for an acceptable price. While it appears that the microbiological water quality of the tubewells equipped with R & W Pumps is at least as good as that of tubewells equipped with Bucket Pumps, further testing is required to confirm this opinion.

The R & W Pump has the potential for being sustainable in Maputaland, providing that the users are actively involved in the pump installation and that adequate education in the use, maintenance and repair of the pump has been provided by the implementing agency.

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DEDICATION

This dissertation is dedicated to the author's parents, Patrick and Helen MacCarthy, who have always been very supportive in his studies and travels.

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GLOSSARY OF TERMS USED

Biddim – A geo-textile material used to prevent fine sands from entering the slotted casing of a tubewell.

Bucket Pump – Simple appropriate technology pumping system used to lift water from wells.

Rope and Washer Pump (R & W Pump) – An appropriate technology water-lifting device that can be built and maintained at the village level.

Tubewell – A small diameter borehole.

Windlass – A horizontal cylinder with a crank, used to wind rope.

Vonder Rig – A type of man-powered auger used to drill tubewells.

CURRENCY EXCHANGE RATE

The approximate value of the South African currency, the Rand, as of February 2004, is:

6.6 Rand = 1.0 USD [Dollars, United States]
12.5 Rand = 1.0 GBP [Pounds Sterling, Great Britain]
8.4 Rand = 1.0 EUR [Euros, EU] (XE.com, 2004)

LIST OF ACRONYMS AND ABBREVIATIONS USED

CGS	Council for Geoscience (South Africa)
IRC	International Water and Sanitation Centre
l	litre
ml	millilitres
m	Metre
mm	Millimetre
µm	Micrometre (1/1,000,000 metre)
NORAD	Norwegian Agency for Development Cooperation
PID	Partners in Development
revs	revolutions
SDC	Swiss Agency for Development and Cooperation
UFWP	Ubombo Family Wells Programme
uPVC	Polyvinyl Chloride (unplasticised)
WSP	Water and Sanitation Programme

1 INTRODUCTION

1.1 Background

The Ubombo Family Wells Programme (UFWP) has been in operation since the mid 1990's in the Maputaland region of northern KwaZulu Natal province, South Africa. Developed by Partners in Development (PID), a South African engineering and development consultancy, this programme aims at providing low-cost potable water supplies to rural families in the Maputaland area. The UFWP makes use of appropriate technologies in water supply, construction, and operation.

Partners in Development has found that the best way of obtaining a low-cost water supply in Maputaland is to extract water from the ground through wells equipped with pumps. This approach is effective due to the relatively shallow ground water depths in the area, combined with sandy soil conditions. The current method used to extract water from the ground is to pump it through tubewells, which are small-diameter boreholes. These tubewells are drilled into the sandy soil, using a hand-powered auger. The use of a manual auger allows for maximum use of local labour, which is a relatively cheap commodity in Maputaland. The drilled well is lined with a uPVC (polyvinyl chloride, unplasticised) pipe to protect the walls of the tubewell from collapsing. The tubewell is then equipped with a hand-operated pump. All materials used in the construction of the tubewells are produced in South Africa, with much of the construction being done at the local level in Maputaland.

The current system of pumping water from the tubewells consists of a long, narrow galvanized iron bucket, attached to a rope and windlass. The bucket is lowered to the bottom of the well to collect water, and then raised to the surface. From there the water is poured into a container. While this "Bucket Pump and windlass" system is very reliable, the pumping rate is low and there have been problems with acceptability among local government officials. The implementation of an improved pumping system is desirable to the users, and would increase the likelihood of acceptance of the UFWP among local officials.

PID has been awarded a contract through the South African Council for Geoscience (CGS) and the Norwegian Agency for Development Cooperation (NORAD) to investigate the use of appropriate water pumping technologies. The contract calls for the implementation of 100 additional family water sources in Maputaland, from July 2003 to June 2004 (CGS, 2003). This project, a continuation of the UFWP, includes research on the use of Rope and Washer Pumps as a means of lifting water from tubewells. The Rope and Washer Pump (R & W Pump), also commonly referred to as the Rope Pump, is an appropriate technology water-lifting device that can be built and maintained at the village level.

NORAD and CGS have provided funding to: (1) develop the R & W Pump for use with tubewells in Maputaland; (2) equip the 100 tubewells in the project with R & W Pumps; and (3) monitor and evaluate the performance of these R & W Pumps (CGS, 2003).

1.2 Scope of the Study

This study focuses on the development of the R & W Pump for use with tubewells in Maputaland. It covers the initial design and construction of R & W Pumps for use with tubewells. The study reports the findings of five months of monitoring and evaluating the performance of several reference R & W Pumps. This research has lead to an acceptable design for the remaining R & W Pumps to be built under the NORAD and CGS funded project, as well as for future projects under the UFWP. The study is intended to determine the overall feasibility of using the R & W Pump in the UFWP, as described in the research objectives.

1.3 Research Objectives

The objectives of this study are as follows:

1) To design and construct a Rope and Washer Pump for use with tubewells in Maputaland, South Africa.

2) To determine the economic feasibility of using Rope and Washer Pumps as a means of extracting water from tubewells in Maputaland, South Africa.

3) To determine an effective, locally available material for washers used on the Rope and Washer Pump.

4) To determine whether or not the Rope and Washer Pump is more efficient than the Bucket Pump in extracting water from tubewells (in terms of pumping time and ease of pumping).

5) To determine the water quality, through biological testing, of a sample of tubewells equipped with Rope and Washer Pumps.

6) To evaluate the potential sustainability of Rope and Washer Pumps to be used in the Ubombo Family Wells Programme.

1.4 Dissertation Structure

In order to provide an adequate understanding of the context in which the R & W Pump is to be used in Maputaland, South Africa, it is necessary to have a significant amount of background information on both the UFWP and the R & W Pump.

Chapter 2 of this document provides an overview of the UFWP, including the drilling technology used and the current water pumping system. Project sustainability is also discussed.

Chapter 3 introduces the R & W Pump. A brief history of the R & W Pump is given, with examples of projects where it has been implemented. This is followed by an introduction to the components that make up the R & W Pump. Issues of sustainability with R & W Pumps are discussed.

Chapter 4 explains the research methods that were used in carrying out this study. The constraints on the fieldwork are given, as well as a summary of the programme of work.

Chapter 5 analyses the design and construction of the R & W Pump for tubewells. Problems with prototype and subsequent designs are explained, as well as what has been done to solve these problems.

Chapter 6 provides an analysis of the final R & W Pump design for this project. Various aspects of the R & W Pump are analysed, to correspond with the research objectives.

Chapter 7 summarises the findings of this research project, according to the specific research objectives. This chapter includes technical, social, and economic aspects relevant to the implementation of the R & W Pump with tubewells in Maputaland.

Chapter 8 provides recommendations for further implementation of the R & W Pump in Maputaland. It stresses what needs to be done to ensure that the R & W Pump can be sustainable for the UFWP. Suggestions for improvements to the pump design are given, as well as recommendations for further study on the UFWP.

2 THE UBOMBO FAMILY WELLS PROGRAMME

2.1 Introduction

The Ubombo Family Wells Programme (UFWP) was started in the Maputaland area of northern KwaZulu Natal province, South Africa in 1996. Under the direction of Partners in Development (PID), a South African engineering and development consultancy, this programme has since achieved the construction of over five hundred shallow family wells (Nash, 2004).

2.1.1 Maputaland

The Maputaland area forms the coastal plain of northern KwaZulu Natal. It covers the area east of the Ubombo Mountains to the Indian Ocean. Maputaland extends from the north of Lake St. Lucia to the Mozambique border (Figure 2.1). The rural population is very dispersed, with homesteads typically a few hundred metres apart, and there are large spaces with no settlement. The rural population of Maputaland is currently about 120,000 (Still and Nash, 2002). While there are higher population densities around the regional centres, such as Manguzi, Mbazwane, and Mseleni, a significant proportion of the population lives in more remote areas. Due to the great importance of land in Zulu culture, this situation is not likely to change in the near future (Deverill et al., 1999a).

Figure 2. 1a Map of South Africa Showing Maputaland area [red circle on map] (CIA, 2003)

Figure 2. 1b Map of Maputaland area (Deverill et al., 1999a)

The Maputaland coastal plain is relatively flat and sandy, with numerous dune ridges. Natural vegetation is comprised of small trees, brush and grassland. An extensive shallow aquifer underlays much of Maputaland. The mean annual rainfall varies from around 1000 mm along the coast to about 600 mm further inland (ibid.).

Maputaland is a relatively under-developed region of South Africa. Tourism, forestry, and civil service provide limited employment in the area. The lack of sufficient sustainable economic opportunities in Maputaland has resulted in much of the population being dependent on government support (Deverill et al., 1999b).

2.1.2 Hydrogeology of Maputaland

The vast majority of the soil in the area is sand, mixed with pockets of clay and rock. The top of the shallow water table generally lies at a depth of two to twenty-five metres. This water has generally been found to be of good chemical quality. Deeper groundwater tends to be saline, particularly towards the West and South of Maputaland. Such higher salinity occurs where the sand layers are thinner and the water is drawn up from underlying cretaceous formations. Seasonal fluctuations in the shallow water table have been reported as generally between 0.7 to 1.2 metres (ibid.). However, droughts in recent years have caused the shallow water table to drop more than two metres in several areas.

2.1.3 Water Supply in Maputaland

Prior to the introduction of the UFWP in Maputaland, the main types of potable water supply systems in the area consisted of: (1) large piped water supply systems around the regional centres; (2) small piped systems with water pumped from a deep borehole; and, (3) community handpumps attached to boreholes. The common theme for each of these three types of water systems is that they have proven to be very difficult to maintain by the communities without significant support from an outside source (Still and Nash, 2002).

Large Piped Water Schemes

Large piped water schemes in Maputaland occur around the villages of Shemula, Manguzi, Mbazwane, Mseleni and Jozini. The operation and maintenance of each of these projects is currently subsidised, to varying degrees (ibid.). Still, maintenance remains a major problem. According to Kwenzile Nsele, a water user of the Mseleni Water Project, the piped water at his tap often does not flow for days at a time. He estimated that he has had running water 50% to 60% of the time over the past year (Nsele, 2003). Other users of this water project have reported similar experiences.

The reason that there is a need to subsidise the operation and maintenance of these projects is due to insufficient, or even non-existent, cost recovery from supplied water. The real cost of water for these projects is generally greater than R10/kl, with only a fraction of this cost being recovered (Still and Nash, 2002). The Mseleni Water Project charges only R1/kl for water, with metres required for all connections. Another problem with the Mseleni Water Project, and common to other projects in Maputaland, has been the equity of water delivery. It is common that those users at the front end of the piped system will use large amounts of water, leaving little or no water for those users towards the end of the system (Fishlock, 2002).

Dorothy Nsindeni, a user of the Mbazwane Water Project who has a tap at her house, states that her family has never been charged for water. They have used the system for 5 years, and it was only recently that the project personnel mentioned to them the possibility of charging for water (Nsindeni, 2003).

Small-scale Piped Water Schemes

There are also a number of small-scale gravity flow water schemes in Maputaland. These systems typically consist of a borehole, from which water is pumped by an engine to a reservoir, and supplied by gravity flow through pipes to a number of taps. These schemes have not received support or subsidisation for operation, and have typically not worked for more than a few months after installation (Still and Nash, 2002).

Community Handpumps

There have been numerous projects providing boreholes with handpumps to communities in Maputaland over the past two decades. Many of these handpumps are no longer functional. Among the reasons for the non-functioning of these handpumps are: the inability of the users to repair the pumps themselves; and the non-availability locally of replacement parts for the pumps. The failure of these handpumps has led to much scepticism amongst the local populations as to the suitability of boreholes as domestic water sources (ibid.).

2.2 History – Ubombo Family Wells Programme

The UFWP began in 1996 with a series of pilot experiments to determine appropriate water supply systems for the rural areas of Maputaland. The project initially received extensive support from the Mvula Trust. This trust, established in 1993, focuses on assisting rural South African communities with access to improved water supply and sanitation. The Mvula Trust appointed PID to perform a comprehensive study to "investigate the potential for developing a sustainable water supply programme in the area" (Deverill et al., 1999a). This initiative led to a full-scale water supply programme, which began in 1997 and is still continuing at this time. This programme has in the past been funded by The Mvula Trust, AusAID and the European Union.

Initially, the UFWP focused on the construction of large diameter hand dug wells, to provide water to rural families for domestic use. This strategy was based on recommendations of the initial study done by PID, which considered the physical, social, institutional and economic makeup of Maputaland (ibid.). During the first phase of the project, research was also done into the drilling of small diameter tubewells. As described in detail in a report to the Mvula Trust: The Development of Hand Augered Tubewells in Southern Maputaland (Deverill et al., 1999b), this method of supplying groundwater was found to have great potential. Based upon previous projects carried out by the Blair Research Institute of Zimbabwe, drilling was done using a man-powered auger, and the tubewells were lined and equipped with pumps (Still and Nash, 2002). The construction of tubewells has proven to cost significantly less than hand dug wells. In addition, the bacteriological water quality from the tubewells is generally much better (Deverill et al., 1999b).

2.3 Hand Augered Tubewells

The drilling of small diameter wells using hand-operated equipment has proven to be very successful in Maputaland. This approach is effective due to the relatively shallow ground water depths found in the area, combined with predominantly sandy soil conditions.

2.3.1 Vonder Rig Auger

The manual auger that is used in the UFWP, the Vonder Rig, was developed by V & W engineering of Zimbabwe. The main components of the Vonder Rig can be seen in Figures 2.2 and 2.3. The Vonder Rig consists of a steel tripod from which drilling rods are hung. A robust worktable aligns the extension rods of the auger as it drills into the ground. A winch, which is attached to one of the tripod's legs, is used to raise and lower the auger. The Vonder Rig is capable of drilling through soils and weathered rock formations. However, it is not possible to drill through hard rock (Morgan, 1990). The sandy soil found throughout Maputaland makes drilling with the Vonder Rig relatively easy, with water table depths of up to twenty metres achievable within six working days (Deverill et al., 1999b).

Figure 2. 2 Photo Showing Vonder Rig Auger, Worktable, and Tripod Winch

Figure 2. 3 Photo of Vonder Rig in Operation in Maputaland

The Vonder Rig has proven to be very successful in the UFWP, with most of the drilling being done through sandy soil. Problems have occurred when the auger hits rock or small stones. When these circumstances occur, the hole is abandoned, and a new tubewell is started (ibid.).

2.3.2 Drilling the Tubewell

Once a site has been properly located (usually at a low point in the area, where the water table depth is likely to be shallow), the Vonder Rig is set up, and drilling begins. This operation requires four to seven healthy adults, including an experienced operator. A few people turn the crossbar attached to the auger rod, while at the same time exerting a downward pressure. As the supporting cable is loosened, this action allows the auger to move downward and cut into the soil. This operation is performed until the auger has filled with soil, at which point it is extracted from the ground and emptied. The process is continued until the water table is reached (Morgan, 1990).

Once the tubewell has been drilled to the water table, a different method is required for further excavation. This change in strategy is due to the instability of the saturated sand. As this sand slurry is taken out of the well, it is quickly replaced by adjacent material collapsing inward. In order to prevent such a collapse from occurring, the well is at this point lined with uPVC piping (Deverill et al., 1999b).

2.3.3 Lining the Tubewell

The installation of the lining does not allow for further augering, as the auger bit has a larger diameter than the lining. Therefore, a bailing method is used for further drilling. This method uses a bailer with a foot valve or flap valve to extract soil. As this bailing is being done, the lining is forced downwards to protect the additional length of borehole that has just been excavated. The Vonder Rig is equipped with a type of clamp that is fitted on the portion of the lining above ground. Two of the workers can sit on this clamp as the bailing procedure is performed, thus applying downward pressure and causing the lining to descend. Bailing is continued until the well has been dug four to five metres into the water table (ibid.).

The tubewell is lined throughout its depth with a 125 mm diameter, Class 9 uPVC pipe, which has a sufficient strength to withstand the bearing pressure of the surrounding soil. The well screen is located at the bottom three metres of the pipe. This screen, also Class 9 uPVC pipe, has 1mm wide slots throughout its length, allowing for water to pass through the screen into the tubewell.

The well screen is wrapped in a geotextile material. This material, sold as U14 Biddim in South Africa, has an effective pore size of 250 μm, and prevents the infiltration of fine sands into the tubewell.

The conventional technique used to prevent infiltration of fine sands into drilled wells is to install a gravel pack of coarser sand around the pipe. This is done after the pipe has been installed. Established drilling convention uses a minimum thickness of 75-100 mm for the gravel pack. The size of the hole drilled with the Vonder Rig would allow only an insufficient gravel pack thickness of about 20-25 mm. Nevertheless, geotextile coverings have proved to be an effective alternative to gravel packs (Ball, 2001). Experience shows this to be the case with tubewells in the UFWP (Deverill et al., 1999b).

A “biddim” plug is used to seal the bottom of the well. This plug is necessary to prevent sand coming up through from below the tubewell lining. This type of plug, which the UFWP adapted from a tubewell drilling project in Niger, consists of cement mortar wrapped in geotextile fabric. The prepared plug is dropped to the bottom of the well. It is then tamped in place using a drill extension pipe attached to a rope. The cement mortar sets under water (Naugle, 1996).

2.4 <u>The Bucket Pump</u>

The UFWP uses a Bucket Pump system, which consists of a long, narrow bucket attached to a rope and windlass (a horizontal cylinder with a crank), as shown in Figures 2.4 and 2.5. The bucket is lowered to the bottom of the well on the rope to collect water, and then wound to the surface.

Figure 2. 4 Bucket Pump being lowered into tubewell

Figure 2. 5 Bucket Pump in use in Maputaland

2.4.1 Bucket

The bucket is made of regionally manufactured steel, which is galvanised to prevent corrosion, and has a capacity of approximately 5.5 litres (Still and Nash, 2002). The bucket is fitted with a non-return foot valve at the bottom, as shown in Figure 2.6. This foot valve, fitted with a rubber washer, a bolt, and locknuts, is pushed up to the open position as the bucket is lowered into the water table. The bucket then quickly fills with water. As the bucket is lifted, the valve closes, holding the water in the bucket as it is raised to the surface, with the rubber washer providing a good seal. At the surface, the user pours the water from the bucket into another container. This can be done by either tilting the bucket so that the water pours out the top end, or by pushing the foot valve up so that the water is released through the bottom (Deverill et al., 1999b). Typical pumping rates are estimated at 4-5 litres/minute.

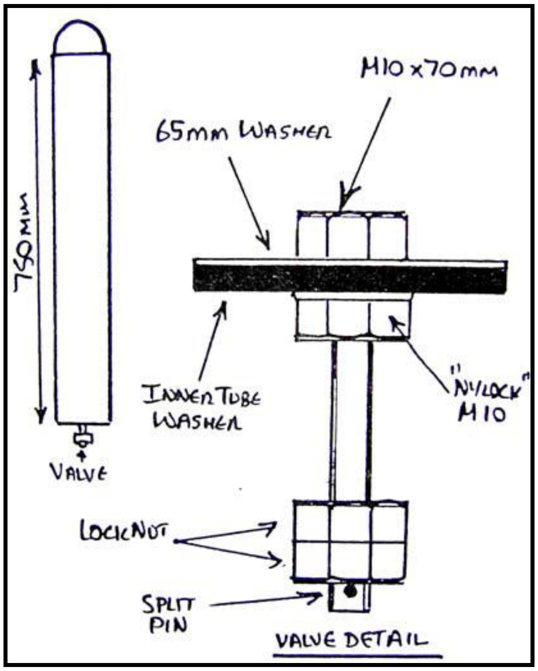

Figure 2. 6 Valve Detail of UFWP Bucket Pump (Deverill et al., 1999b)

2.4.2 Windlass and Supports

The windlass consists of a steel spool, axle, and handle. It is attached to two wooden gum tree pole supports, as can be seen in Figure 2.4. The gum tree poles, which are cut from locally grown trees, have proven to be adequate supports for the Bucket Pump. The windlass itself is constructed in Maputaland by a local welder.

The gum tree poles are firmly installed in the ground next to the tubewell, such that the spool of the windlass is in line with the top of the tubewell. The bases of the gum tree poles are encased in concrete, and a concrete apron is constructed around the tubewell. This apron prevents infiltration near the lining of the tubewell.

2.5 Project Sustainability

The results of continual monitoring and evaluation of the UFWP over the past five years show that this project provides a sustainable source of water supply to rural families in Maputaland. This success is due to the use of the appropriate technology water pumping system, which can be maintained and repaired at the local level.

The average cost of the tubewells equipped with Bucket Pumps in the UFWP is approximately R5000, including all overhead costs (Still and Nash, 2002). Of this total cost, the beneficiaries are required to pay R600, with the remaining amount being covered by the programme. This payment is manageable for many families, but is still a large amount of money, as the monthly cash income of the average household in Maputand is approximately R800. The government old age pension is R700/month, and the going rate for casual work in the area is R45/day (Still, 2004). The monetary contribution by the beneficiaries is believed to be important to helping them have a feeling of ownership of the tubewell and pump, which makes them more likely to maintain and repair it.

Most tubewells have been very successful, with the owners showing a willingness to maintain and repair them. Routine repairs, such as replacing the rope or foot valve washer, can be done by the owners themselves. Other repairs, such as welding of the bucket, can be performed by local technicians in Maputaland. The convenience and simplicity of the Bucket Pump makes the users more likely to maintain and repair them, rather than to use an alternative water source.

2.6 Conclusion

The Ubombo Family Wells Programme has proven to provide a sustainable source of potable water to rural families in Maputaland. The use of appropriate technologies in all aspects of the project (drilling, pump construction, pump operation) is the key to the project's sustainability.

Due to the close proximity of the tubewell to the homestead, there is usually a significant time-savings over alternative water collection points. However, pumping rates of the Bucket Pump are low (4-5 litres per minute). The development of an improved pumping system could provide a savings in time spent collecting water, and potentially lead to the use of larger quantities of water for domestic purposes.

3 THE ROPE AND WASHER PUMP

3.1 Introduction

The Rope and Washer Pump (R & W Pump), also commonly known as the Rope Pump, is an appropriate technology water-lifting device for use in developing communities. It is suitable for use on shallow wells and boreholes. The main advantages of the R & W Pump include its low cost, durability, and simple operation. It has the ability to be both constructed and maintained at the small community or family level in developing countries. The R & W Pump is capable of providing a relatively high discharge of water for handpumps installed at shallow depths (less than thirty metres). With a more advanced design of the R & W Pump, it is possible to extract water from depths of over sixty metres (Bombas de Mecate, 2003).

The technology of the R & W Pump has been around for over a thousand years (Alberts, 2000). There are records of designs of similar pumps from ancient China and early twentieth century France (WSP, 2001). The R & W Pump has been marketed throughout much of the developing world, with varying degrees of success. It has achieved extensive implementation in Nicaragua, Central America, over the past fifteen years. In Nicaragua, the R & W Pump has been developed by the local organisation Bombas de Mecate, in conjunction with several international organisations, including the Swiss Agency for Development and Cooperation (SDC) and the International Water and Sanitation Centre (IRC). The R & W Pump has been installed on over 22,000 hand-dug wells and drilled wells in Nicaragua (SKAT, 2001). It is now "the national standard pump for the water and sanitation sector" in Nicaragua, with several private enterprises manufacturing the pump (AguaSan, 2003). Figure 3.1 shows an R & W Pump installed on a well in Nicaragua (Bombas de Mecate, 2003).

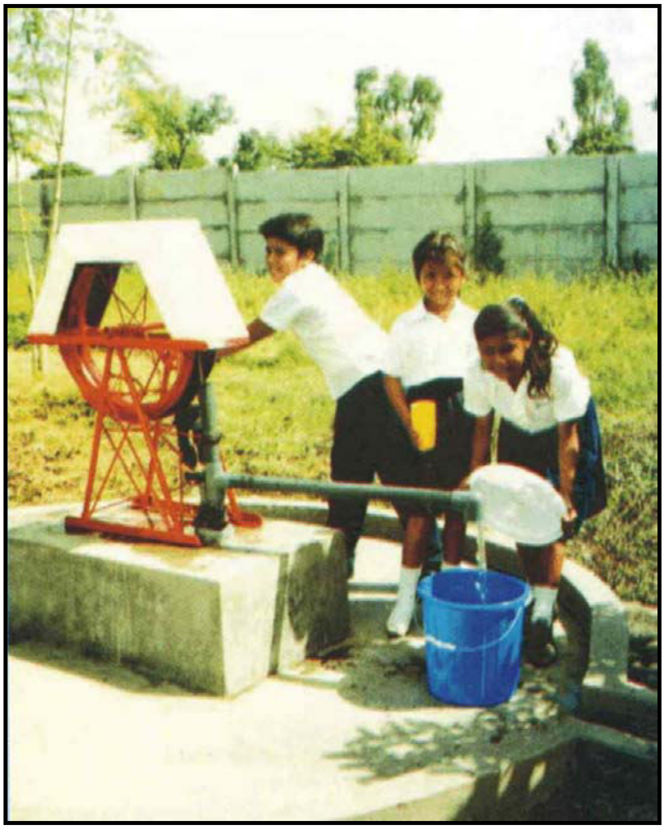

Figure 3. 1 Photo of R & W Pump in use in Nicaragua (AguaSan, 2003)

Versions of the R & W pump operated by windmills, animals, bicycles, motors, or engines have been built successfully. Rope & Water Pumps have been used extensively for both domestic water supply and irrigation.

In Africa, the R & W Pump has been implemented in many small-scale projects, as well as some larger projects. Bombas de Mecate has worked jointly with the World Bank Water and Sanitation Programme (WSP) and the Ghanaian Government to transfer the technology of the R & W Pump from Nicaragua to Ghana.   Bombas de Mecate personnel visited Ghana to help with the selection of suitable manufacturers, confirm the local availability of materials, and help start the production process. This project led to the installation of 100 trial R & W Pumps in Ghana (WSP, 2001).

3.2 Rope and Washer Pump Design

The basic design of the R & W Pump consists of five principal components: (1) a pulley wheel attached to supports; (2) a rope with washers attached to it at equally spaced intervals; (3) a top guide, including a spout; (4) a rising main pipe; and (5) a bottom guide. A diagram of these components, as installed on a tubewell, is shown in Figure 3.2.

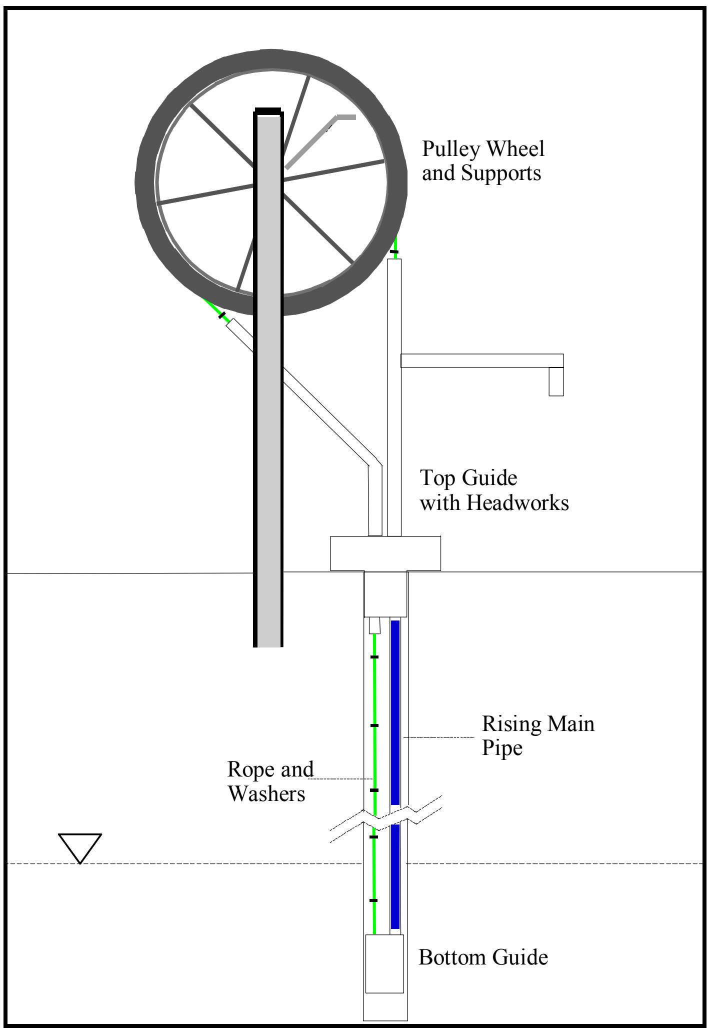

Figure 3. 2 Main Components of a Rope and Washer Pump

The rope and washers run up through the rising main pipe, out through the top guide, around the pulley wheel, and back through the opposite side of the top guide. From there, the rope and washers descend to near the bottom of the well, below the water table. They enter the bottom guide, which is attached to the lower end of the rising main pipe, with the rope thus forming a continuous loop. As the pulley wheel is turned, the rope and washers ascend the rising main pipe, with water entering through the bottom guide. Supported by the washers, the water is lifted through the rising main pipe, and discharged through a spout above the ground (Lambert, 1990).

A description of each component of the R & W Pump follows.

3.2.1 Pulley Wheel and Support

The function of the pulley wheel is to rotate the rope and washers through the pump. An adequate wheel can be made using the two sidewalls cut from an old truck tyre. For wells less than 30 metres deep, 20-inch (510-mm) diameter tyres are generally used. These rubber tyre rings, when inverted and placed together, form a v-shaped groove, which provides an excellent grip for the rope and washers. This grip is needed to prevent slippage of the rope on the wheel (ibid.). The tyre rings are held together with clips, and fitted over a spoked tyre rim with an axle. These parts are commonly constructed of steel, although wood or other materials of sufficient strength can be used. The pulley wheel must be strong to accommodate extensive use. (Bombas de Mecate, 2003).

A handle on one or both sides is used to turn the pulley wheel. A support structure holds the pulley in place above the well. For pumps installed on large diameter wells, the support structure is usually built onto the well cover. For drilled wells, however, the supports must be firmly set in the ground around the tubewell.

3.2.2 Rope and Washers

A polypropylene rope of sufficient strength is ideal for use on R & W Pumps. Washers made out of rubber or plastic are fitted onto the rope. The washers are of a diameter slightly smaller than the inside diameter of the rising main pipe. This allows the washers to effectively lift the water through the pipe, while still being able to move through the pipe with minimal friction. The washers are spaced at even intervals along the rope. The recommended spacing of the washers depends on the washer characteristics, as well as the depth of the well. They are generally spaced at one to four metres apart. Knots are tied on the rope, at either side of each washer, which keeps them in position along the rope (Lambert, 1990).

Effective washers for the R & W Pump can be made either from rubber or plastic. Rubber washers cut from old tyres have been used in many past projects. These washers can be made at the village level, using locally produced tools to cut the rubber. As long as the washers are relatively uniform, and slightly smaller in diameter than the inside of the rising main pipe, they will pump water adequately.

The Bombas de Mecate project in Nicaragua produced engineered plastic washers using injection moulding. This design resulted in the production of uniform washers that significantly reduce the friction within the rising main pipe, compared with slightly non-uniform rubber washers. In addition, the angled top of the designed washer reduces the chance of it becoming caught on entrance to the pump pipes. It has been found that the use of these washers allows for pumps to be installed at depths of over sixty metres (Bombas de Mecate, 2003).

3.2.3 Top Guide (Including Headworks)

The top guide discharges the water from the pump, as well as guiding the rope back into the well after it has passed over the pulley wheel. For tubewells, the top guide consists of a covering for the top of the tubewell, from which guide pipes extend, as can be seen in Figure 3.2. The rising main pipe is attached to the bottom of the top guide. A straight pipe extends from the cover of the well up towards the pulley wheel. The rope and washers feed through this pipe to the pulley wheel. Attached to this pipe is a spout where water is discharged. The back side of the top guide has a bent pipe that guides the rope and washers back into the tubewell (Van Hermert et al., 1992).

3.2.4 Rising main Pipe

The rising main pipe is a rigid pipe, usually made of uPVC, through which water is carried from the bottom guide to the top guide. Most lightweight pipe materials that are designed for use in water systems can generally be used for the rising main pipe. The pipe must be strong enough to support the column of water and the bottom guide, as well as the pipe hanging below it. As the weight of the water in the pipe is supported by the washers (on the rope), the largest pressure within the pipe during pump use is only as great as the weight of water between the washers (Bombas de Mecate, 2003).

The diameter of the rising main pipe depends on the depth from which the water is to be pumped. It is only possible to lift a certain weight of water (around 10 kg) within the rising main pipe, without the pumping becoming very difficult (ibid.). Thus, for deeper well depths, where the water column being lifted in the rising main pipe is large, the diameter of pipe must be smaller than for shallow wells. For pumps deeper than 12 metres, a pipe of internal diameter not greater than 20 mm is recommended (Lambert, 1990).

3.2.5 Bottom Guide

The bottom guide sits below the water table, just above the bottom of the well. It is attached to the lower end of the rising main pipe. The function of the bottom guide is to effectively change the direction of the rope and washers, and allow them to smoothly enter the rising main pipe. This component must be built precisely, as minor problems with the bottom guide can cause the rope and washers to 'catch'. In this case, it is often difficult for the user to determine the cause of malfunction, as the entire pump must be taken out of the well to examine the bottom guide.

The tubular section of the bottom guide, which is oriented horizontally, changes the direction of the rope and washers as they pass over it. The use of a material that allows the rope and washers to smoothly pass over this section is crucial to the function of the bottom guide. Past projects have used wood, plastic, glass, or ceramic for this part of the guide.

3.3 Sustainability of the R & W Pump

The R & W Pump has proven to be sustainable in projects where the implementation included proper training in its use and repair. In 1995, the International Water and Sanitation Centre (IRC) performed an independent evaluation of the R & W Pump, based on the experience in Nicaragua. The purpose of this evaluation was to assess the short-term and long-term performance of the Nicaraguan R & W Pump, as well as its potential for application in other countries. The IRC report concluded that the R & W Pump "can potentially form a valuable addition to the range of appropriate groundwater lifting technologies in other countries" (IRC, 1995).

A study of R & W Pumps installed on five different projects in Nicaragua and El Salvador found that most families with R & W Pumps felt responsible for maintaining and repairing their pump. They also were found to be capable of performing the repairs themselves (Uiterweer, 2000).

3.4 Conclusion

Due to its simple design, the R & W Pump can be constructed and maintained at the village level in developing countries. Its use of materials which are readily available in many parts of the world help make the R & W Pump a sustainable hand pump option in developing communities. Because of these factors, combined with the R & W Pump's relatively high rate of discharge for a hand pump, it is important to conduct research to evaluate the feasibility of using R & W Pumps in place of Bucket Pumps on the Ubombo Family Wells Programme (UFWP).

4 THE RESEARCH

4.1 Research Methods

The research performed during the development of the Rope and Washer Pump (R & W Pump) for tubewells in Maputaland used various methods to gather and analyse information. The main research methods used in this project consist of the collection of information through: (1) experiment; (2) direct observation; (3) survey; and (4) literature review. Both qualitative and quantitative data are analysed in this project.

The author was involved extensively in all aspects of the implementation of the R & W Pump study. Therefore, much of the data collected for this research project have been primary data. This includes all information that has been directly collected by the author, through observation and experiment. All of the work done towards the improvement of the prototype design of the R & W Pump, as well as most of the data from monitoring the reference R & W Pumps, are primary data.

Secondary data that have been used include the background information on the Ubombo Family Wells Programme (UFWP) and R & W Pumps, where the data was collected through literature review and interviews of participants in past projects. Secondary data have also been used from the monitoring of the reference R & W Pumps, when the author was unable to collect information personally. In this case, the author had to rely on other project participants to collect data. In addition, secondary data have been collected when the author has directly interviewed the users of the R & W Pumps during monitoring visits.

4.2 Constraints on the Fieldwork

There were several constraints on the research performed in the development of the R & W Pump for the UFWP. The main constraint was time. The relatively short period of time allowed for field research made it difficult to gather quality data relating to the social factors involved in the implementation of R & W Pumps. This was due to the majority of the research time being used to analyse the technical aspects of the implementation of the R & W Pump. While the existing social factors in Maputaland were heavily considered in carrying out the project, the research focused on the implementation of a technically sound pumping system. Nevertheless, observed social factors have been analysed where possible to evaluate the potential sustainability of the R & W Pump for the UFWP.

Monitoring of the R & W Pumps was performed on a regular basis after they were installed. However, there was a six-week period (mid-August to the end of September 2003) when the author was unable to perform any fieldwork. This break was due to a back injury. The four reference R & W Pumps which had been installed up to this point were monitored by the pump users and PID staff during this period. The installation of the remaining reference R & W pumps was delayed until October 2003. A project risk assessment, which was carried out prior to the start of the fieldwork, is included in Appendix A.

Another constraint on the research involved delays in the funding of the R & W Pump project. The delay in final contract documents between Partners in Development (PID) and the Council for Geoscience (CGS) led to delays in the ordering and delivery of materials for the R & W Pump research. This situation resulted in a smaller number of reference R & W Pumps (seven) being used in the research than originally planned. Nevertheless, these seven reference R & W Pumps have proven adequate for troubleshooting problems with the design of the R & W Pump, as well as for analysing pumping data. Two additional R & W Pumps, which were installed outside of the project area, have also provided some of the data contained in this study.

4.3 The Programme of Work

The programme of work was determined according to the project objectives. As the author was involved in most aspects of design, construction, and monitoring of the reference R & W Pumps, the majority of the time was spent performing these tasks. After significant monitoring of several of the reference R & W Pumps, various changes were made to the design. Such refinements continued throughout the project, until an adequate final design was accomplished. The basic programme of work for the entire project is broken down according to the specific objectives as follows.

4.3.1 Design and Construction of a R & W Pump for Use with Tubewells

The initial prototype R & W Pump for this project was constructed by the PID project co-workers Stephen Nash and Hector Ngubane. This pump was built at the beginning of the project (July 2003) and served as the first reference R & W Pump. The author was involved extensively in the design and construction of the remaining reference R & W Pumps used in this project. This activity involved several modifications to the first prototype design, as well as the analysis of materials used in pump construction, and development of efficient procedures for pump production. It also includes the original design of an effective hygienic cover for the R & W Pump.

4.3.2 Economic Feasibility of the R & W Pump for Tubewells

The economic feasibility of the R & W Pump for tubewells was determined considering the current cost of Bucket Pumps used in the UFWP. The cost of the R & W Pump was compared to that of the Bucket Pump, considering various options for materials to be used in the construction of the R & W Pump. Maintenance costs of the R & W Pump and Bucket Pump were compared. Improvements to the design of the R & W Pump to improve its economy were also considered. Production techniques were evaluated to minimise the cost of production of the R & W Pump as much as possible.

4.3.3 Determination of Effective, Locally Available Materials for Washers

Experiments were done with several different types of washer materials to determine their suitability for use on R & W Pumps. Rubber and plastic washers were tested on reference pumps at shallow, medium, and deep depths, in order to compare flow rates and energy required for pumping with the respective materials. These trials were carried out using multiple different spacings of the washers on the rope, and the results were analysed and are presented.

4.3.4 Efficiency of the R & W Pump

The efficiency of the R & W Pump was determined through the analysis of pumping trials carried out on both the R & W Pump and the Bucket Pump. These data have been analysed for shallow, medium, and deep tubewells, relative to the range of depths of tubewells drilled in the UFWP.

4.3.5 Determination of Water Quality

The microbiological quality of water in a sample of tubewells equipped with R & W Pumps has been analysed. These results are compared to the same testing done on a sample of tubewells equipped with Buckets Pumps. The bacteriological testing was done by a PID staff member, who is experienced in water quality testing. Recognized testing procedures were followed, as observed by the author.

4.3.6 Evaluation of Potential Sustainability

The evaluation of the potential sustainability of R & W Pumps used with tubewells in the UFWP was done, considering the following criteria:

1) Durability of the R & W Pump.
2) Ability of the users to maintain and repair the R & W Pump.
3) Willingness of the users to maintain and repair the R & W Pump.

These criteria are analysed based on the extensive fieldwork that was done by the author during this project, which included the training of pump users in installing and repairing the R & W Pump.

5 DESIGN AND CONSTRUCTION OF THE ROPE AND WASHER PUMP FOR TUBEWELLS

5.1 Introduction

The primary objective of this research project was to design and construct a Rope and Washer Pump (R & W Pump) for use with tubewells in Maputaland, South Africa. This chapter gives a presentation and analysis of the work programme carried out in designing and building an effective R & W Pump for the given situation. The other research objectives, which are directly related to the actual design and performance of the R & W Pump, are further analysed in Chapter 6 – Analysis of Final Rope and Washer Pump Design.

The analysis of the R & W Pump design is primarily based upon the monitoring of seven reference R & W Pumps that were installed in Maputaland between July and October 2003. These R & W Pumps are described in Table 5.1. A summary of the monitoring of each of the reference R & W Pumps is included in Appendix B.

Table 5.1 Reference Rope and Washer Pumps

#	Pump Name	Well Depth (metres)	Water Table Depth (metres)	Water Depth (metres)	Tubewell Characteristics
1	Garden Pump	8.5	5.0	3.5	-Sufficient recharge
2	Penelope Pump	23.4	22.1	1.3	-Slow recharge
3	Ncube Pump	7.5	6.1	1.4	-Sufficient recharge
4	Ikawu Pump	18.7	14.9	3.8	-Fine sand in water -Sufficient Recharge
5	Pateni Pump	24.1	19.1	5.0	-Slow recharge -Water milky colour
6	Thwala Pump	22.0	18.4	3.6	-Sufficient recharge
7	School Pump	15.4	13.1	2.3	-Slow recharge

The reference R & W pumps were monitored on a regular basis from installation until the end of the field research in mid-January 2004. In addition to the seven reference R & W Pumps, three other R & W Pumps were installed during the research period. It was not possible to monitor these pumps on a regular basis, as two of them were installed outside of the immediate project area, and the other one was installed near the end of the monitoring period. One of these pumps (Manguzi Pump) is located near the town of Manguzi in northern Maputaland, and another pump (Ponta D'Ouro Pump) is in Ponta D'Ouro, southern Mozambique. Qualitative data from these two pumps are analysed for determining potential sustainability of the R & W Pump for the Ubombo Family Wells Programme (UFWP). The third non-reference R & W pump (James Pump), which is located in Emphaketini in the immediate project area, was installed in December 2003.

The design of each of the main components of the R & W Pump, as introduced in Chapter 3, is detailed in its respective subsection. The initial design of each component is explained, with brief descriptions of the production materials and procedures when necessary. This is followed by the results of monitoring the performance of the specific pump component over a five-month period (mid-August 2003 to mid-January 2004) on the seven reference R & W Pumps. Modifications leading to the final design of the specific component are discussed, together with an analysis of the performance of the pump component. Conclusions are given, along with recommendations on what should be done to further improve the pump component and/or production process.

The design of the R & W Pump takes into consideration significant social and political factors. As mentioned in Chapter 2, one of the major difficulties in acceptance of tubewells equipped with Bucket Pumps was the notion that they are an 'inferior' water supply compared to piped water systems. Despite the success of the UFWP, not all local officials see tubewells equipped with Bucket Pumps as an adequate source of potable water (Still and Nash, 2002).

The prototype tubewell R & W Pump design used for this project was based on a Bombas de Mecate design published in *The Rope Pump: the challenge of popular technology* (Van Hermert et al., 1992). This design was initially altered to make better use of materials that are locally available in Maputaland. Significant changes were initially made to the design of the bottom guide and the pulley wheel supports. The first prototype was designed and constructed by project co-workers (Steve Nash and Hector Ngubane) at the beginning of July 2003. The monitoring and design changes to the prototype R & W Pump were carried out by the author, in consultation with project co-workers.

Figure 5.1 is a master diagram of the prototype R & W Pump for tubewells. This diagram shows all the main components of the R & W Pump, as installed on a tubewell. Labelling of the smaller parts of individual pump components is included in further diagrams throughout this chapter.

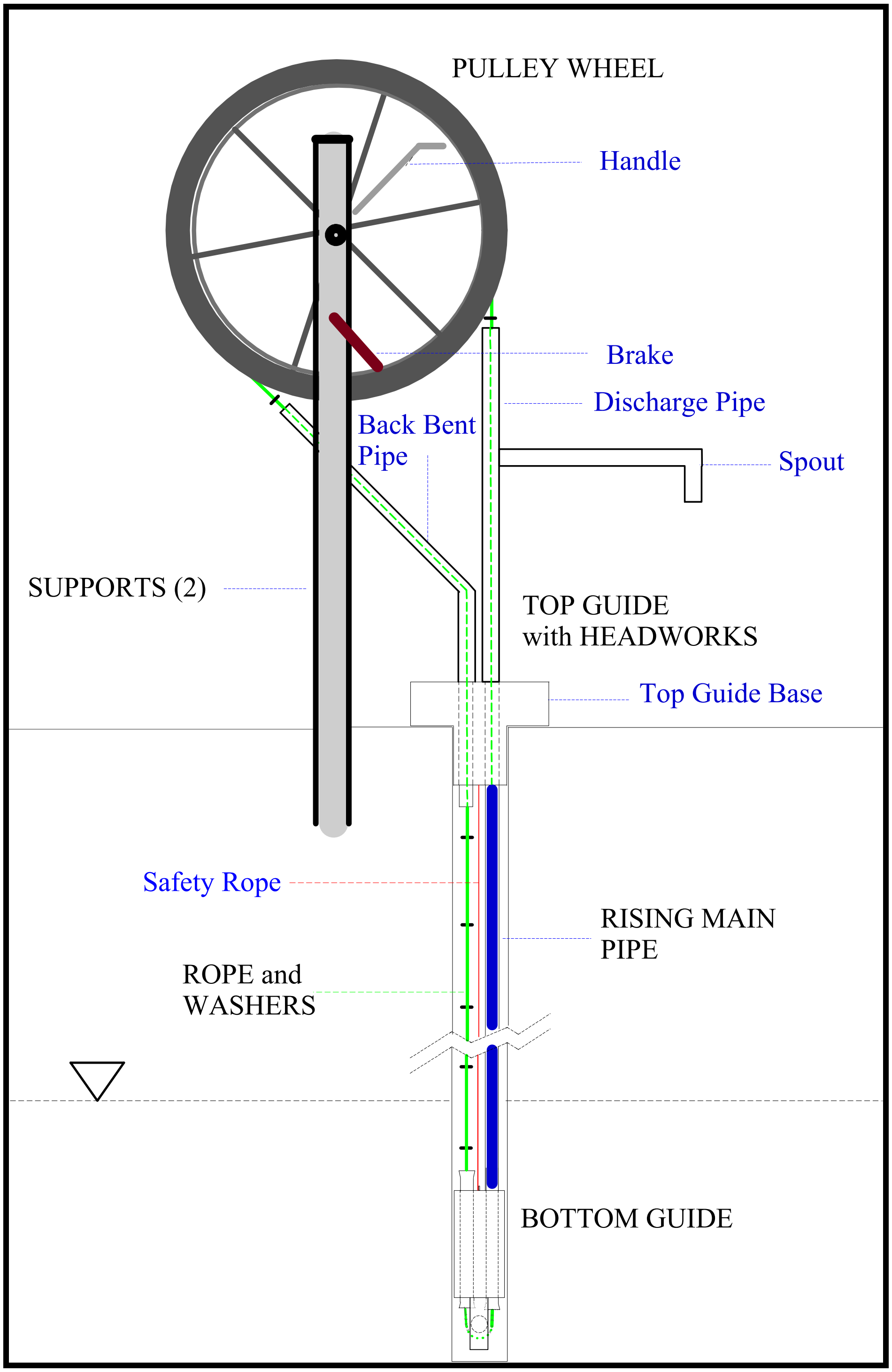

Figure 5. 1 Master Diagram of Prototype R &W Pump for Tubewells

The function of the R & W Pump is best described using Figure 5.1. The rope and washers run up through the rising main pipe, out through the discharge pipe of the top guide, and around the pulley wheel. From there, the back bent pipe guides the washers to the top guide base and into the tubewell. The rope and washers then descend to near the bottom of the well, below the water table. They enter the bottom guide, which acts to change their direction. They then enter the attached rising main pipe, thus forming a continuous loop. As the pulley wheel is turned, the rope and washers ascend the rising main pipe, with water entering through the bottom guide. Supported by the washers, the water is lifted through the rising main pipe and top guide base to the discharge pipe, from where it flows out through the spout.

5.2 <u>Design – Pulley Wheel and Supports</u>

5.2.1 <u>Initial Design</u>

The pulley wheel and supports consist of a wheel and handle supported by two gum tree poles, as shown in Figure 5.1 and Figure 5.2. The wheel is constructed from the sidewalls of a salvaged 20-inch (510-mm) diameter truck tyre, as described in Chapter 3. The rim of the wheel is fabricated from mild steel, which is welded together on a jig to maintain the circular shape of the wheel. The use of gum tree poles as supports for the pulley wheel was adapted from the UFWP Bucket Pump model, in order to make use of locally available materials. A braking system for the pulley wheel is attached to one of the poles, and acts as a safety mechanism to prevent people from being hit by the moving handle as the pulley wheel moves backwards. The brake makes contact with pegs that are welded perpendicular to the rim on the pulley wheel, which allows the wheel to move only in the direction of pumping. Figure 5.3 shows the pulley wheel braking system.

Figure 5. 2 Photo of reference R & W Pump in use (Garden Pump)

Figure 5. 3 Photo of pulley wheel braking system. Pegs (grey) on pulley wheel make contact with the brake (red).

5.2.2 Results of Monitoring Performance of Pulley Wheel and Supports

Five months of monitoring the reference R & W Pumps has shown the pulley wheel and supports to be very robust. While there were no problems concerning the overall strength of this system, monitoring revealed the following concerns with the pulley wheel and supports:

1) Slight wear on the gum tree poles, where the axle of the pulley wheel is inserted;
2) Non-use of the braking mechanism by the users during pump operation; and,
3) R & W Rope becoming caught between the two tyre rims of the pulley wheel, when pumping at an extremely fast rate.

5.2.3 Analysis and Modifications of Pulley Wheel and Supports

Wear on Gum Tree Poles

Slight wear on the gum tree poles of the reference R & W Pumps usually became evident within two months after pump installation. This wear occurs as the pulley wheel axle continuously rubs against the inside of the drilled holes of the poles, and was considerably greater on one of the deepest reference R & W Pumps (Thwala Pump). This wear is due to the weight of the large column of water being lifted by the pump. Wear was not a problem on two other deep pumps (Penelope and Pateni Pumps), which had low recharge rates, and thus had not been subjected to lifting a large volume of water.

The wear on the gum tree poles is not seen to be a significant problem. It is similar to the wear experienced on the supports of the Bucket Pump, and regular greasing of the holes should minimise it. Nevertheless, the wear on the poles should be monitored over a longer-term period, in order to determine if it is a significant problem. If so, then a non-corrosive metal sleeve should be inserted at each of these points.

Non-Use of Brake

The brake's function is to prevent the pulley wheel from turning in the direction opposite to the pumping direction, as the pulley wheel is released. This happens as the remaining water in the rising main pipe forces the washers downward in the opposite direction to the pumping direction. When in the operating position, the brake makes a loud sound as it hits each peg during pumping, which can be aggravating to the user. The majority of users of the reference R & W Pumps have found the use of the brake during pump operation to be annoying, and decided to disengage the brake during pumping, and then set it back to its working position as soon as pumping was completed (*i.e.* before the pulley wheel turns backwards).

The non-use of the brake during pumping is not seen to be a problem as long as the users are aware of its purpose. The users of the reference R & W Pumps realized this, and know that they should engage the brake when finished pumping.

Despite the general non-use of the brake during pumping, it should still be installed on all R & W Pump models. The users of the reference R & W Pumps engaged the brake when pumping was complete, and generally left it in place until the next time that pumping started. This method of using the brake is also common on projects in Nicaragua (Bombas de Mecate, 2003). In addition, a couple of owners of the reference R & W Pumps used padlocks to lock the brake to the spokes of the pulley wheel, in order to prevent others from using the pump.

Rope Catching in Pulley Wheel

During testing of the Ikawu reference R & W Pump, the rope (5-mm diameter polypropylene) became caught between the two tyre rims of the pulley wheel. This problem occurred during extreme pumping conditions, while the user was pumping as fast as possible (around 90 revs/minute). Upon inspection, it was determined that there was a small gap in between the tyre rims at a few places around its circumference. Smaller gaps were found on a couple of the other reference R & W Pump pulley wheels, which were not found to be a problem under normal pumping conditions (40-60 revs/minute). Nevertheless, to prevent the rope becoming stuck between the rims, a thin (20-30 mm) strip of rubber (which can be cut from an old tyre inner-tube) may be tied around the middle of the pulley wheel, at the joining of the tyre rims. This sufficiently covers the gap, with the rubber of the inner-tube providing a grip for the rope and washers similar to that of the tyre.

5.2.4 Conclusion on design of Pulley Wheel and Supports

It was determined that the overall design of the Pulley Wheel and Supports is of sufficient strength and quality. The wear on the gum tree poles, due to the pulley wheel axle, should be monitored on a longer-term basis to determine if this aspect of the design needs to be improved.

5.3 Design – Rope

5.3.1 Initial Design

All ropes that were used during this project were made of polypropylene, which has proven to be of sufficient strength in previous R & W Pump projects (Bombas de Mecate, 2003). The ropes that were tested on the reference R & W Pumps are: (1) 4-mm diameter twisted polypropylene rope; (2) 5-mm diameter braided polypropylene rope; and (3) 7-mm diameter braided polypropylene rope. Each of the rope types used is available locally in Maputaland.

The 4-mm diameter polypropylene rope was used on the Garden Pump, which was the first reference R & W Pump installed. The remaining reference R & W Pumps used either the 5-mm diameter polypropylene rope or the 7-mm diameter polypropylene rope.

5.3.2 Results of Monitoring of Rope Performance

The use of quality rope and washers has proven to be critical to the proper functioning of the R & W Pump. The most common problems with the ropes tested were the ropes either breaking, or detaching at the point where the rope ends were tied together to form the loop (loop connection). While this problem was often caused by malfunction of another pump component (*e.g.* washers or top guide), a few aspects are important to consider in order to ensure the proper functioning of the rope.

The monitoring of the different ropes used on the reference R & W Pumps throughout the project highlighted the following key areas:

1) Characteristics of washers used,
2) Connection of rope ends to make a loop,
3) Tightness of installed rope.

5.3.3 Analysis and Modifications of Ropes Tested

The 4-mm diameter polypropylene rope performed reasonably well on the Garden Pump, with the only problem being that the rope became detached at the loop connection. This occurred once during the first month of monitoring the Garden Pump. Once a stronger knot was tied, there were no more problems with this rope during the next six weeks. At that point (mid-September) the rope was changed to a 5-mm diameter polypropylene rope, to accommodate the testing of different washers on the Garden Pump.

While the strength of the 4-mm rope was sufficient to lift the 5 metre-long column of water (1.5 kg) from the Garden Pump tubewell, it was foreseen that a stronger rope would be needed to lift larger quantities of water from deeper tubewells. For this reason, the remaining six reference R & W Pumps have used either the 5-mm diameter or 7-mm diameter polypropylene ropes.

Washer Characteristics

The choice of which diameter rope to use (5-mm or 7-mm) was based primarily on the size of the hole in the washers to be used on the rope. Initially, a 5-mm diameter rope was used on the Ncube Pump, with tyre rubber washers attached. A problem was encountered with several of the washers slipping down over the knot tied below the respective washer. It was determined that this slippage was caused by the combination of two forces acting on the washers. The first force is a gravity force due to the weight of the column of water above the washer, which exerts a downward force on the washer as it is lifting the water through the rising main pipe. The second force, which works in concert with the first force, occurs during pumping and is due to the washer rubbing against the sides of the pipes or bottom guide. The combination of these forces leads to the rubber washer gradually being forced over the knot below it. The washer is then pushed down the rope, towards the next washer.

This problem was solved through the use of the 7-mm diameter polypropylene rope with tyre rubber washers. The larger diameter of the knots tied with the 7-mm diameter rope eliminated the possibility of slippage. It was possible to use the 5-mm diameter rope with a later version of the tyre rubber washers, which had a slightly smaller centre hole. The users of the Manguzi Pump experienced a similar problem, and effectively solved it themselves by tying rubber bands around each knot.

The nylon plastic washers have a centre hole of approximately 5 mm diameter, which allows the 5-mm diameter polypropylene rope to fit tightly through it. Larger diameter ropes cannot fit through this hole, and thus all pumps with nylon plastic washers used 5-mm diameter ropes.

Loop Connection

The majority of the problems with the rope on the reference R & W Pumps resulted in the rope detaching at the point where the rope ends were tied together to form a loop. When this problem occurs, one or both ends of the rope usually falls into the tubewell. It is then necessary to remove the pump (the rising main pipe with the top and bottom guides attached) from the tubewell. The rope is then fed through the rising main pipe and guides, and reattached after re-installing the pump in the tubewell. A hard steel wire (1-mm diameter) can be used to effectively feed the rope through the rising main pipe and guides. Before attaching the rope, its ends should be heated over an open flame in order to melt the individual rope fibres together, thus preventing fraying.

The 5-mm and 7-mm diameter polypropylene ropes used are commonly referred to as ski ropes. These ropes are braided, which allows a strong connection to be made by making a small loop at each end of the rope, and inserting the end of the rope back through the middle of its diameter. This connection, called a "self-splicing loop", is illustrated in Figure 5.4 (Alnet, 2003). When the rope is pulled, the weave of the rope tightens around the inserted end. As long as there is some tensile force on the rope, this connection is difficult to undo. Linking the loops made at either end of the rope allows for a strong connection. In the field, this method worked very well. The rope connection did come undone occasionally on a couple of the ropes, and this was notably a problem on the Penelope and School Pumps. For these two pumps, it was determined that the rubber tyre washers were becoming caught at the bottom or top guides, which caused the loop connection to loosen. In these cases, 2-mm diameter polypropylene rope was threaded through the weave of the rope where the ends were inserted to form the loop. This approach worked very well, eliminating the problem of the loop connection coming undone.

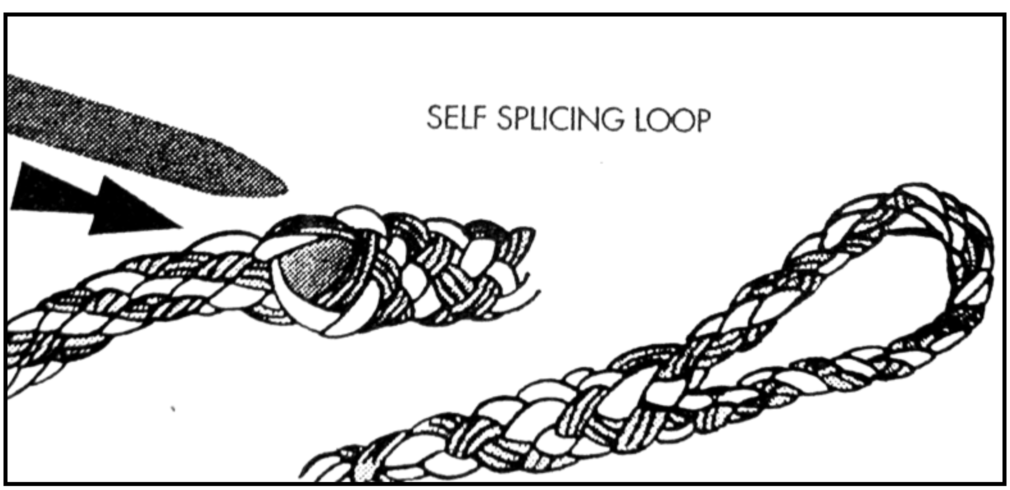

Figure 5. 4 Self-splicing loop for braided rope (Alnet, 2003)

Two locally available brands of 5-mm and 7-mm diameter polypropylene rope were used during this project, Alnet and Net King. The Net King ropes proved to be generally of higher quality, and had a tighter braid than the Alnet ropes, which made the loop connections stronger. There were problems with the loop connections of the Alnet ropes frequently coming undone, as well as the rope fraying easily. It is therefore recommended that Net King ropes, or equivalent quality ropes, be used on R & W Pumps in this project.

Rope Tightness

The rope should be installed on the R & W Pump such that it is tight enough to allow the rope and washers to adequately grip the tyre of the pulley wheel. The exact tightness of the rope depends on the characteristics of the washers, mainly the amount of friction they cause within the rising main pipe. Thus, an adequate tension in the rope can only be determined by trial and error. If the rope is too loose, it won't grip on the pulley wheel. There is also the risk that there will be slack in the loose rope at the bottom of the pump, which can cause it to become caught around the frame of the bottom guide.

The length of the rope always increases a small amount after initial use on the R & W Pump. This lengthening is due to the knots on each side of the washers tightening as the pump is used. Therefore, if the loops at the rope ends are to be threaded (*e.g.* with 2-mm rope), this threading should be done after initial pumping, when the knots at each side of the washers have already tightened. Instructions on the installation and initial start-up of the R & W Pump are included in Appendix C.

5.3.4 <u>Conclusion to Rope Performance</u>

The 5-mm and 7-mm diameter polypropylene ropes have both proven to be of sufficient strength for use on the R & W Pumps in the UFWP. Through extensive monitoring and troubleshooting of the reference R & W Pumps, adequate rope installation methods were determined. These installation methods result in the rope requiring little maintenance. The ropes still need to be monitored on a longer-term basis, in order to estimate their life expectancies. It is recommended that the locally available Net King brand of ropes, or equivalent quality ropes, be used on the R & W Pumps in the UFWP.

5.4 Design – Washers

5.4.1 Initial Design

Four different types of washers were tested on the reference R & W Pumps. Table 5.2 lists these washer types, as well as the process used in producing them and the availability of production materials.

Table 5.2 Washer Types Tested on R & W Pumps

Washer Type	Production Process	Availability of Materials
Tyre Rubber	-Punched out of old tyres or conveyor belts	-Salvaged tyres available locally in Maputaland -Salvaged conveyor belt material available in regional Capital
Rubber Washers	-Injection moulded- sold as standard tap washers	-Tap washers available in regional industrial town
Nylon Plastic	-Injection moulded	-Custom made for PID in provincial capital
Foam Plastic	-Punched from the soles of plastic sandals	-Cheap sandals sold in local shops in Maputaland

5.4.2 Results of Monitoring Washer Performance

The monitoring of the various types of washers on the reference R & W Pumps found the tyre rubber and nylon plastic washers to be the most feasible for use on the R & W Pumps.

An analysis of the pumping performance of the tyre rubber and nylon plastic washers is presented is Chapter 6.

5.4.3 Analysis of Washers Tested

Tyre Rubber Washers

The tyre rubber washers can be punched out of the side walls of old vehicle tyres, or alternatively from similar rubber used for conveyor belts. The conveyor belts have proven to be easier to work with than the tyres, as the belt is of a uniform thickness, whereas the thickness of the sidewalls of the tyres varies with radial distance. Various thickness of tyre rubber material were evaluated on the reference R & W Pumps, ranging from 5mm to 10mm. It was found that a thickness of 5-7mm is ideal for use on the R & W Pumps for this project. Locally produced washers of greater thickness proved to have more irregularities, due to the difficulty in penetrating the material with the punching tool. This irregularity led to the thick washers causing more friction within the rising main pipe, which made pumping more difficult on the shallow wells, and not possible at all on the deep wells (Thwala and Pateni Pumps).

Nylon Plastic Washers

The nylon plastic washers are of an engineered design and were custom-made for the project (produced in the provincial capital). The design of these washers was based on a Bombas de Mecate design. Figure 5.5 shows a diagram of the engineered washer design. This design was developed to minimise the friction within the rising main pipe of the pump, which thus allows for water to be pumped from greater depths (Bombas de Mecate, 2003). The nylon plastic washers are produced with an injection-moulding machine. There is currently no capacity to produce these washers in Maputaland. However, it is possible that an injection-moulding machine will be bought by the project in the future.

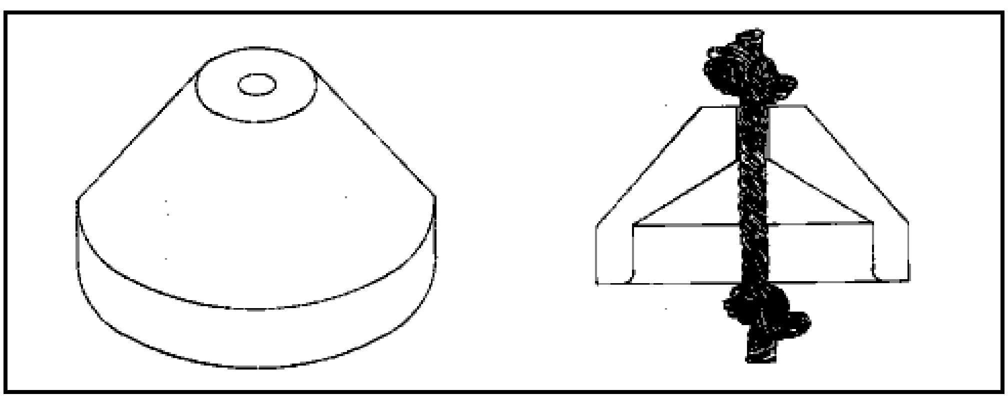

Figure 5. 5 Diagram of engineered washer design [isometric and cross-sectional views] (Bombas de Mecate, 2003)

Overall, the nylon plastic washers performed well on the reference R & W Pumps. However, the occurrence of sand in the water of a few of the reference R & W

Pump tubewells caused these washers to become jammed in the rising main pipe. If pumping was continued, small fragments of the uPVC rising main pipe were shaved off and entered the water. Therefore, it was determined that it is not feasible to use nylon plastic washers in tubewells where there is a presence of sand. As most newly installed tubewells initially contain a significant presence of sand, nylon plastic washers cannot be used until this sand is flushed out of the tubewell.

There are a couple of possible solutions to the problem with washers jamming in the rising main pipe. The first solution would be to slightly decrease the diameter of the washers (by 0.5-1.0 mm) so that the fine grains of sand will have space to move between the washers and the pipe. Although this decrease in washer size should stop the jamming and wearing of the pipe, it will also decrease the efficiency of the nylon plastic washers. This would most likely negate any advantage of this type of washer over tyre rubber washers, and is therefore not recommended. A second, more feasible way of solving this problem is to make the injection-moulded washers out of a softer material, such as a hard rubber. While retaining the engineered design of the washer, this alternative should allow the washers to compress a small amount within the rising main pipe, and thus the presence of sand would not cause jamming or wearing on the pipe. This is what currently happens with the tyre rubber washers when there is the presence of sand, and no problems have occurred with these washers.

Rubber Tap Washers

Tap washers proved to be slightly too small in diameter (19mm) to efficiently pump water through the rising main pipe, (20mm internal diameter). It is still possible to pump water with these washers spaced at one-metre intervals along the rope. However, the pumping must be done at a very fast rate, which takes too much energy. The thickness of the tap washers (4mm) also proved to be too small, and this could lead to problems with durability of the washers over a long time period. As it is only feasible to buy the tap washers at the standard sizes that are sold regionally (i.e. 19mm, 25mm diameters), it was decided that they should not be used on any of the R & W Pumps in this project.

Foam Plastic Washers

The foam plastic washers were cut from cheap sandals that are available locally in Maputaland. These washers proved to be unacceptable for use on the R & W Pumps. The foam plastic washers, when placed on a rope at one-metre intervals, proved to initially pump water at an efficient rate from a deep reference R & W Pump (Thwala Pump). However, it shortly became evident that the washers were not of sufficient strength. Within a few days of usage (pumping 400-500 litres/day), several of the washers had torn from the rope. In addition, several other washers had torn slightly around the centre hole, causing them to move downwards on the rope. The foam plastic washers were used on the Thwala well for a period of seven days, at which point only half of the washers remained on the rope. It was thus determined that these washers have insufficient strength to handle the various forces exerted upon them during normal pumping. This is similar to experience using foam plastic washers on R & W Pumps in Cameroon, where it was determined that this type of washer was not durable enough for use on R & W Pumps (Eyestone, 2003).

5.4.4 Conclusion on Washer Performance

Through five months of monitoring the various types of washers on the reference R & W Pumps, it was determined that washers made from tyre rubber (or a similar material) are very effective for use on the R & W Pump. These washers can be produced locally in Maputaland, and are thus readily available. Engineered plastic washers, made by an injection-moulding process, have also proven to work well on the reference R & W Pumps, in the absence of sand in the water being pumped. However, these washers are currently not available locally in Maputaland. An analysis with further conclusions for washer selection is presented in Chapter 6, based on the quantitative data collected for the tyre rubber and nylon plastic (injection-moulded) washers.

5.5 Design – Rising Main Pipe

5.5.1 Initial Design

A 25-mm diameter uPVC pipe was used for the rising main pipe of each of the reference R & W Pumps. The selection of this pipe, which has an internal diameter of 20mm, was based on previous research. Bombas de Mecate (2003) recommend that the weight of the column of water within the pipe not exceed 10 kg, as weights in excess of this amount are very difficult to pump. The weight of the column of water in a full rising main pipe is calculated with the formula:

$$W = \pi \ x \ (d^2/4) \ x \ h \ x \ \rho_{H20}$$

Where: W = weight of the water column

d = inside diameter of the pipe

h = height of the pipe

π = constant = 3.14

ρ_{H20} = density of water = 1000 g/l

This design formula leads to a calculated maximum water column height of 32 metres for the 25-mm diameter uPVC pipe. As none of the tubewells in the UFWP exceed water table depths of 25 metres, this size pipe should work well for all of the R & W Pumps to be installed for this project. Table 5.3 shows the weight of water columns for various pipes at depths common to tubewells in the UFWP.

Table 5.3 Water Column Weights For Pipes at Various Depths

External Pipe Diameter (mm)	Internal Pipe Diameter (mm)	Water Column Height (metres)	Water Column Weight (kilograms)
25-mm uPVC, Class 16	20	10	3.1
		15	4.7
		20	6.3
		25	7.9
		30	9.4
32-mm uPVC, Class 16	28	5	3.1
		10	6.2
		15	9.2
		20	12.3*
40 mm uPVC, Class 16	34	5	4.5
		10	9.1
		12	10.9*
		15	13.6*
*Denotes column weights which exceed recommended maximum values			

5.5.2 Results of Monitoring Rising Main Pipes

There were no problems with the water column weights being too great for pumping. The only problem that was directly related to the rising main pipe (*i.e.* not caused by washers in the pipe) was the pipes becoming unglued at the couplings.

5.5.3 Analysis and Modifications to Rising Main Pipe Design

Glue at Couplings

Problems with the PVC glue used on the rising main pipes occurred with two of the reference R & W Pumps (Thwala Pump and School Pump). For the School Pump, this problem was attributed to the use of PVC glue that had already started to set within its container. For the Thwala Pump, it was determined that sufficient time had not been allowed for the glue to dry prior to installation of the rising main pipe in the tubewell. These problems illustrate the need for much attention to be paid to the construction and installation of the rising main pipe.

Each of the reference R & W Pumps was equipped with a 4-mm diameter polypropylene safety rope (Figure 5.1). This rope runs from the bottom guide to the top guide and prevents the bottom guide and piping from becoming stuck at the bottom of the tubewell if the rising main pipe becomes disconnected. This has proven to be an important part of the pump design, as retrieving the guide and piping from the tubewell would otherwise prove to be very difficult.

5.5.4 Conclusion to Rising Main Pipe Design

The 25-mm diameter uPVC pipes have proven to work well on the reference R & W Pumps. The rising main pipes of these pumps should continue to be monitored for problems with the glue at the coupling connections. A fast-dry PVC glue should be used, with sufficient time allowed for the glue to dry prior to the pump being installed in the tubewell. It is important that only quality glue is used, which has not deteriorated over time. It is imperative that the glue be properly applied to the couplings and/or pipe, in order to minimise the chance of the rising main pipes become disconnected. If the manufacturer's instructions are followed for the application and storage of the glue, the glued joints should be of sufficient strength. It is recommended that a safety rope be attached from the bottom guide to the top guide, to prevent the loss of piping and the bottom guide in the tubewell should the rising main pipe become disconnected.

5.6 <u>Design – Top Guide</u>

5.6.1 <u>Initial Design</u>

The top guide is made up of a base and above-ground pipes, as shown in Figure 5.1. A diagram of the prototype top guide base is shown in Figure 5.6. The base consists of two short lengths (250-300 mm) of uPVC pipes, embedded in concrete. The first prototypes used 25-mm diameter uPVC pipes on both the front and back sides of the top guide base. The lower end of the front base pipe attaches to the top of the rising main pipe with a coupling. The top of the front base pipe is then connected to the discharge pipe and spout.

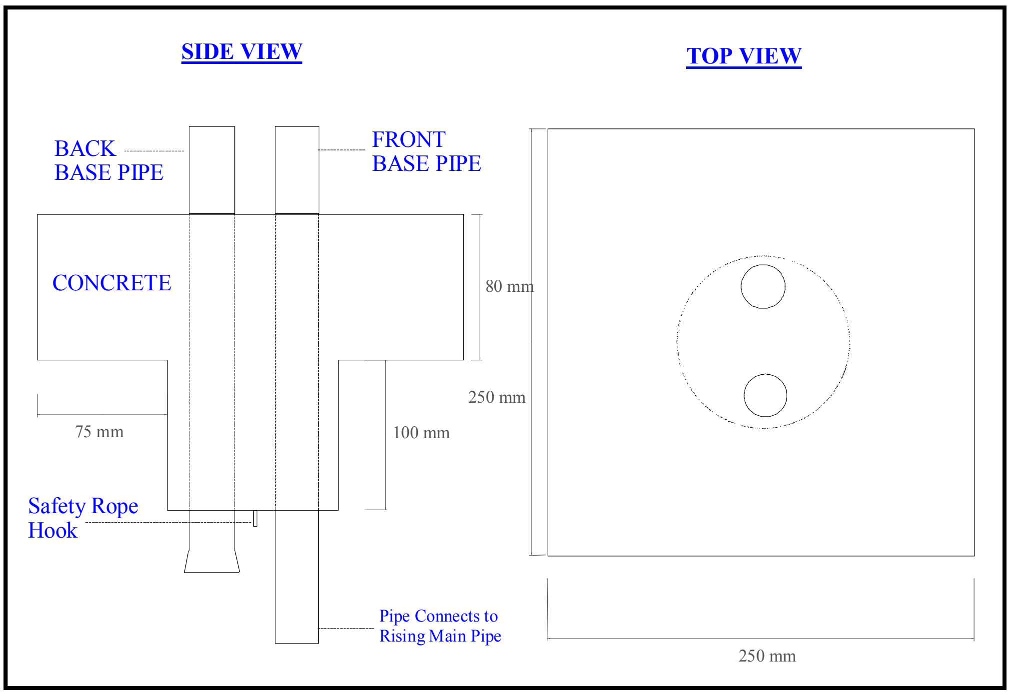

Figure 5. 6 Diagram of prototype Top Guide base

The back base pipe helps guide the rope back into the tubewell, to where it descends to the bottom guide. The lower end of the back base pipe is flared out, to prevent the washers from catching on it when the rope is moved in the direction opposite to the pumping direction. The top end of the back base pipe is connected to the bent back pipe (Figure 5.1), which extends to near the back of the pulley wheel. Figure 5.7 shows a photo of a prototype top guide base.

Figure 5. 7 Photo of prototype Top Guide base (side view)

The concrete base of the top guide is cast within a mould. The bottom part of the mould consists of a 125-mm diameter uPVC pipe, so that the formed cylindrical section can later fit into the top of the 125-mm diameter tubewell pipe. The top part of the mould is square, such that the bottom of the square base of the guide will rest on the concrete apron surrounding the tubewell.

The discharge pipes and the bent back pipe are made of 32-mm diameter uPVC pipe. These above-ground pipes are slightly larger in diameter than the rising main pipe. For the discharge pipe and spout, this helps the water to flow from the spout without overflowing out the top of the discharge pipe. The larger diameter of the bent back pipe allows the rope and washers to be easily guided into it and move through it.

In order to create a bent back pipe, a section of pipe is filled with sand and slowly heated over a flame. When sufficiently hot, the pipe can be bent to the appropriate angle for use on the top guide. The sand within the pipe helps to keep an adequate diameter at the point where the pipe is bent. In practice, this method was not very effective. It proved difficult to obtain a sufficient bend in the pipe while maintaining an adequate cross-section at the point of bend. If the cross-section is not large enough, washers will become stuck at the bend. During installation of the reference R & W Pumps, it often took multiple attempts of heating the pipe to achieve a bend with a suitable cross-section.

An alternative method of bending the pipe is to use a spring built for this purpose, which fits tightly inside the pipe. The pipe can then be bent manually, without adding heat. In order to bend the pipe, the section to be bent should be set upon the corner of a sturdy object, and then a force exerted on both sides of this section. This method proved to work very well in the field, with the spring helping to maintain a sufficient cross-section around the bend of the pipe.

5.6.2 Results of Monitoring Top Guide

The results of monitoring the reference R & W Pumps proved the top guide design to be adequate in the function of the pumps. However, there were several ways in which the design and production of the top guide were improved.

5.6.3 Analysis and Modifications of Top Guide Design

The following items were changed in the design and production of the prototype top guide:

1) Use of a larger pipe (32-mm diameter) on the back side of the top guide base
2) Use of embedded couplings to connect the base pipes to the above ground pipes
3) Change in the mould design for the top guide
4) Use of galvanised steel piping for the discharge pipe and spout

Use of Larger Pipe on Back Side of Base

During the first month of monitoring the reference R & W Pumps, it became evident that some of the rubber washers would occasionally become caught at the reducing coupling as they entered the 25-mm diameter pipe on the back side of the top guide base. This usually caused the rope to jump slightly during pumping, which was not considered to be a problem. However, occasionally a washer would remain stuck at this point, and the pulley wheel would have to be turned in the opposite direction (¼ to ½ a revolution) before pumping was continued. This obstruction interfered with the continuous pumping motion, as well as the flow rate of the pump.

The purpose of the back pipe is simply to guide the rope and washers through the base of the top guide and into the tubewell. Therefore, a larger pipe can be used on the back side of the top guide base. It was decided to use a 32-mm diameter uPVC pipe for this purpose, so that it had the same diameter as the bent back pipe that connects to it. This proved to work well, as the constant pipe size throughout the back side of the top guide eliminated the chance of washers becoming caught at this point.

Embedding of Couplings in Concrete

Couplings are used to connect the top guide base pipes to the above-ground pipes. The initial prototype top guides used base pipes that extended 10-50 mm above the top of the concrete. At that point, couplings connected the pipes to the above-ground pipes. It was decided to change this design so that the couplings would be attached to the base pipes prior to setting them in the concrete, with the top of the couplings being flush with the top of the concrete. This design change is primarily for aesthetic purposes, as the embedded couplings help make the top guide more professional looking compared to the earlier prototypes.

Change in Mould Design

The design of the mould used to make the top guides was changed in order to make the removal of the mould easier. The original mould used a single piece of 125mm diameter uPVC piping for its bottom section. This mould proved to be difficult to remove from the top guide base after the concrete had cured. In addition, the concrete cylinder that it formed was a very tight fit into the top of the tubewell.

It was thus decided to cut the uPVC pipe in half across its circular plane. A small section (30mm) was cut from the length of each of these halves, in order to slightly decrease the diameter of the pipe. The two halves were then taped together. This mould worked fairly well on three prototype top guides. The reduction in pipe diameter allowed the bottom of the top guide bases to fit more easily into the top of the tubewell, and by removing the tape after the concrete had cured, the mould was much easier to remove, and could be used again.

While the improved mould design proved adequate in the construction of the top guide base, the process of constructing the base still took too long, due to time spend preparing the mould (taping, etc.). It is believed that a more effective mould can be made from steel piping of the required size, and result in a more efficient production process. The pipe should be cut in two or three equal sections across its circular plane, and held together using a steel band. The inside of the pipe should be greased before use, to allow easy removal of the mould from the concrete.

Galvanised Steel Piping

The above-ground uPVC pipes used for the top guide have performed well throughout the monitoring of the reference R & W Pumps. However, it was recognised that over the long-term, it would be better to use stronger pipes for the discharge pipe and spout. The use of sturdy pipes is also likely to make the R & W Pump more acceptable to local officials and donors (Nash, 2004). Therefore, two of the reference R & W Pumps (Thwala Pump and School Pump) were equipped with galvanised steel piping for the discharge pipe and spout. 32-mm internal diameter galvanised steel pipes were used. uPVC piping was used for the bent back pipe, as it would prove difficult to find either a galvanised steel pipe with the necessary bend or the proper angled bent coupling (elbow) to combine with two pipes.

5.6.4 Conclusion to Top Guide Design

The final design of the top guide worked well and has proven to be robust. The only remaining concern is with the production of the top guide. Despite the improved design of the top guide mould, production of this component is still more complicated and time consuming than it should be. It is recommended that a new steel mould be designed for the bottom, cylindrical section of the top guide base.

5.7 Design – Bottom Guide

5.7.1 Initial Design

The bottom guide design, shown in Figure 5.8, consists of a polished stainless steel tube (32-mm external diameter) welded to a stainless steel frame. This frame is aligned with two 300mm lengths of 25-mm diameter uPVC piping, so that the uPVC pipes lie perpendicular to the stainless steel tube, on either side of the frame. The pipes and the top of the frame are embedded in concrete, as shown in Figures 5.8 and 5.9 The uPVC pipes are flared at the pipe entry and exit points, to allow the rope and washers to enter and exit the pipes without becoming caught.

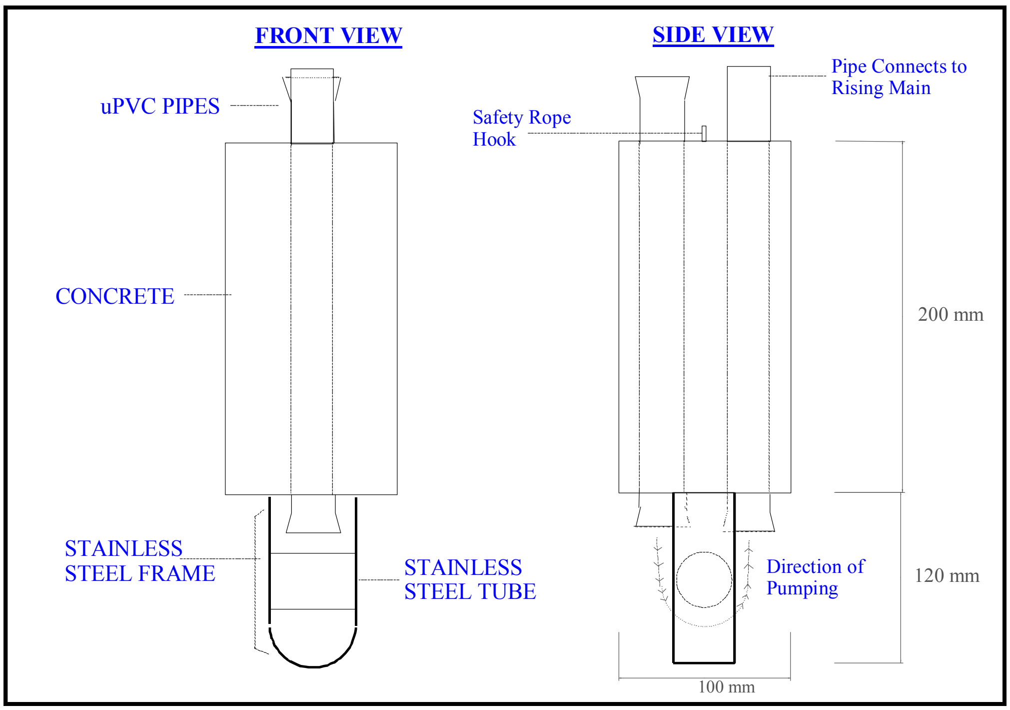

Figure 5. 8 Diagram of Bottom Guide

The use of a stainless steel guide is apparently unique to the UFWP, as no documentation was found on the use of this material in previous R & W Pump projects. The bottom guide is cast in concrete within a cylindrical mould made of 110-mm diameter uPVC pipe. This size of mould, which is later removed, allows for the guide to easily fit through the 125-mm diameter tubewell lining.

Figure 5. 9 Photo of prototype Bottom Guide (rear view)

5.7.2 Results of Monitoring Bottom Guide

Extensive monitoring of the reference R & W Pumps showed the stainless steel tube to be a very effective material for the bottom guide. There were no problems with the polypropylene rope or plastic/rubber washers moving on the stainless steel.

The following factors have proven to be important to the design and construction of the bottom guide:

1) Spacing and alignment of pipes and tube;
2) Flaring of pipe ends;
3) Use of larger pipe on downward side of guide; and,
4) Quality of concrete.

5.7.3 Analysis and Modifications of Bottom Guide Design

Spacing and Alignment of Pipes and Tube

The spacing between the uPVC pipes and the stainless steel tube of the bottom guide is important to the function of the R & W Pump. The stainless steel tube must be set perpendicular to the uPVC pipes, at a sufficient distance (10-20mm) such that the washers are completely out of the pipes when touching the tube. The uPVC pipes must be set such that the rope and washers can move adequately around the stainless steel tube. Proper alignment is important to ensure that the rope and washers do not become caught on the side of the stainless steel frame.

Flaring of Pipe Ends

The flaring of pipe ends at any point where the rope and washers enter the pipe is critical to the function of the pump. Without such flaring, the washers would become caught on the pipe end, thus causing the pump to jam. As the rope and washers also sometimes move in the direction opposite to the pumping direction, all points where the rope and washers enter or exit the pipes should be flared. Flaring of the pipes can best be achieved by slowly heating the end of the pipe over a flame, then inserting a flaring tool (a bottle end can often be used) into the pipe, causing the end to expand.

Use of Larger Pipe on Downward Side of Guide

The prototype design of the bottom guide used 25-mm diameter uPVC pipe on both the down-flow and up-flow sides of the guide. Monitoring of the reference R & W Pumps showed that the washers had a tendency to become caught where they entered the pipe. Adequate flaring of the pipe ends, where the rope and washers enter or exit the pipe, has proven to greatly reduce the chance of this happening. Nevertheless, it was found that the use of a slightly larger diameter pipe (32-mm diameter) on the down-flow side of the bottom guide additionally reduces the chance of the rope and washers becoming caught upon entry into the pipe. This improvement to the design was used on the bottom guides of two reference R & W Pumps (Thwala Pump and Ikawu Pump), with no observed problems over a period of two months.

Quality of Concrete

The quality of the concrete used in the construction of the initial prototype bottom guides proved to be inadequate, in some cases. Often, the concrete would not cure properly between the pipes and the mould. This caused small pieces of the concrete to break off at these points prior to, or during, the installation of the

R & W Pump. This problem was attributed to two main factors: (1) an inconsistent, weak concrete mix, combined with inadequate mixing of the concrete; and (2) the use of stones that were too large to be compacted properly between the guide mould, pipes, and frame, as the concrete was placed.

The final design of the bottom guide uses a strong concrete mix (1 part cement: 2 parts sand: 2 parts ½ inch crushed rock). When this mix was used for five bottom guides, none of the previous problems were encountered. The use of small stones (½ inch nominal size, crushed) allows for the satisfactory placement of the concrete within the mould, between all of the guide parts. It is recommended that the concrete be allowed to cure for a minimum of seven days prior to removing the mould. If properly cured, the concrete should have reached approximately 75% of its design strength by this time (ACI, 1998).

5.7.4 Conclusion to Bottom Guide Design

The final design of the bottom guide was very effective on the reference R & W Pumps. It is important that the bottom guide is built to specification, under strict quality control. As this guide will rest near the bottom of the tubewell, it is not visible during pump operation, and thus it is often difficult for users to diagnose the cause of any malfunction of the component.

5.8 Design – Hygienic Cover

It was necessary to design a hygienic cover for the R & W Pump for tubewells, to prevent contamination of the pump and the water. Such a cover must protect the rope and washers from direct exposure (to dirt, hands, sun, etc.) and be:

1) constructed of locally available materials;
2) economically feasible, in line with the costs of the designed R & W Pump as a whole;
3) easily attached to the pulley wheel supports, as well as detachable for pump maintenance; and,
4) resistant to the elements (rain and wind).

After attempting various designs, a new, simple cover was designed and built by the author, which meets all of the above conditions.

5.8.1 Design of Maputaland Hygienic Cover

The Maputaland Hygienic Cover design uses materials that are readily available in the local area. As shown in Figure 5.10, the cover frame consists of: (1) two loops made from 25-mm diameter polyethylene pipe, (2) two mild steel supporting rods, which are attached to, and separate, the polyethylene pipes; and (3) a mild steel supporting bracket, which connects the pipes to the top of the windlass poles. This frame is attached to the poles of the R & W Pump pulley wheel supports using nails and rubber washers. The polyethylene pipes are bent around the top of the poles. With the assistance of the supporting bracket, these pipes naturally bend to an excellent circular shape, which sufficiently covers the pulley wheel.

Figure 5. 10 Photo of Maputaland Hygienic Cover frame installed on R & W Pump (Thwala Pump)

Figure 5. 11 Photo of Maputaland Hygienic Cover with new hand-made Zulu mat (Thwala Pump)

The frame of the hygienic cover can be effectively covered with a straw mat (Figure 5.11), which is a common Zulu craftwork in Maputaland. These mats can be bought at most village markets in the area, and are very reasonably priced. A mat large enough to make two covers can be bought for R10-R20, depending on the artwork. The mat can be secured to the polyethylene pipes (which have holes punched in them) at various points with cotton twine. A waterproof nylon cover was initially used in place of the straw mat, but this proved to seriously detract from the appearance of the pump.

5.8.2 Results of Monitoring of Hygienic Cover

The design of the Maputaland Hygienic Cover was a late development in the research project. Therefore, the current design has only been tested on one pump so far. This cover was monitored for one month, with few problems. Since the cover is relatively simple, no further problems are anticipated.

The tested hygienic cover was subjected to weather conditions (which included some high winds and heavy rains) and normal pump usage for a period of one month. In addition, the straw mat was directly doused with five litres of water on a daily basis for two weeks. This dousing was performed to determine the effect of large amounts of rain on the top of the cover. While the appearance of the cover did change significantly over the month, the straw material only slightly deteriorated. This minor deterioration of the mat was determined to be due to excessive exposure to water. It is estimated that an untreated mat would have to be changed once a year. It is possible to coat the straw mat with either a sealant or paint to prevent it from deteriorating.

The Maputaland Hygienic Cover proved to be effective in protecting the rope and washers. The back side of the cover frame was removed several times, to simulate maintenance on the rope and washers, and proved to be simple to attach and detach.

5.8.3 Conclusion to Hygienic Cover Design

The Maputaland Hygienic Cover sufficiently protects the rope and washers from direct exposure. This cover can be constructed at a low price, using materials that are available locally. The cover is easily attached to the R & W Pump pulley wheel supports, and can be detached simply. Initial monitoring showed the cover to be sufficiently resistant to the wind. It appears that rain has a slowly deteriorative effect on the straw mat cover. Coating the straw mat with either a sealant or paint can negate this deterioration. Alternatively, the mat may have to be occasionally replaced.

5.9 Conclusion

The development of the R & W Pump for use with tubewells in Maputaland has led to a final project R & W Pump design that is believed to be acceptable for the remaining pumps to be built and installed for the UFWP. This design is robust and requires minimal routine maintenance. Figure 5.12 shows the final design of the R & W Pump for tubewells in use.

Figure 5.12 Photo of final project design of the R & W Pump in use (Thwala Pump)

It is expected that there will be minor changes to the R & W Pump design as the UFWP programme continues. These changes could be due to several factors, which include: (1) Observations made during longer term monitoring of the R & W Pumps within the UFWP; (2) Changes in the availability of local materials; and (3) Improvements to the moulds used in the construction of the pump components.

It is recommended that pump specifications and tolerances be recorded in writing and agreed between the pump builder and PID. Such a protocol would help to ensure the quality and consistency of the pumps being built, and would minimise the chance of inadequate components being installed on the R & W Pumps. Moulds or jigs should be used in the production of each component of the R & W Pump. This is important to consistency, particularly since it is likely that several different assistants will be building the pump components at different times. Strict quality control is needed, particularly for the production of the bottom guide.

6 ANALYSIS OF FINAL ROPE AND WASHER PUMP DESIGN

6.1 Introduction

This chapter provides an analysis of the final design of the R & W Pump for tubewells from various perspectives. Each of the subheadings in this chapter corresponds to a specific research objective, as introduced in Chapter 1. The aims of the research associated with each objective are explained, followed by a summary of the work programme carried out by the author in achieving that objective. This summary is followed by a presentation and analysis of the results obtained, and conclusions are stated.

6.2 Economic Feasibility

6.2.1 Introduction

In the development of the R & W Pump for tubewells in Maputaland, the cost of the designed pump was an important consideration in ensuring that the pump could be successfully integrated into the Ubombo Family Wells Programme (UFWP). Partners in Development (PID), the agency charged with implementation of the UFWP, had determined that the cost of the designed R & W Pump must not significantly exceed the current price of the UFWP Bucket Pump model presently used by the programme. The design and production process took this into consideration in the selection of materials used in the production of the R & W Pump. Nevertheless, the primary objective remained the development of a durable and functional pump. Production processes were also analysed to help minimise the cost of producing the R & W Pump.

The research performed on this project led to the development of an effective, technically sound final design for the R & W Pump for tubewells, as described in Chapter 5. Pumps of this design can be produced locally in Maputaland, for a price slightly greater than that of the Bucket Pump.

6.2.2 Programme of Work to determine Economic Feasibility

The process of evaluating the economic feasibility of the R & W Pump started with an analysis of the initial design and construction of the prototype R & W Pumps. An analysis of the material and production costs led to the evaluation of the procedures used in production of the pump components.

The improvements to the design of the R & W Pump throughout the research project led to a small increase in the cost of pump materials. This increase was primarily due to the use of galvanised steel piping for the discharge pipe and spout, as well as the addition of the Maputaland Hygienic Cover to the pump design. These design improvements are important to the pump design and justify the costs involved. Costs of other improvements to the pump design throughout the research were negligible.

6.2.3 Presentation and Analysis of Economic Data

The production cost for R & W Pumps of the final design was approximately R990 per pump. This price includes the cost of all the materials used and the construction price of the main components, but excludes the installation cost. Table 6.1 summarises the costs of each component of the R & W Pump. A complete pricing list of all materials used in the production of the R & W Pump is included in Appendix D.

Table 6.1 Cost Summary – R & W Pump for Tubewells (18 metre depth)

R & W Pump Component	Price of Materials (R)	Construction Price (R)	Total Price (R)
Pulley Wheel and Supports (including concrete apron)	255	125	380
Rope (7-mm diameter)	45	-	45
Rubber Tyre Washers (40)	10	30	40
Rising Main Pipe	125	-	125
Top Guide with Galvanised Steel Discharge Pipe & Spout	125	75	200
Bottom Guide	30	100	130
Maputaland Hygienic Cover	30	10	40
Transport of Materials	30	-	30
TOTAL PRICE	**650**	**340**	**990**

The cost of the installation of the R & W Pump is not included in the calculated final price in Table 6.1, because it is expected to remain the same as that for the Bucket Pump (approximately R300/pump). The UFWP drilling teams perform the installation with the assistance of the owner (or owner's representative) of the R & W Pump and tubewell. The owner is responsible for attaching the washers to the rope, as well as assisting in the entire pump installation.

The calculated price of the R & W Pump is based on a pump depth of 18 metres. This is estimated to be the median depth of the pumps to be installed for the UFWP. The costs of the rising main pipe and rope and washers are dependent upon depth, and thus their costs will be variable. The rising main pipe costs about R5 per metre, and the rope R1 per metre.

Table 6.2 Cost Summary – Bucket Pump for Tubewells (PID, 2003)

Bucket Pump Component	Price of Component (R)
Windlass and Supports (including concrete apron)	385
Rope (10-mm diameter)	45
Galvanised Steel Bucket	250
Galvanised Steel Pipe Cover	195
Transport of Materials	30
TOTAL	**905**

The production cost of the R & W Pump is about 10% greater than the production price of the Bucket Pump as seen by comparing the data in Tables 6.1 and 6.2. The slightly higher price of the R & W Pump is acceptable to the UFWP (Nash, 2004). However, if it was necessary to decrease the cost of the pump, there are a couple of simple options:

(1) The use of 32-mm diameter uPVC piping and connections for the discharge pipe and spout would decrease the cost of the R & W Pump by about R70. While it is recommended that galvanised steel piping be used for these pipes for durability purposes, uPVC piping has proved to be adequate for R & W Pumps in this project.

(2) Elimination of the Maputaland Hygienic Cover from the R & W Pump would decrease the price by R40. The hygienic cover is not necessary for proper functioning of the R & W Pump, but its use is recommended for protection of the rope and washers.

Any other significant changes in the materials used in the production of the R & W Pump need to be thoroughly analysed, as the quality of the materials used is important to the strength and durability of the pump. It is anticipated that future improvements to the production processes of the R & W Pump in Maputaland could lead to decreased material and/or production costs. However, as the R & W Pump is currently produced by a local contractor, it is expected that any savings due to improvements in the production process would accrue to the benefit of the contractor.

The use of nylon plastic washers will also increase the cost of the R & W Pump. These washers, which must currently be ordered from the provincial capital, cost R5.50/washer (R4.50/washer more expensive than tyre rubber washers). For economic reasons, it is recommended that these plastic washers only be used if they can be bought at a lower price. Even at a less expensive price, the performance of the nylon plastic washers must still be considered (*e.g.* when there is a presence of sand).

Maintenance costs of the R & W Pump can be expected to average about R110/year for a family pump, as shown in Table 6.3. This estimate assumes replacement of the rope once a year, replacement of the tyre rubber washers once every two years, and replacement of the rising main pipe once every four years. It also assumes that grease is regularly added to the bearing points of the pulley wheel axle, and that the straw mat of the hygienic cover is replaced once a year. It can be expected that the maintenance costs of community R & W Pumps will be greater, in line with increased pump usage.

Table 6.3 Estimated Yearly Maintenance Costs – R & W Pump

R&W Pump Component	Estimated Annual Maintenance Price (R)
Rope	40
Washers	20
Rising Main Pipe	30
Grease	10
Straw Mat Cover	10
TOTAL	**110**

This estimated maintenance cost of the R & W Pump is similar to the maintenance cost for the Bucket Pump, which is typically average about R95 per year (Nash, 2004).

6.2.4 Conclusion to Economic Feasibility

The R & W Pump for tubewells as designed in this project is economically feasible for the UFWP. The current production price of the R & W Pump is slightly greater than that of the Bucket Pump, and is acceptable for the UFWP. Any future changes in the materials used to construct the pump should be evaluated in terms of strength and durability of these materials. It is expected that further improvements to the production process could lead to reduced material costs.

6.3 Washer Analysis

6.3.1 Introduction

Testing of various washer materials revealed that both tyre rubber and nylon plastic washers can be used to effectively pump water from the R & W Pump for tubewells, as presented in Chapter 5. The other types of washers tested (rubber tap washers and foam plastic washers) were inadequate for use on the R & W Pump for tubewells, primarily due to insufficient strength and the low pumping rates provided.

Pumping tests were performed using the tyre rubber and nylon plastic washers in order to determine pumping rates. For each of these two washer types, multiple rope and washer configurations were tested, in order to determine a spacing of the washers on the rope that allows for the most efficient pumping.

6.3.2 Programme of Work for Washer Analysis

Pumping tests were performed on three of the reference R & W Pumps, in order to collect quantitative data for analysing the flow rates of different washer spacings, for both tyre rubber and nylon plastic washers. The reference R & W Pumps selected for these tests (Table 5.1) had to be representative of the range of depths likely to be encountered throughout the UFWP. In addition, it was important that the recharge of the tubewells for the selected pumps be greater than the rates at which water was to be pumped during the tests.

Pump Selection

Of the seven reference R & W Pumps, three of these (Penelope, Pateni, and School Pumps) could not be used for pump testing, due to low rates of water recharge. Of the four other reference R & W Pumps, three pumps were selected that adequately represented shallow, medium and deep water tables, relative to the depths found in the UFWP. These pumps are described in Table 6.4.

Table 6.4 Rope and Washer Pumps used for Pumping Tests

Pump Name	Pump Depth (metres)	Relative Water Table Depth	Depth to Water Table (metres)
Ncube Pump	7.4	Shallow	6.1
Ikawu Pump	18.1	Medium	14.9
Thwala Pump	21.5	Deep	18.4

Pumping Subject Selection

In order to collect consistent data for the pumping tests, it was necessary to use the same subjects to perform the pumping for each of the rope configurations on the three R & W Pumps. It was important to use subjects who are representative of the people that will be using R & W Pumps. As girls and women are often responsible for collecting water for the family, it was important that at least one of the subjects be female. The selected subjects were Jomo Thwala, a healthy 24-year old male, and Pindila Thwala, a healthy 14-year old female. One of the reference R & W pumps (Thwala Pump) is located at the Thwala family homestead, and thus Jomo and Pindila were already accustomed to using the R & W Pump.

For each rope configuration, the subjects were instructed to pump twenty-five litres of water into a bucket. This testing was timed with a stopwatch, starting from the moment that the pulley wheel was first turned. The subjects were instructed to pump at normal rates, trying to exert the same amount of energy for each test (*i.e.* more difficult pumping leads to a slower pumping rate). There was at least half an hour of elapsed time between pumping trials for each rope and washer configuration, which ensured that subject fatigue was not a significant factor in the results of the pumping trials.

Each subject performed one pumping trial for each rope and washer configuration. As the collected data are meant to determine approximate pumping rates, and are not meant to be scientific, it was decided that further trials were unnecessary. In addition, further trials would have increased the likelihood of subject fatigue being a factor in the results of the pumping trials. Calculated pumping rates are presented to the nearest litre/minute.

Rope and Washer Configurations

Six different washer configurations were tested on each of the three pumps, with 5-mm diameter polypropylene ropes being used. Three ropes used tyre rubber washers, and three ropes used nylon plastic washers. Washers were tied at equally spaced intervals along each rope, at selected spacing intervals of one metre; two metres; and four metres. These washer spacings corresponded with common spacings used in previous R & W Pump projects (Bombas de Mecate, 2003).

6.3.3 Presentation of Washer Analysis Data

The performances of the multiple configurations of the tyre rubber washers and nylon plastic washers at various depths are presented in Figures 6.1 and 6.2, respectively. A complete list of all the data collected for the pumping trials is included in Appendix E.

The data of the pumping trials of each of the two subjects shows mostly the same trends. Pindila Thwala consistently pumped water faster than Jomo Thwala. Of the eighteen trials that each subject performed, Pindila pumped at a faster rate than Jomo on 15 of these trials. On average, Pindila pumped at a rate of 3 litres/minute faster than Jomo (20 l/minute to 17 l/minute). Averages of Pindila's and Jomo's times are used for the data presented.

The pumping test results show that both water table depth and the set-up of the washers on the rope are significant factors in the flow rate of the pump. They also show a distinct, albeit not great, difference between the flow rates when tyre rubber or nylon plastic washers were used.

Washer Configurations

The configuration of the washers proved to be significant to the pumping rate of the R & W Pump. Average flow rates for all washer configurations, including the three different water table depths, ranged from 12 litres/minute to 26 litres/minute. While much of this variance can be attributed to the different water table depths, the average flow rates at each depth still varied by at least 6 litres/minute.

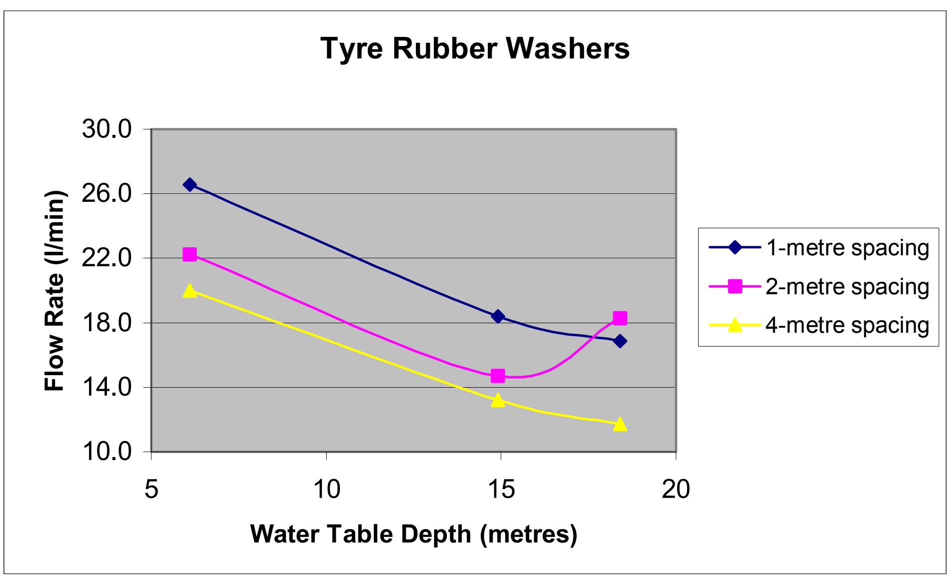

Figure 6. 1 Pumping Rates at Various Spacings for Tyre Rubber Washers

Figure 6.1 shows the pumping performance when using tyre rubber washers. Pumping rates varied from 12 litres/minute when pumping from the deepest well and using washers spaced at 4-metre intervals, to 26 litres/minute when pumping from the shallow well with washers spaced at one-metre intervals. At each pump depth, the difference in pumping rates for the three washer configurations varied by 5 to 6 litres/minute.

For the shallow and medium depth pumps, the trends in difference in pumping rates between the three washer configurations were similar. For the deep well, the difference in pumping rates between the rope with washers spaced at 1-metre and the rope with washers spaced at four-metres also remained relatively constant compared to the other two pumping depths.

However, the rope with washers spaced at two-metre intervals performed better on the deep well. This situation was also experienced during the monitoring of two of the deep reference R & W Pumps (Thwala Pump and Pateni Pump). While the tyre rubber washers spaced at one-metre intervals decrease the amount of losses within the pipe (compared to larger spacings), each washer is also causing friction within the pipe. For deep wells, the combined friction of all washers makes pumping difficult. Therefore, the increased spacing of two-metres decreases the friction within the pipe by half, leading to a higher pumping rate.

Based upon the collected data, it is recommended that tyre rubber washers be spaced at one-metre intervals for shallow or medium depth pumps, and at two-metre intervals for deep pumps.

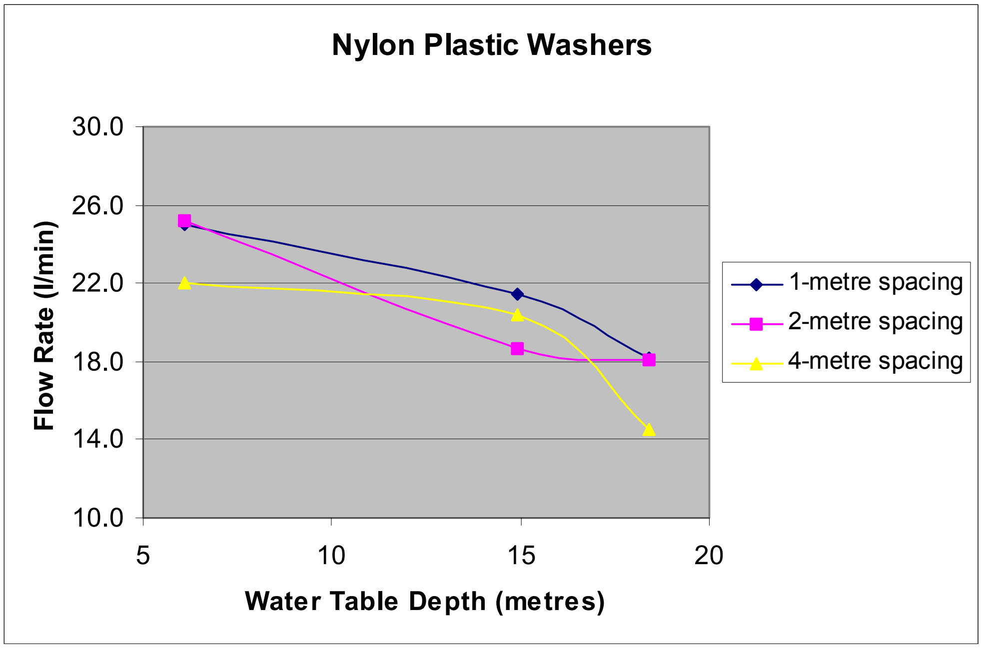

Figure 6. 2 Flow Rates at Various Spacings for Nylon Plastic Washers

Figure 6.2 shows the pumping performance when using nylon plastic washers. These pumping rates varied from 14 litres/minute, pumping from the deepest well using washers spaced at 4-metre intervals, to 25 litres/minute when pumping from the shallow well with washers spaced at two-metre intervals. At each pump depth, the difference in pumping rates for the three configurations varied by 3 to 4 litres/minute.

The pumping rates with washers spaced at one-metre and two-metre intervals are approximately the same for the shallow and deep pumps, while the one-metre spacing resulted in a pumping rate of 3 litres/minute higher than the two-metre spacing for the medium depth pump. The pumping rates with washers spaced at four metres were 3-4 litres/minute less than that found with the other two spacings, for the shallow and deep pumps. For the medium depth pump, the rope with four-metre spacing provided a pumping rate greater than that for the rope with two-metre spacing, but still less than that for the rope with one-metre spacing.

It is recommended that nylon plastic washers be spaced at two-metre intervals for all pump depths. While the performance of these washers is similar when they are spaced at one-metre intervals, the current cost of the washers (R5.50 each) makes the two-metre spacing more economical. The four-metre spacing is less efficient overall, but still provides a reasonable flow rate and should be considered if availability or cost of the nylon plastic washers is a concern.

6.3.4 Conclusion to Washer Analysis

The analysis of the pumping data proved that both the tyre rubber washers and the nylon plastic washers can efficiently pump water from the designed R & W Pump. However, only the tyre rubber washers are available locally at the current time. In addition, it is not possible to use nylon plastic washers when there is a presence of sand in the water being pumped. Therefore, it is recommended that these washers be used on the R & W Pumps in the UFWP. In order to make pumping most efficient, the spacing of the rubber tyre washers should be chosen according to the depth of the water table in the particular well.

6.4 Pump Efficiency

6.4.1 Introduction

The efficiency of the R & W Pump is determined by comparing its pumping rate with that of the Bucket Pump. It was quite obvious from observed pumping that it is possible to pump water at a much faster rate with the R & W Pump than with the Bucket Pump. Nevertheless, an analysis is important to determine the time-savings in pumping with the R & W Pump. A more efficient pump may also result in a more consistent use of water for hygienic purposes, which can lead to improved health conditions.

6.4.2 Programme of Work to determine Pump Efficiency

The same data that were used in the previous washer analysis section are analysed to determine the efficiency of the R & W Pump. The data from the optimal rope and washer configurations that have been recommended are used to compare pumping rates of the R & W Pump with those of the Bucket Pump at shallow, medium, and deep depths. The data from pumping trials of the Bucket Pumps is included in Appendix E.

Tests were performed on three tubewells equipped with Bucket Pumps to determine their pumping rates. These tests were performed by Jomo Thwala and Pindila Thwala, the same subjects as for the R & W Pump tests. The pumping rates for the two subjects were similar (within 0.5 litres/minute for each depth) and the data presented comprise an average of these trials. The tubewells, which are described in Table 6.5, were chosen such as to represent shallow, medium, and deep water tables, relative to the depths found in the UFWP.

Table 6.5 Bucket Pumps used for Pumping Tests

Pump Name	Tubewell Depth (metres)	Relative Water Table Depth	Depth to Water Table (metres)
Kwamboma Pump	8.3	Shallow	4.3
Zweli Pump	18.3	Medium	14.9
Jomo Pump	22.0	Deep	18.4

Of the three Bucket Pumps tested, the medium depth tubewell (Zweli Pump) and deep tubewell (Jomo Pump) had water table depths that were the same as those of the corresponding R & W Pump tubewells. The Jomo Pump was actually installed on the same tubewell as the Thwala Pump (prior to the installation of that R & W Pump). The water table depth of the shallow Bucket Pump tested (Kwamboma Pump) was, however, 1.8 metres less than that of the shallow R & W Pump tested (Ncube Pump), as this was the closest depth of a tubewell equipped with a Bucket Pump that was available in the project area.

6.4.3 Presentation and Analysis of Pump Efficiency Data

The results of the pumping tests performed with the Bucket Pumps showed the pumping rates to be much slower than those of the R & W Pumps, regardless of pumping depth. Table 6.6 shows a comparison of the pumping rates for R & W Pumps and Bucket Pumps.

Table 6.6 Comparison of Pumping Rates for R & W Pumps and Bucket Pumps

Relative Water Table Depth (m)	Bucket Pump-Pumping Rate (litres/minute)	R & W Pump-Pumping Rate (litres/minute)		Efficiency Improvement Factor For R & W Pump	
		Plastic Washers	*Tyre Rubber Washers*	*Plastic Washers*	*Tyre Rubber Washers*
Shallow	8	25	26	3	3
Medium	5	19	18	4	4
Deep	4	18	18	5	5

These data show that the efficiency of the R & W Pump over the Bucket Pump increases with water table depth. From these data, the R & W Pump is estimated to be three to five times more efficient than the Bucket Pump. For each of the three water table depths, both of the testing subjects also reported that they were considerably more fatigued after pumping 25 litres of water from the Bucket Pump compared to pumping the same amount using the R & W Pump.

Figure 6.3 shows the time taken to pump 25 litres of water from the pumps at various depths for the R & W Pump (average of times for pumps using tyre rubber washers and nylon plastic washers) and the Bucket Pump.

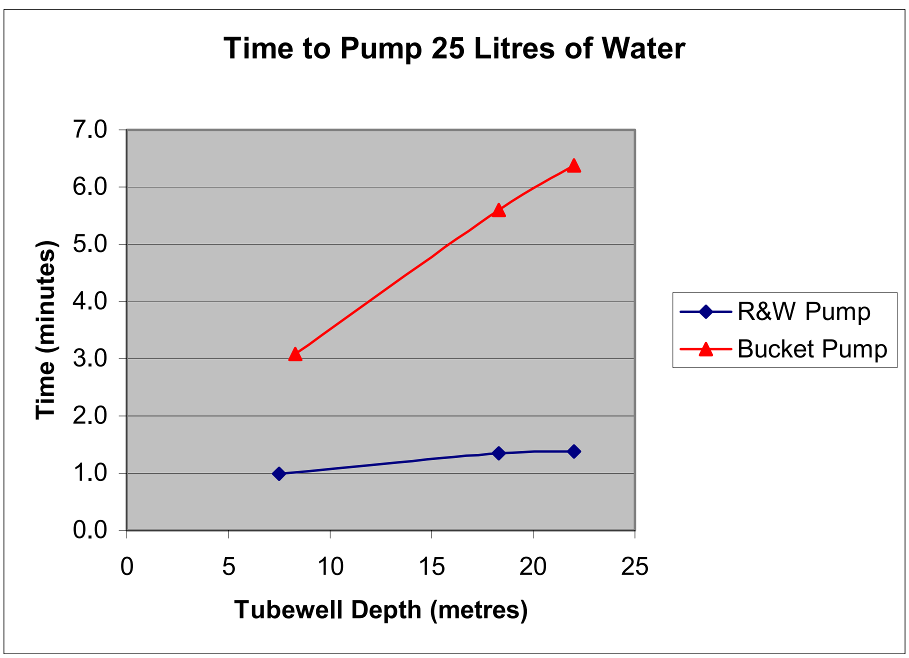

Figure 6. 3 Pumping time Comparison of R & W Pump to Bucket Pump

It can be seen from Figure 6.3 that there is a large difference in pumping times. It is assumed that a family of six uses an average of 50 litres of water per person per day, which can be expected when water is supplied to a yard level (WHO, 2003). This quantity of water would require daily pumping of between 36-80 minutes using a Bucket Pump, depending on the pump depth. Pumping the same amount of water from the R & W Pump requires 12-18 minutes, and saves roughly 25-60 minutes of pumping daily. The effect of the user taking breaks during pumping, because of fatigue, would further increase the time differences.

Differences in water usage patterns of families using R & W Pumps and Bucket Pumps should be researched for the UFWP. Past studies have shown that the use of larger quantities of water for domestic purposes generally leads to better hygienic conditions (Esrey, 1996). Thus, the likely increase in water usage by users of the R & W Pump, due to its greater efficiency, may lead to better overall hygienic conditions for the families.

6.4.4 Conclusion to Pump Efficiency

The R & W Pump has a considerably greater efficiency than the Bucket Pump. The R & W Pump provides a higher rate of pumping than the Bucket Pump, and is less strenuous in pumping the same amounts of water. Differences in levels of water usage between users of R & W Pumps and users of Bucket Pumps should be researched, as increased levels of domestic water use can lead to better hygiene conditions.

6.5 Water Quality

6.5.1 Introduction

Microbiological testing was performed on a sample of tubewells equipped with R & W Pumps and Bucket Pumps, in order to determine their water quality. These samples were tested for the presence of faecal coliforms, which are an indicator of faecal pollution in the water, suggesting the possible presence of bacteria, viruses and/or parasites (WRC, 1998). The water quality testing was performed towards the end of the research project, as until then several of the reference R & W Pumps were frequently being altered or adjusted during monitoring.

6.5.2 Programme of Work to determine Water Quality

Water quality testing was done on five tubewells equipped with R & W Pumps and five tubewells equipped with Bucket Pumps, with samples being taken from these pumps at two separate times during the project research. These samples were tested for the presence of *E. coli*, which is a standard test used for determining the likelihood of faecal contamination in water.

The first set of samples was taken in December 2003, and the second set five weeks later, in January 2004. The testing was done by Dorothy Nsindeni, a PID staff member who is experienced in water quality testing. Standard water sample collection and testing procedures of the South African Water Research Commission were followed (WRC, 2001), as observed by the author.

The first samples were taken soon after the ropes on four of the tested R & W Pumps were changed. Three of these pumps (Thwala, Ikawu, and Ncube Pumps) had been used for the testing of the different ropes used in the washer analysis. A fourth R & W Pump (James Pump) was installed the week prior to the testing, with several different ropes tested on the pump at that time. It was realised that there was a significant possibility that the extensive changing and handling of the ropes on these four pumps had contaminated the water in their tubewells. Nevertheless, due to time constraints on the research, it was decided to perform the testing at that time, and do additional testing at a later stage.

The second set of samples was taken five weeks later. At that point, only one of the tested R & W Pumps (James Pump) had undergone maintenance in the preceding three weeks.

6.5.3 Presentation and Analysis of Water Quality Data

The results of the two sets of water samples show comparable microbiological water qualities between the R & W Pumps and the Bucket Pumps. These results are shown in Table 6.7.

Table 6.7 Microbiological Water Quality Testing Results

Pump Name and Type	Faecal Coliforms Count (*E. coli*)	
	Data Set 1 Dec. 2003 Samples	*Data Set 2* Jan. 2004 Samples
Thwala R & W Pump	34*	24*
Ncube R & W Pump	48*	9
Penelope R & W Pump	0	4
Ikawu R & W Pump	10	4
James R & W Pump	86*	10
Zweli Bucket Pump	13*	42*
Kwamboma Bucket Pump	33*	4
Patleni Bucket Pump	36*	13*
Nduna Bucket Pump	22*	10
Emphaketeni Bucket Pump	48*	13*
*Denotes faecal coliforms counts above 10 per 100 ml, which is the guideline limit for a Class 1 water in terms of South African drinking water standards (WRC, 1998).		

The South African government has published a series of guidelines for drinking water entitled Quality of Domestic Water Supplies (WRC, 1998). These guidelines state that while it is ideal to have no faecal coliforms present in drinking water, a range of 1-10 faecal coliforms per 100 ml is unlikely to cause clinical infections in healthy adults (but may do so in sensitive groups). Clinical infections are common amongst all groups when higher concentrations of faecal coliforms are present (WRC, 1998).

The first set of data shows that the water from three of the five tested R & W Pumps, as well as all five of the tested Bucket Pumps, had concentrations in excess of ten faecal coliforms per 100 ml. The second data set shows much lower concentrations of faecal coliforms overall, with four of the five R & W Pumps and two of the five Bucket Pumps having faecal coliforms concentrations of ten or less per 100 ml of water.

It is believed that the extensive handling and changing of the ropes was a factor in the high levels of faecal contamination of the R & W Pumps in the first data set. This hypothesis seems justifiable based on the fact that the R & W Pump whose rope was not changed prior to the first set of testing had a very good water quality (0 coliforms/100 ml). In addition, four of the five R & W Pumps tested showed low levels of contamination (0-10 coliforms/100ml) in the second data set, when none of these ropes had been recently changed. However, because there was also a significant decrease in the faecal coliforms concentration of the second data set for the Bucket Pumps, it is highly possible that another factor could be responsible for the decrease in faecal coliforms in the second data set.

Previous data collected on the water quality of Bucket Pumps in the UFWP shows the faecal coliforms concentrations to peak in the summer months of December-March (Still and Nash, 2002). It is quite possible that this yearly peak occurred during collection of the first data set.

6.5.4 Conclusion to Water Quality

Testing of the microbiological water quality demonstrated a need for longer-term microbiological testing of the R & W Pumps. The results of the second set of testing show four of the five tested tubewells equipped with R & W Pumps to have an acceptable drinking water quality. While it appears that extensive changing of the ropes may have contaminated these tubewells prior to the collection of the first set of data, further testing is needed to confirm this hypothesis.

6.6 Potential Sustainability of the Rope and Washer Pump for the Ubombo Family Wells Programme

6.6.1 Introduction

The research for this project focused on the development of a technically effective R & W Pump for use with tubewells in Maputaland. The design and monitoring of the technical aspects of the R & W Pump took up the majority of the available field research time. Nevertheless, the social factors of implementing a sustainable pumping system have also been largely factored into the design of the R & W Pump and its implementation for this project.

It will be necessary to evaluate the sustainability of the R & W Pump for the UFWP at later stages in the project, following the longer-term evaluation of project R & W Pumps. However, it is now possible to evaluate the potential sustainability of the R & W Pump for this programme, from data that were collected throughout the research. Therefore, the potential sustainability of R & W Pumps used with tubewells in the UFWP is evaluated here, from three perspectives:

1) Durability of the R & W Pump.
2) Ability of the users to maintain and repair the R & W Pump.
3) Willingness of the users to maintain and repair the R & W Pump.

6.6.2 Programme of Work to determine Potential Sustainability

Each of the aspects used in considering the potential sustainability of the UFWP R & W Pumps was extensively monitored during the implementation of the reference R & W Pumps. In addition, the experiences of users of two other R & W Pumps that were installed by PID during the research period are also described. These pumps are the Manguzi Pump, located outside of Manguzi in northern Maputaland, and the Ponta D'Ouro Pump, located in Ponta D'Ouro, Mozambique (5km from the South African border). These two pumps were not monitored on a regular basis, as they were installed outside of the immediate project area.

The experiences of the users of the Manguzi Pump and Ponta D'Ouro Pump help to determine the ability and willingness of users to maintain and repair their R & W Pumps.

6.6.3 Presentation and Analysis of Sustainability Data

R & W Pump Durability

The final design of the R & W Pump for the UFWP is believed to be very durable, as described in Chapter 5. In order for this pump to be sustainable, it is necessary that it be properly installed, according to Pump Installation and Startup Procedures, as described in Appendix C.

Each of the static R & W Pump components installed in the tubewell (top guide, rising main pipe, and bottom guide) is strongly built, and if properly installed there should be little or no maintenance required on these parts. The most likely problem to occur is the disconnection of the rising main pipe at a coupling, as was experienced during the field research. The likelihood of this happening is greatly reduced if all pipe connections are made using PVC glue, ensuring that the glue manufacturer's application instructions are followed. It is also important to use a safety rope that attaches to the top and bottom guides, as this will prevent the loss of piping and the bottom guide in the tubewell should a disconnection occur.

The pulley wheel and supports are strongly constructed and should require little maintenance. It is important that the supports be firmly encased in concrete at their bases, as well as the concrete apron surrounding the tubewell. The bearing points of the pulley wheel on the supports should be regularly greased, to prevent excessive wear.

Ability of Users to Maintain and Repair the R & W Pump

The ability of the pump users to maintain and repair the R & W Pump is vital to its sustainability. For this to happen, it is important that at least one of the users (and preferably more) have a good understanding of how the pump works. As the concept of the R & W Pump is quite straightforward, most individuals are capable of understanding its operation. This understanding can best be acquired through hands-on involvement in the installation of the pump. It is therefore recommended that at least one of the local users be involved extensively in the installation of each R & W Pump. This person should then be responsible for maintaining and repairing the pump, and possibly for transferring their knowledge to other users.

The installation and monitoring of the reference R & W Pumps involved the users as often as possible. The project team frequently worked with the pump users in installation and repair. However, such participation was not always possible due to constraints during the monitoring visits. As the primary aim at that point of the field research was to develop the technical aspects of the R & W Pump, participation of the users was sometimes neglected. In hindsight, it is clear which pumps were installed with user participation, as small problems with these specific pumps (*e.g.* rope becoming loose or detaching) were usually taken care of by the users themselves. On the other hand, when the users were not involved in the installation (or subsequent repairs), they looked to the monitoring team to fix even minor problems with their pumps. A list of routine repairs that can be carried out by the R & W Pump users is included in Appendix F.

Willingness of Users to Maintain and Repair the R & W Pump

The best examples of users being willing (and able) to repair their R & W Pumps occur with the two non-reference pumps described. The Manguzi Pump and Ponta D'Ouro Pump were well maintained and repaired by the users themselves since installation. The Ponta D'Ouro Pump was installed at the beginning of August 2003. Several local users were involved in the installation, and have been entirely responsible for pump maintenance and repair since that time. The pump has been in regular use and, as of December 2003, was said to be functioning well (Nash, 2004).

The Manguzi Pump was installed in September 2003, after which it was maintained and repaired solely by the local users until December 2003 (at which point the owner installed an electric submersible pump in place of the R & W Pump). In October, the users of the Manguzi R & W Pump had problems with several of the washers sliding over the knots on the rope (as explained in Chapter 5). A couple of the users then took it upon themselves to solve this problem, by tying rubber bands around the knots, which prevented the washers from sliding over them. This proved to work very well and illustrates the willingness of the users to maintain and repair the R & W Pumps themselves.

Monitoring of reference R & W Pumps has shown that users of each of these pumps were willing to maintain and repair their pump once they had adequate knowledge and training.

6.6.4 Conclusion to Potential Sustainability

The simplicity of the R & W Pump concept is the key to its sustainability. While not as basic in its function as the Bucket Pump, the R & W Pump function can be fully understood by most users, which makes them likely to maintain and repair it. The durability of the designed R & W Pump should help to ensure that only routine repairs are necessary on the pumps.

It is vital to the sustainability of the R & W Pumps in the UFWP that there is an adequate transfer of knowledge from the UFWP drilling teams to the pump users. In order for this to occur, the UFWP drilling team leaders must act as trainers during the pump installation. It is critical that at least one representative of the pump owner be involved extensively in the installation of the pump. This person should then be responsible for pump maintenance and repair.

The implementation of the Bucket Pump within the UFWP has been very successful in the past. The vast majority of these pumps are maintained and repaired by the users themselves. In order for this to also be the case with the R & W Pumps in this project, proper training in pump repair and maintenance must be given to the users. This training, combined with a durable R & W Pump and the willingness of the users to maintain and repair their pumps, can lead to the successful and sustainable use of R & W Pumps in Maputaland.

6.7 Conclusions

The final design of the R & W Pump for tubewells in Maputaland provides a higher level of service for domestic water supply than Bucket Pumps that have been previously used in the UFWP. This design of the R & W Pump is slightly more expensive than the UFWP Bucket Pump model, and its price is acceptable to the UFWP.

The R & W Pump provides a much higher pumping rate than the Bucket Pump, which makes it desirable to its users, and more likely to be acceptable to local officials. Tyre rubber washers are recommended for use on the R & W Pump, as they provide an acceptable pumping rate and are available locally in Maputaland. The R & W Pump is less strenuous than the Bucket Pump in pumping the same amounts of water.

While it is believed that the R & W Pump will provide a better quality of water than the Bucket Pump, further microbiological testing needs to be carried out. Initial tests showed similar microbiological qualities of water from both types of pump, but the data from two different testing periods is variable, and thus more extensive testing should be performed.

The final design of the R & W Pump for this project has the potential to be sustainable for the UFWP. Proper installation of the pump, involving the local users, is necessary to ensuring the ability of the users to maintain and repair their pump. The ability and willingness of the users to maintain and repair the R & W Pumps will be the final determining factors in project sustainability.

7 CONCLUSIONS

The research performed during this project has led to the development of an effective Rope and Washer Pump (R & W Pump) for use with tubewells in Maputaland. The designed R & W Pump provides a considerably higher rate of flow than the Bucket Pump that has previously been used by the Ubombo Family Wells Programme (UFWP), and represents a significant increase in the level of service provided. The R & W Pump has the potential for being sustainable in Maputaland, providing that the pump users receive adequate education on pump repair and maintenance. The high pumping rate of the R & W Pump makes it more likely to be accepted by local officials than the Bucket Pump.

The conclusions of this research project are summarised according to the specific research objectives, as follows. Recommendations based on these conclusions are presented in the next Chapter.

R & W Pump Design and Construction

The final project R & W Pump design is acceptable for use on the remaining pumps to be installed for the UFWP. The design is robust and requires minimal routine maintenance. It is expected, however, that there will be minor changes to the R & W Pump design as the UFWP programme progresses. These changes could be due to several factors, which include: (1) Observations made during longer-term monitoring of the R & W Pumps within the UFWP; (2) Changes in the availability of local materials; and (3) Improvements to the moulds used in the construction of the pump components.

Economic Feasibility

The designed R & W Pump was determined to be economically feasible for the UFWP. The current production price of the R & W Pump is only slightly greater than that of the Bucket Pump, and is acceptable for the UFWP. Future proposals to change the materials used to construct the pump for economic reasons should be evaluated in terms of the strength and durability of the materials. It is expected that further improvements to the production process will lead to a reduction in the cost of R & W Pump materials and/or construction.

Washer Analysis

The analysis of four types of washers proved that both tyre rubber washers and nylon plastic washers can efficiently pump water from the R & W Pump. However, only the tyre rubber washers are locally available at present in Maputaland. The nylon plastic washers were ineffective when sand was present in the tubewell water. Therefore, the tyre rubber washers should be used on the R & W Pumps in the UFWP. In order to optimise pumping efficiency, the spacing of the rubber tyre washers should be chosen depending on the depth of the water table in the particular well.

Pump Efficiency

The R & W Pump has a considerably greater efficiency than the Bucket Pump. The R & W Pump provides a considerably higher rate of pumping than the Bucket Pump, with the comparative advantage in efficiency increasing with water table depth. Pumping a fixed amount of water using the R & W Pump is also less strenuous compared to using the Bucket Pump.

Water Quality

The testing of the microbiological water quality carried out for this project highlighted a need for longer-term microbiological testing of the R & W Pumps. It was only possible to carry out two sets of testing, and results from these two data sets vary significantly from each other. While it appears that the microbiological water quality of the tubewells equipped with R & W Pumps is at least as good as that of tubewells equipped with Bucket Pumps, further testing is required to confirm this hypothesis and to understand the performance of the pumps in the longer-term.

Potential Sustainability

While the actual sustainability of the R & W Pump in the UFWP cannot be determined at this stage in the project, it was possible to analyse the potential sustainability of the R & W Pump in the UFWP based upon the fieldwork performed during this research project. This analysis considered the durability of the designed R & W Pump, as well as the ability and willingness of the users to maintain and repair their R & W Pumps.

The simplicity of the R & W Pump concept is the key to its sustainability. The principle of the R & W Pump can be fully understood by most users, which makes them capable of maintaining and repairing the pumps. The durability of the designed R & W Pump helps to ensure that only routine repairs are necessary on the pumps.

For the R & W Pump to be sustainable in the UFWP, an adequate transfer of knowledge must occur from the drilling teams, who carry out the installation, to the pump users. The Project Technicians, who lead the drilling teams, should act as trainers during the pump installation. It is critical that at least one representative of the pump owner be involved extensively in the installation of the pump. This person should then be responsible for pump maintenance and repair.

The sustainability of the Bucket Pump within the UFWP has been demonstrated in the past, with the vast majority of these pumps being maintained and repaired by the users themselves. To ensure a similar level of sustainability with the R & W Pump, proper training in pump repair and maintenance must be given to the users. This training, combined with a durable R & W Pump and the willingness of the users to maintain and repair their pumps, should lead to the successful and sustainable use of R & W Pumps in the Ubombo Family Wells Programme.

8 RECOMMENDATIONS

Recommendations for the Rope and Washer Pump (R & W Pump) for tubewells are based on the conclusions reached from this project research. These recommendations address the following areas: (1) the design of the R & W Pump for tubewells; (2) implementation of the R & W Pump in the Ubombo Family Wells Programme (UFWP); and, (3) further studies to be carried out on the R & W Pump for tubewells in Maputaland, South Africa.

1 R & W Pump Design

The final project R & W Pump design is acceptable for the remaining pumps to be built and installed for the UFWP. The following recommendations relate to further improvements that could be made to the design and production of the R & W Pump for the UFWP.

1.1 Written Pump Specifications and Tolerances

Pump specifications and tolerances should be recorded in writing and agreed upon by the pump builder and Partners in Development (PID). Such a protocol would help to ensure the quality and consistency of the pumps being built, and would minimise the chance of inadequate components being installed on the R & W Pumps. Strict quality control is important, particularly for the bottom guide.

1.2 Washer Design

It was determined that both tyre rubber washers and engineered nylon plastic washers can pump water effectively from the R & W Pumps. However, use of nylon plastic washers is not currently feasible with R & W Pumps. This is due to their ineffectiveness when sand is present in the tubewells (as is the case with most newly developed tubewells). In addition, these washers are not currently available locally in Maputaland. It is recommended that the use of different types of engineered washers be explored, using a softer washer material (*e.g.* hard rubber), the performance of which would not be affected by the presence of sand in the tubewells.

1.3 Redesign of Top Guide Base Mould

An improved mould should be designed for producing the top guide base component of the R & W Pump. Specifically, a steel mould should be designed for the bottom, cylindrical section of the top guide base (see Figure 5.6). This improvement to the mould design would enable more efficient production of the top guide base.

1.4 Improvement to Hygienic Cover

The Maputaland Hygienic Cover design proved to be very effective in covering the R & W Pump. However, the monitoring suggested that rain may cause the straw mat to deteriorate over time. It is recommended that the use of sealant or paint on the mat cover be tested to determine its effectiveness in protecting the straw mat from the effects of rain.

2 Implementation of the Rope & Washer Pump for the UFWP

For the R & W Pump to be sustainable for the UFWP, it is necessary that an adequate transfer of knowledge take place from the implementing agency (PID) to the pump users. The following recommendations are made to help ensure that the users of the R & W Pump receive sufficient knowledge in pump function and repair.

2.1 User Participation in Pump Installation

At least one representative of the pump owner should be involved extensively in the installation of the pump. This person should then be responsible for pump maintenance and repair, as well as possibly transferring their knowledge to other pump users. This requirement should be clarified with the pump owners well before the installation of the R & W Pump.

2.2 Training of Project Technicians in Knowledge Transfer Skills

The UFWP Project Technicians should receive training in how best to transfer their knowledge to the user who is assisting with the pump installation. The team leader should make sure that the user is actively involved in the pump installation. Explanations of routine and non-routine maintenance and repairs to the R & W

Pump should be given. A training manual with descriptive drawings or photos should be prepared to assist the drilling team and aid in future trainings.

2.3 Emphasis on Hygiene Education

In addition to the technical knowledge of how to maintain and repair the R & W Pumps, it is important for the users to have an understanding of how to keep their tubewell water clean, and how to make use of the upgraded water source to improve the health of their family. Therefore, it is recommended that hygiene education be an integral component to the implementation of the R & W Pumps for the UFWP.

3 Further Studies on the Rope and Washer Pump

A number of additional studies could usefully be performed on the R & W Pumps for tubewells. In addition to longer-term monitoring and evaluation of the performance of the R & W Pumps for tubewells, the following studies are recommended as important to the development of the Ubombo Family Wells Programme.

3.1 Long-term Monitoring of Microbiological Water Quality of R & W Pumps

Longer-term microbiological testing is needed to determine the quality of water from tubewells equipped with R & W Pumps. This testing should investigate sources of contamination, including the likelihood of contamination during pump installation and maintenance. The impact on water quality of the Hygienic Cover should also be explored.

3.2 Water Usage

Water usage patterns of families using R & W Pumps should be investigated. These data should be compared to water usage of families using Bucket Pumps, as well as users of other water source types. Past studies have shown that the use of larger quantities of water for domestic purposes generally leads to better hygienic conditions

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Appendix A
University of Southampton
Project Risk Assessment

Appendix B

Summary of monitoring of reference R & W Pumps

Summary of monitoring of reference R & W Pumps

Reference R & W Pump #	1
Pump Name	Garden Pump
Well Depth (metres)	8.5
Water Table Depth (metres)	5.0
Water Depth (metres)	3.5
Depth of Pump (metres)	7.8
Date Pump Installed	July 1, 2003
Previous Pump?	No, new tubewell
Tubewell Characteristics	Sufficient recharge

Monitoring Summary

-4-mm diameter rope used July to mid-September, with rubber tyre washers attached at one-metre intervals. Only problem with this rope and washers was the rope becoming detached once.

-5-mm diameter rope used from mid-September, to accommodate nylon washers used. Nylon washers attached at one-metre intervals. No problems with rope and washers as of mid-January 2004.

-Pump operated smoothly during all monitoring visits, except for the first visit, when the 4-mm rope had become detached.

-This Pump is used by a local community group to water their garden several times a week.

Reference R & W Pump #	2
Pump Name	Penelope Pump
Well Depth (metres)	23.4
Water Table Depth (metres)	22.1
Water Depth (metres)	1.3
Depth of Pump (metres)	23.3
Date Pump Installed	July 29, 2003
Previous Pump?	Yes – Bucket Pump (functional)
Tubewell Characteristics	Slow Recharge (about 5-8 litres/min.)

Monitoring Summary

-Since installation of this pump, the recharge has been very slow. This tubewell is several years old, and it appears that the water table has dropped significantly in this area, such that the depth of water in the tubewell is also very low (1.3 metres).

-7-mm diameter rope used, with washers spaced at one metre.

-During the two months of pump operation, the rope became detached several times. This was determined to have been due to washers catching at the top or bottom guides. This led to the loop connection coming loose.

-Problem was solved by threading 2mm diameter rope through the ends of the loop connections. The pump has been operating well since that point, as of mid-January 2004. Recharge rate of the pump has not changed.

-This pump is used by about 12 people for their domestic water supply. They report that they prefer the R & W Pump to the Bucket Pump, despite the low recharge rate.

Reference R & W Pump #	3
Pump Name	Ncube Pump
Well Depth (metres)	7.5
Water Table Depth (metres)	6.1
Water Depth (metres)	1.4
Depth of Pump (metres)	7.4
Date Pump Installed	July 31, 2003
Previous Pump?	Yes – Bucket Pump (functional)
Tubewell Characteristics	Sufficient recharge

Monitoring Summary

-This pump worked well throughout the monitoring period. It is owned by the Ncube family, but is heavily used by the neighbouring community. It is estimated that 25-30 families receive their domestic water from this pump.

-George Ncube, a drilling technician with the UFWP, maintains the pump.

-Original rope installed was 5-mm diameter, with rubber tire washers spaced at one-metre intervals.

-Rope has been changed once due to wear, in mid-November 2003. This was done after over three months of usage. Wear was faster because of much usage of the pump by the community.

-Rope and washers were changed in mid-December to use nylon plastic washers. A 5-mm diameter rope was used, with washers spaced at four-metre intervals.

-Pump continued to work well as of mid-January 2004.

-Users of this pump report that they prefer it to the Bucket Pump, mainly due to the high pumping rate.

Reference R & W Pump #	4
Pump Name	Ikawu Pump
Well Depth (metres)	18.7
Water Table Depth (metres)	14.9
Water Depth (metres)	3.8
Depth of Pump (metres)	18.1
Date Pump Installed	August 20, 2003
Previous Pump?	No, new tubewell
Tubewell Characteristics	Sufficient recharge, Fine sand in water

Monitoring Summary

-First rope used was 5-mm diameter with rubber tyre washers attached at one-metre intervals. This rope is still in use. A few of the washers have slipped over their knots and toward the other washers. These washers were simply cut off, and the pump works fine.
-Rope has become detached a couple of times. Users have reported no problems with the rope since October. They are capable of repairing the rope themselves should it break.
-Rope was changed briefly in September to accommodate the use of nylon washers. However, there was a presence of sand in the tubewell, which caused these washers to get jammed, and thus the original rope and washers were put back on the pump.
-In October, a new biddim plug was put in the bottom of the tubewell to decrease the amount of sand. This seemed to work well, however, there still seems to be a small amount of fine sand present in the water.
-This pump was used for the testing of various configurations of washers in December. Testing went well.
-Users have reported that they are happy with the pump. It is used by a family of about 10.

Reference R & W Pump #	5
Pump Name	Pateni Pump
Well Depth (metres)	24.1
Water Table Depth (metres)	19.1
Water Depth (metres)	5.0
Depth of Pump (metres)	23.6
Date Pump Installed	October 3, 2003
Previous Pump?	No, new tubewell
Tubewell Characteristics	-Insufficient Recharge (about 2 litres/minute) -Water is a milky colour

<u>Monitoring Summary</u>

-This pump works well, but the water is not used much because it is a milky colour. The

-Initially, a 7-mm diameter rope was used with tyre rubber washers attached at one-metre intervals. This proved very difficult to pump, due to the cumulative friction of the washers over the deep depth. The same size rope was used with tyre rubber washers attached at two-metre intervals, which was much easier to pump. Pumping was still a bit difficult, as can be expected due to the deep depth.

-Recharge of this tubewell is slow. There is a depth of water of 5.0 metres, which allows for some storage of water in the tubewell. After that is pumped, the recharge was measured at about 2 litres/minute in November 2003.

-Owners are not happy with the tubewell, due to the milky colour of the water. However, there is also piped water close to their house, so it is not urgent for them to have another water supply.

-Pump water remained milky colour in January 2004. Pump not in regular use.

Reference R & W Pump #	6
Pump Name	Thwala Pump
Well Depth (metres)	22.0
Water Table Depth (metres)	18.4
Water Depth (metres)	3.6
Depth of Pump (metres)	21.5
Date Pump Installed	October 8, 2003
Previous Pump?	Yes – Bucket Pump (functional)
Tubewell Characteristics	Sufficient recharge

Monitoring Summary

-This pump was monitored a few times a week since installation until mid-January. Many of the improvements and adjustments to the pump design were tested on this Pump.

-Originally pump was set up with tyre rubber washers spaced at one-metre intervals, on a 7-mm diameter rope. This proved to be very difficult to pump, the washers were causing a lot of friction. Rope was changed to tyre rubber washers at two-metre intervals, This made pumping much easier, while still a bit stiff.

-After two weeks, rope and washers were changed to 5-mm diameter rope with nylon plastic washers spaced at two-metre intervals. This proved easier to pump than the rope with tyre rubber washers at the same spacing. Nylon plastic washers are causing less friction.

-In December, foam plastic washers were tested on the pump for one week, spaced at one-metre intervals. Initially these washers pump well, but not as well as the tyre rubber or nylon plastic washers. Within a few days several of the washers had torn completely off of the rope, and others had slipped over the knots. After one week, only half of the washers remained on the rope.

-Rubber tap washers were also tested in December, these didn't work very well. The washers were about 1mm too small for the pipe, thus pumping had to be done very fast (80-90 revs/minute) to receive a decent flow of water. The washers also showed wear after a few days use, suggesting that they are not strong enough.

-A couple of times the rising main pipe became disconnected. This was found to have been due to inadequate drying time for the glue prior to the installation.

-Maputaland Hygienic Cover tested on this pump.

-Users previously had Bucket Pump, and much prefer the R & W Pump

-The Thwala family maintains the pump well. About 40 people use it.

Reference R & W Pump #	7
Pump Name	School Pump (Emphaketini)
Well Depth (metres)	15.4
Water Table Depth (metres)	13.1
Water Depth (metres)	2.3
Depth of Pump (metres)	15.3
Date Pump Installed	October 16, 2003
Previous Pump?	Yes – Pulsar Pump (broken)
Tubewell Characteristics	Slow Recharge (about 5 litres/min.)

Monitoring Summary

-Recharge of this slow is slow. Water depth allows for some storage.
-7-mm diameter rope used, with spacing at two-metre intervals.
-Initially had problems with rope becoming disconnected, because of the washers catching at the top and bottom guides. This was solved by threading 2-mm diameter rope through the loop connections.
-Rising main pipe became disconnected once, in November. This was determined to have been due to bad glue, which had already begun to set up in its container. Repaired, and it hasn't been a problem since.
-A few of the school kids know how to attach the rope, and can do it themselves should it become disconnected.
-Users are relatively happy with the pump, but a bit discouraged by the slow recharge rate of the tubewell.

Appendix C
Pump Installation and
Startup Procedures

R & W Pump Installation and Startup Procedures

Tools required for Pump Installation

-hacksaw

-guide wire for rope (hard steel)

-wire for threading washers on rope

-spade

-hammer

-tool for flaring bent back pipe

-gas burner

-pliers

-knife

-lighter/matches

-tape measure

-fish line with weight attached

-spring for bending bent back pipe

Materials required for Pump Installation

-Bottom Guide

-Rising main pipe (uPVC)

-PVC glue

-Couplings

-Top Guide

-Above-ground pipes (Headworks)

-Fittings for above-ground pipes (reducers, collars, tee, elbow)

-Polypropylene braided ski rope (5-mm diameter or 7-mm diameter)

-Polypropylene twisted rope – Safety rope (4-mm diameter)

-Polypropylene rope (2 mm)

-Washers (nylon plastic or tyre rubber)

-Pulley wheel and handle attached to gum tree poles

-Maputaland Hygienic Cover material

  -HDPE Piping

  -Mild steel bracket and two supports

-Zulu Straw Cover

-Cotton twine

-Nails

-spare rubber washers (8)

-Two bags of cement, 50kg (for apron and base of gum tree poles)

R & W Pump Installation Instructions

The following basic instructions are a guide to installing an R & W Pump on a tubewell that is already completed.

1) Measure depth of tubewell, depth to water table, and depth of water in the tubewell. The R & W Pump should be installed such that the lower end of the bottom guide is 0.2 to 0.5 metres above the bottom of the tubewell.

2) Measure out length for the rising main pipe to be installed at the correct depth, when attached to the top guide base and bottom guide. The pipe connections should be done using the couplings and a fast-dry uPVC glue, with sufficient time allowed for setting of the glue, according to the manufacturer's instructions. The safety rope should be attached from the bottom guide to the top guide base.

3) The pulley wheel should already be attached to the supports. The supports should be firmly set in the ground on either side of the tubewell, such that the front of the pulley wheel (the point where the rope and washers make contact on the wheel) lines up directly above the tubewell. It should be checked that the pulley wheel and supports are set correctly for the braking (that they are not backwards!) The bases of the gum tree poles should be encased in concrete, with earth buried on top, back to ground level. The earth should be well compacted.

4) A concrete apron should be built around the tubewell and pulley wheel supports. This apron should provide good drainage away from the tubewell.

5) The washers should be tied onto the rope, with knots tied at either side of each washer. The spacing of the washers should be determined by the depth of the pump and washer type used. The washers should be spaced to allow for optimal pumping rates. The attaching of the washers on the rope should preferably be done by the owner's family or representatives. The project team leader should explain the process as needed.

6) The headwork pipes should be attached to the top guide base.

7) The guide wire should be fed through the rising main pipe and guides. The rope and washers should then be attached to the guide wire, and fed through. The rope should be installed to make a loop connection, with the connection being temporarily tied above the headwork pipes of the top guide.

8) The top guide, with rising main pipe and bottom guide attached, should be installed in the tubewell after the glue has had sufficient time to set. Several people are needed to perform this task, and more with deeper pumps.

9) The Maputaland Hygienic Cover frame should be installed. However, the attachment of the straw mat should be done after startup of the pump, to allow easier access to the rope and washers for adjustment during startup.

The pump is now ready for startup.

Startup Procedures for the R & W Pump

The startup procedures for the R & W Pump require trial and error in determining an appropriate tension of the rope for optimal pumping.

1) The rope should be tied around the pulley wheel, and connected using small self-splicing loops at either end of the rope. The rope should be snug but not to tight on the pulley wheel. When this has been done, the pump should be tested by turning the pulley wheel. If the rope slips, it needs to be tightened.

2) After initially pumping, the rope lengthens a small amount. This lengthening is due to the knots on each side of the washers tightening as the pump is used. The rope will needed to be tightened after this occurs, and may have to be adjusted slightly during the first few days of operation.

3) To ensure that the self-splicing loops do not become undone, 2-mm diameter rope can be threaded through the self-splicing loop connections. As the initial lengthening of the rope may necessitate frequent adjustments to its tension, this threading should be done after initial pumping, when the knots at each side of the washers have already tightened.

4) As it may be several days before an adequate tension in the rope is finalised, it is important the users have a good understanding of how to go about adjusting the tension on the rope, as well as how to replace the rope.

5) The straw mat of the Maputaland Hygienic Cover should be installed after initial startup.

Appendix D
Pricing List of
R & W Pump
Materials

PRICING LIST OF R & W PUMP MATERIALS

No.	Description	Unit	Quantity per tube well	Cost per unit	Total per Pump
	Rope and Washer Pump				
	(Costs are based on quoted prices, unless specified)				
	Pulley Wheel and Supports				
1	Gum poles (100-125mm x 2.4 long)		2	R 44.00	R 88.00
2	20" Tires (salvaged)	tire	1	R 30.00	R 30.00
3	20mm round bar	metre	1.6	R 14.20	R 22.72
4	12mm round bar	metre	0.6	R 4.77	R 2.86
5	10mm round bar	metre	4.9	R 4.47	R 21.89
6	8mm round bar	metre	1.6	R 2.36	R 3.77
7	22mm x hollow bar	metre	0.1	R 43.32	R 4.33
8	flat bar	metre	0.8	R 5.63	R 4.50
9	Grease	ml	50	R 0.04	R 2.00
10	Cement	pkts	2	R 37.50	R 75.00
					R 255.08
11	**Rope (7mm nylon)**	metre	45	R 1.00	**R 45.00**
	Rubber Tire Washers				
12	Salvaged Tire or Conveyor Belt Material	no.	1	R 10.00	**R 10.00**
	Raising Main Pipe				
13	25mm UPVC Class 16 pipe	metre	18	R 5.40	R 97.20
14	25mm Weld Socket (Coupling)	no.	5	R 3.49	R 17.45
15	4mm Safety rope	metre	20	R 0.55	R 11.07
16	PVC Weld Cement (Glue)	ml	50	R 0.10	R 5.00
					R 125.72
	Top Guide with Galvanised Iron Discharge Pipe & Tap				
17	25mm UPVC Class 16 pipe	metre	0.3	R 5.40	R 1.62
18	32mm UPVC above-ground pipe	metre	1.4	R 7.56	R 10.59
19	No. 8 Galvanised wire	metre	0.5	R 1.00	R 0.50
20	32mm-25mm Galv Reducing Socket	no.	1	R 12.27	R 12.27
21	32mm Galv Tee Socket	no.	1	R 19.80	R 19.80
22	32mm Galv Elbow Socket	no.	1	R 16.30	R 16.30
23	25-32 UPVC Male Adaptor	no.	1	R 6.08	R 6.08
24	32mm Galv Pipe Cut to Size	metre	0.55	R 43.78	R 24.08
25	32mm Galv Pipe Cut to Size	metre	0.25	R 43.78	R 10.95
26	32mm Galv Pipe Cut to Size	metre	0.15	R 43.78	R 6.57
27	32mm Galv Pipe Cut to Size	metre	0.1	R 43.78	R 4.38
28	32mm Weld Socket (Coupling)	no.	1	R 4.20	R 4.20

No.	Description	Unit	Quantity per tube well	Cost per unit	Total per Pump
29	Thread Tape	roll	0.5	R 2.95	R 1.48
30	Cement	pkts	0.05	R 37.50	R 1.88
31	1/2 Crushed Rock	bag	0.2	R 10.00	R 2.00
32	River Sand (unit price estimate)	bag	0.2	R 5.00	R 1.00
					R 123.68
	Bottom Guide				
33	25mm UPVC Class 16 pipe	metre	0.3	R 5.40	R 1.62
34	32mm UPVC above-ground pipe	metre	0.3	R 7.56	R 2.27
35	32mm stainless steel tube x 40mm long	metre	0.04	R 262.20	R 10.49
36	2mm stainless steel plate	sheet	0.01	R 1,421.58	R 14.22
37	Cement	pkts	0.05	R 37.50	R 1.88
38	1/2 Crushed Rock	bag	0.1	R 10.00	R 1.00
39	River Sand (unit price estimate)	bag	0.1	R 5.00	R 0.50
					R 31.97
	Maputaland Hygienic Cover				
40	10mm round bar	metre	1.5	R 4.47	R 6.70
41	HDPE pipe (Class 6), 25mm	metre	3.5	R 2.65	R 9.28
42	Zulu Mat Cover	mat	0.5	R 15.00	R 7.50
43	Cotton String	roll	0.1	R 20.00	R 2.00
44	Nails and Washers (unit price estimate)	unit	1	R 5.00	R 5.00
					R 30.48
45	**Transport of Materials (estimate)**				**R 30.00**
	TOTAL				**R 619.95**
	Comparison of Top Guide Prices When				
	Using uPVC vs. Galvanised Iron Piping				
	Discharge Pipe and Tap				
	Galvanised Iron Discharge Pipe and Tap				
1	25mm UPVC Class 16 pipe	metre	0.4	R 5.40	R 2.16
2	32mm UPVC above-ground pipe	metre	1.4	R 7.56	R 10.59
3	No. 8 Galvanised wire	metre	0.5	R 1.00	R 0.50
4	32mm-25mm Galv Reducing Socket	no.	1	R 12.27	R 12.27
5	32mm Galv Tee Socket	no.	1	R 19.80	R 19.80
6	32mm Galv Elbow Socket	no.	1	R 16.30	R 16.30
7	25-32 UPVC Male Adaptor	no.	1	R 6.08	R 6.08

No.	Description	Unit	Quantity per tube well	Cost per unit		Total per Pump	
8	32mm Galv Pipe Cut to Size	metre	0.55	R	43.78	R	24.08
9	32mm Galv Pipe Cut to Size	metre	0.25	R	43.78	R	10.95
10	32mm Galv Pipe Cut to Size	metre	0.15	R	43.78	R	6.57
11	32mm Galv Pipe Cut to Size	metre	0.1	R	43.78	R	4.38
12	32mm Weld Socket (Coupling)	no.	1	R	4.20	R	4.20
13	Thread Tape	roll	0.5	R	2.95	R	1.48
14	Cement	pkts	0.05	R	37.50	R	1.88
15	1/2 Crushed Rock	bag	0.2	R	10.00	R	2.00
16	River Sand (unit price estimate)	bag	0.2	R	5.00	R	1.00
						R	**124.22**
	uPVC Discharge Pipe and Tap						
1	25mm UPVC Class 16 pipe	metre	0.4	R	5.40	R	2.16
2	32mm UPVC above-ground pipe	metre	1.4	R	7.56	R	10.59
3	No. 8 Galvanised wire	metre	0.5	R	1.00	R	0.50
4	32mm-25mm UPVC Reducing Socket	no.	1	R	5.95	R	5.95
5	32mm UPVC Tee Socket	no.	1	R	6.12	R	6.12
6	32mm UPVC Elbow Socket	no.	1	R	5.10	R	5.10
7	25-32 UPVC Male Adaptor	no.	1	R	6.08	R	6.08
8	32mm UPVC above-ground pipe	metre	0.55	R	7.56	R	4.16
9	32mm UPVC above-ground pipe	metre	0.25	R	7.56	R	1.89
10	32mm UPVC above-ground pipe	metre	0.15	R	7.56	R	1.13
11	32mm UPVC above-ground pipe	metre	0.1	R	7.56	R	0.76
12	32mm Weld Socket (Coupling)	no.	1	R	4.20	R	4.20
13	PVC Weld Cement (Glue)	ml	10	R	0.10	R	1.00
14	Cement	pkts	0.05	R	37.50	R	1.88
15	1/2 Crushed Rock	bag	0.2	R	10.00	R	2.00
16	River Sand (unit price estimate)	bag	0.2	R	5.00	R	1.00
						R	**54.51**

Appendix E

Pumping Trials Data

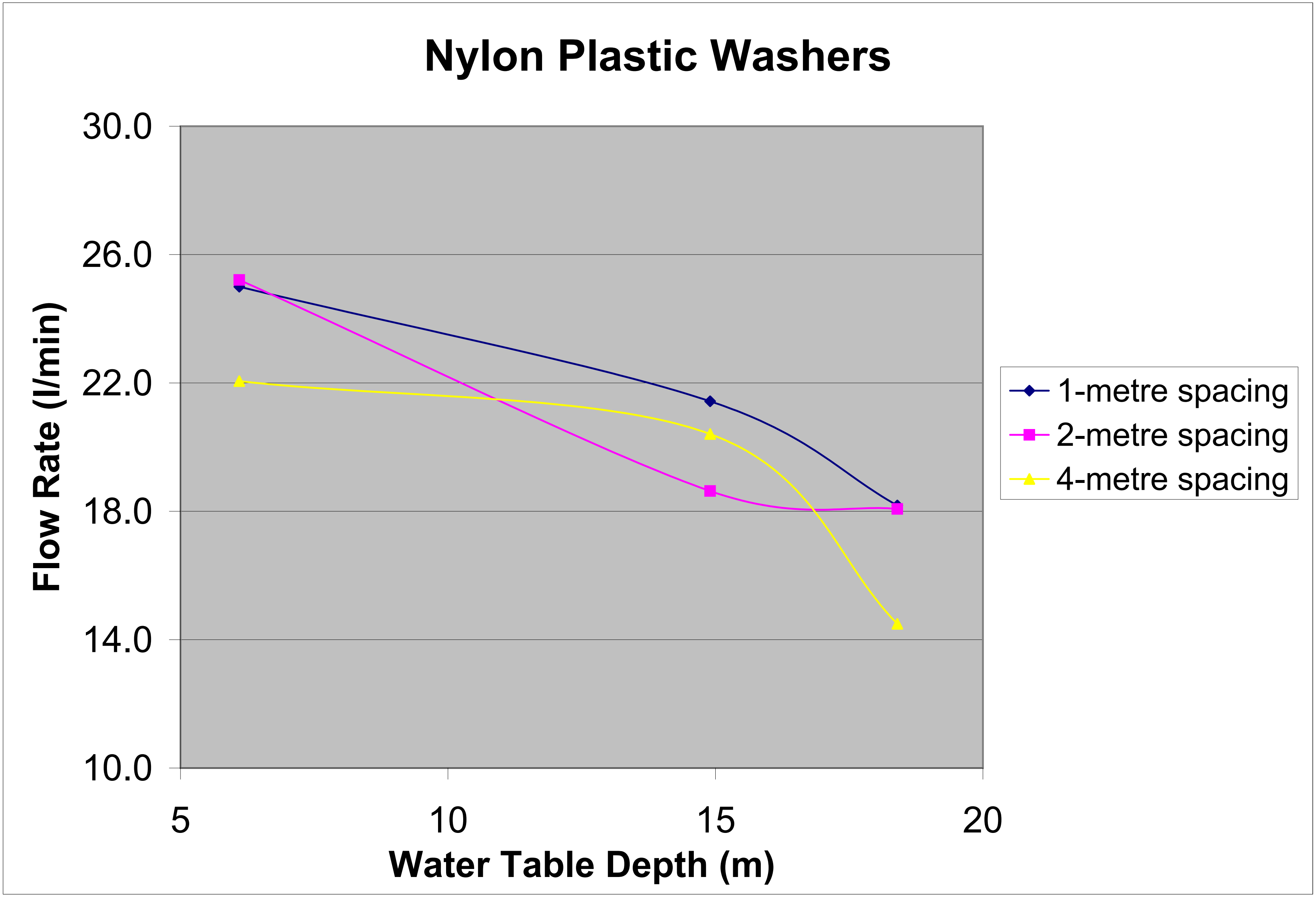
R & W Pump	A	B	C
Pump Name	Thwala	Ikawu	Ncube
Water Table (m)	22	18.1	7.5
Pump Depth (m)	21.5	17.5	7.4

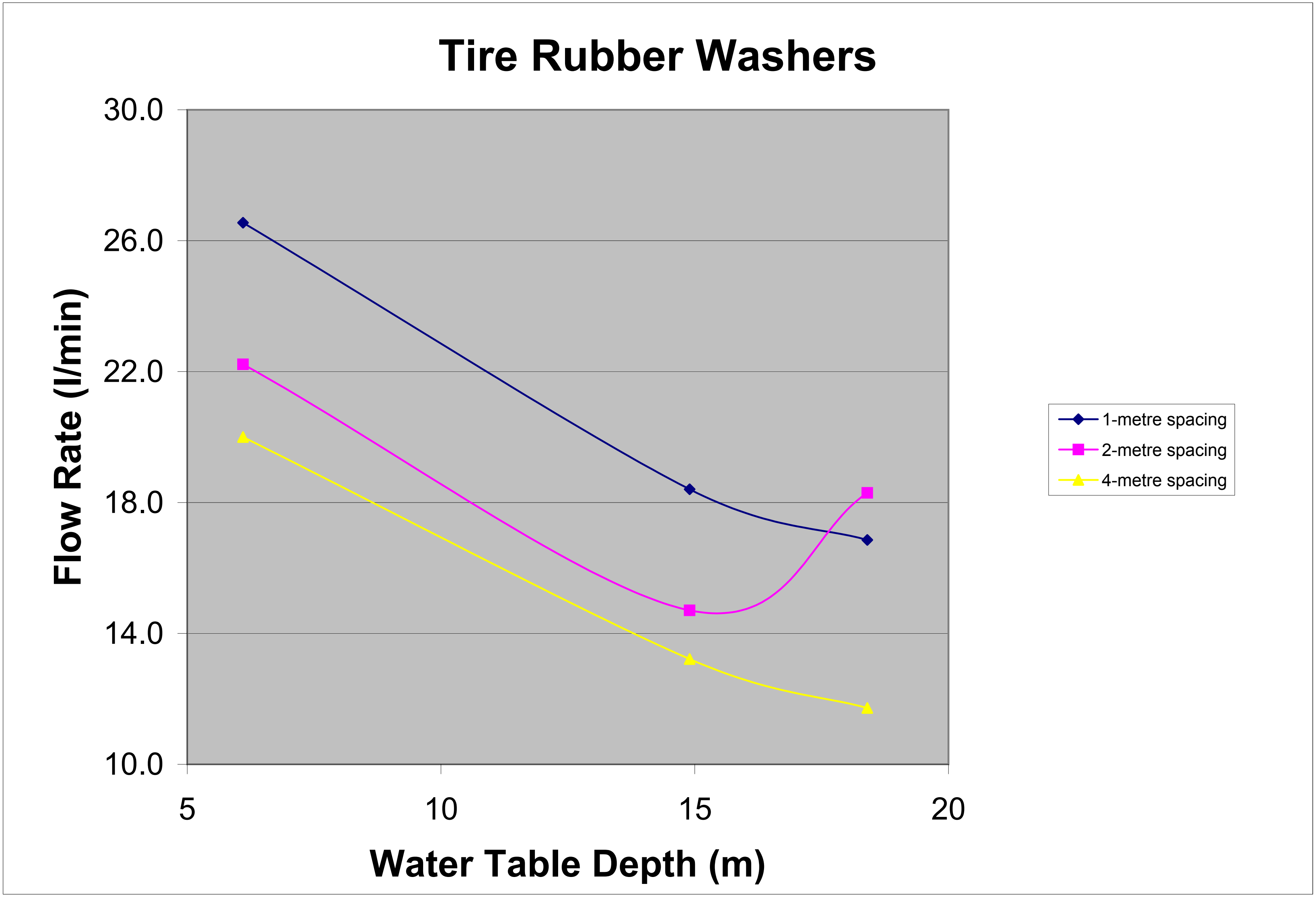
Subjects used to perform pumping:
Jomo Thwala: Healthy 24-year old male
Pindila Thwala: Healthy 13-year old female

			JOMO				PINDILA				AVERAGE					
Rope # / Pump	Washers	Spacing	Time to Start Water	Rev to Start Water	Time to pump 25l	Rev to pump 25l	Time to Start Water	Rev to Start Water	Time to pump 25l	Rev to pump 25l	Time to Start Water	Rev to Start Water	Time to pump 25l	Rev to pump 25l	wt Depth	Litres H20 /minute
1-A	Rubber	1m	15	16	93	76	17	16	85	69	16	16	89	72.5	18.4	16.9
1-B		1m	12	13	81	72	11	11	82	68	11.5	12	81.5	70	14.9	18.4
1-C		1m	6	7	59	56	5	7	54	65	5.5	7	56.5	60.5	6.1	26.5
2-A	Rubber	2m	13	19	82	81	17	17	82	80	15	18	82	80.5	18.4	18.3
2-B		2m	14	13	115	72	12	12	89	75	13	12.5	102	73.5	14.9	14.7
2-C		2m	6	7	80	57	6	6	55	61	6	6.5	67.5	59	6.1	22.2
3-A	Rubber	4m	22	23	148	140	20	20	108	110	21	21.5	128	125	18.4	11.7
3-B		4m	14	13	131	110	12	13	96	85	13	13	113.5	97.5	14.9	13.2
3-C		4m	9	9	87	69	7	13	63	69	8	11	75	69	6.1	20.0
4-A	Plastic	1m	19	16	90	75	14	15	75	68	16.5	15.5	82.5	71.5	18.4	18.2
4-B		1m	12	11	75	68	9	10	65	62	10.5	10.5	70	65	14.9	21.4
4-C		1m	6	6	65	61	6	6	55	56	6	6	60	58.5	6.1	25.0
5-A	Plastic	2m	18	20	79	82	14	13	87	69	16	16.5	83	75.5	18.4	18.1
5-B		2m	11	12	84	69	10	10	77	65	10.5	11	80.5	67	14.9	18.6
5-C		2m	7	6	67	65	5	6	52	58	6	6	59.5	61.5	6.1	25.2
6-A	Plastic	4m	23	20	122	98	16	18	85	81	19.5	19	103.5	89.5	18.4	14.5
6-B		4m	11	11	74	68	11	11	73	67	11	11	73.5	67.5	14.9	20.4
6-C		4m	7	6	83	62	5	6	53	59	6	6	68	60.5	6.1	22.1
				Avg-all trials	16.7			Avg-All trials	20.21							

Bucket Pump Data

Pump Name	Tubewell (metres)	Time to Pump 25l (s)	Pumping Rate (L/m)
Zweli Pump	22	383	3.9
Thwala Pump	18.3	336	4.5
KbomoPump	8.3	185	8.1


Nylon Plastic Washers
30.0
26.0
22.0
18.0
14.0
10.0
Flow Rate (l/min)
5
10
15
20
Water Table Depth (m)
1-metre spacing
2-metre spacing
4-metre spacing



Tire Rubber Washers
30.0
26.0
22.0
18.0
14.0
10.0
Flow Rate (l/min)
5
10
15
20
Water Table Depth (m)
1-metre spacing
2-metre spacing
4-metre spacing

Appendix F

R & W Pump Repairs

R & W Pump Repairs

Routine Repairs

The following routine repairs/maintenance to the R & W Pump can be performed by the pump owner or owner's representative. The knowledge needed to perform these repairs should be transferred during the pump installation.

1) Changing or re-attachment of the rope
2) Changing of the washers on the rope
3) Changing of the straw mat for the Maputaland Hygienic Cover
4) Repair of the rising main pipe due to a disconnection at the couplings.
5) Adjustment of headwork pipes.

Other repairs to the R & W Pump are non-routine, and may require a technician to service.