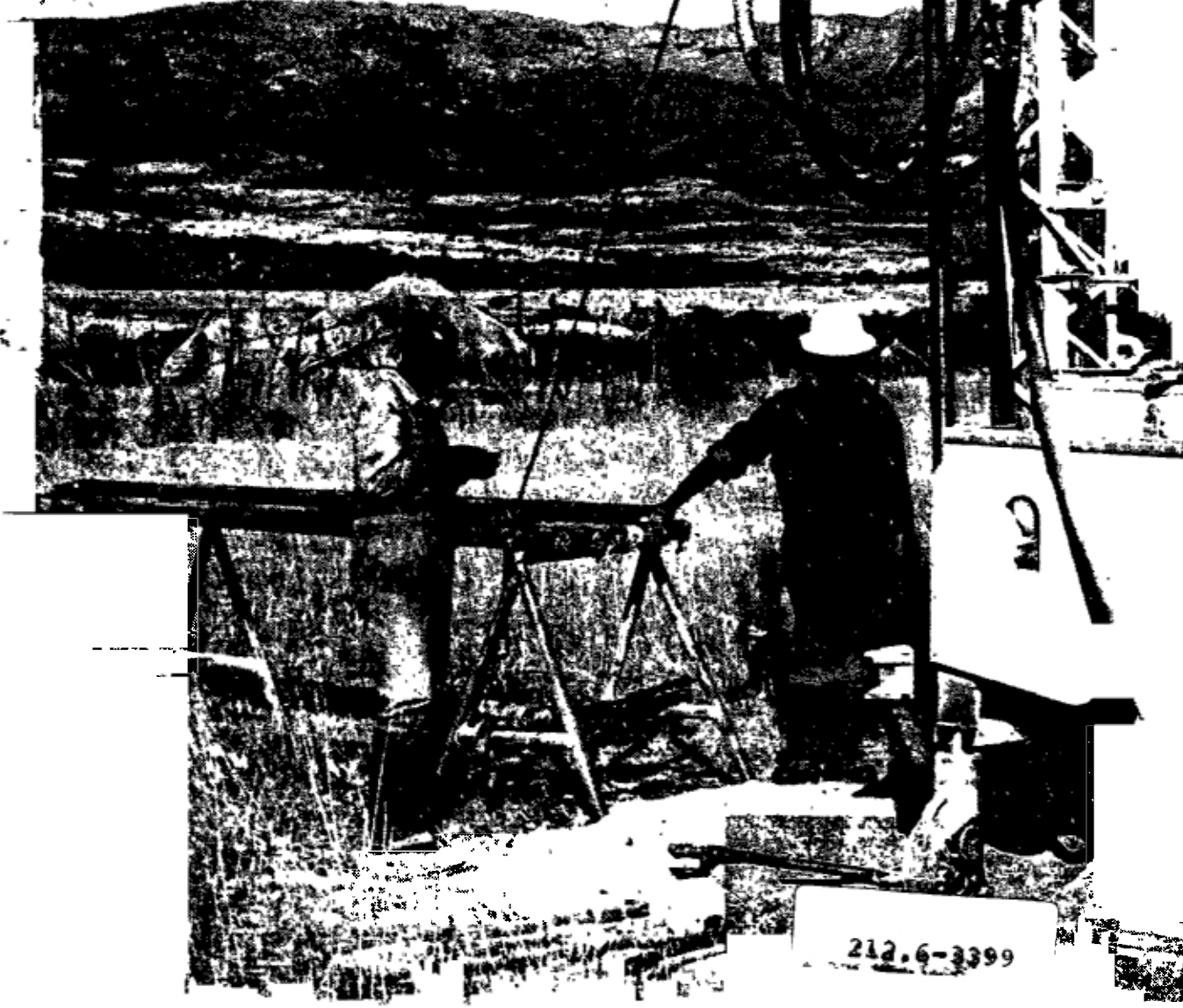


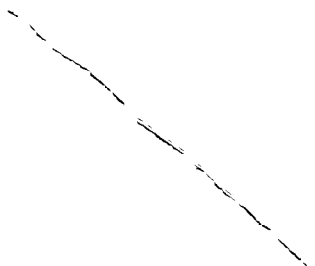
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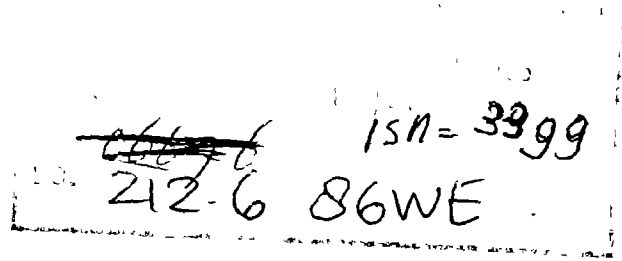






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WELL-DRILLING RIGS IN RURAL AFRICA
- A COMPARATIVE STUDY

by

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SUMMARY

Well-drilling in rural Africa is a subject much discussed today, as the "Water Decade" progresses. One matter concerning the well-drilling organizations is the choice of well-drilling equipment and particularly the choice of the actual drilling rig. It is of great importance that the equipment, often purchased in the western countries, works without any major complications despite the primitive conditions.

The aim of this study is to evaluate the conditions of a well-drilling rig operating in a low-technology project (for hand-pump installation) and to propose an appropriate drilling rig for this purpose.

The range of drilling rigs was limited to those cable-tools and air-percussion rigs suitable for operating on this kind of project. They were divided into four groups and compared according to a number of parameters regarding technical, economic and miscellaneous aspects. The information and facts were gathered from interviews, drilling records and manufacturer specifications over a period of two months in Zimbabwe.

The result of the analysis and interviews shows that a ^{Small} medium-sized well-drilling rig is the most appropriate under the present conditions.

The report concludes with a number of proposals on various aspects of well-drilling.



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INTRODUCTION

Preface

This report is the result of a study carried out by Anette Ohlsson, a student at the Technical University of Linköping.

The fieldwork was performed over a period of seven weeks in Zimbabwe and two weeks in Kenya during July and August 1985.

The report serves two purposes:

- the study is an integral part of the course leading to a Masters Degree in Mechanical Engineering. It is presented as the final project and thesis for graduation requirements. Engaged as tutor at the University was Lennart Hågeryd M.Sc. and in Zimbabwe Mr Lars Carlsson, Project Manager.
- the study is also an account to the Swedish International Development Authority, SIDA, who sponsored this study under the MRT-scheme. With an aim to increase the interest in and understanding about to perform a "Minor Research Task", (MRT). The fieldwork is carried out over two months in a developing country and the cost of living, transportation, insurance etc is covered during this time.

Acknowledgements

I would like to direct my gratitude to everyone in Zimbabwe and Kenya who made my and Torbjörn Arrland's study of well-drilling projects in Africa possible.

In particular I am thankful to our tutor Mr Lars Carlsson and his assistant Mr Ragnar Hurtig, who willingly shared with us their valuable time and gave us the benefit of their knowledge.

The personnel at NORAD; Mr Auge Kruger and Mr Finn Carlssen working at Ministry of Energy and Water Resources and Development (MEWRD), Mr Peer Spone, Mr Ian Clifford, Mr Stig Lien at Interconsult A/S, receive my kindest regards for their help and cooperation in our work both in Harare and out in the field. I am also grateful to Mr Trevor Corrigan and Mr Dave Heywood at Geotest Ltd. who showed us the realities of running a well-drilling project.

At MEWRD I would also like to thank Mr Sharp, Mr Robert Mutepha and Mr Holland for their assistance in our search for information about the projects and the rigs.

Mr Hugo Herm at SIDA in Harare helped us out when we did not get any information and thus deserves special mention.

Mr Don Ferreira and Mr Anders Riesberg at Atlas Copco Ltd., Harare, gave us very kind treatment both during and after working time, which was much appreciated.

In Kenya Mr Christer Johansson and his family are kindly remembered for their warm hospitality and friendliness.

At the Swedish Embassy and Ministry of Water Development in Nairobi we got all the assistance we needed and I would in particular like to thank Mr Willy Hagström and Mr Lars Eric Lindgren.

Finally a special mention to SIDA who financed this study; Mr J-O Johansson, Welldrill Systems AB, who initiated it and gave a lot of encouragement; Mr Ivan Rankin, who corrected the language and helped me with the printing, and to everyone in Sweden and neighboring countries who supported me with facts and information.

Background

In a special session of the United Nations General Assembly in New-York on November 10th 1980 the "International Drinking Water Supply and Sanitation Decade" was officially proclaimed. The target is to provide safe water and adequate sanitation for all people by 1990.

This announcement started off a number of activities in the dry and poor countries of the world. Many new projects sponsored by the wealthier nations were formed.

Africa is the continent particularly in focus where matters dealing with water are concerned, and in particular the demand for water in *rural* areas.

There are many ways of collecting water: traditionally from springs, rivers and wells. The hydro-geological and climatic conditions set the terms for how the water can be produced. One of the best ways to ensure a permanent and clean water supply is to use the ground water resources and drill a well. The method is fast, has a high success rate of finding water and can be used almost anywhere.

To fulfil the ambitious target of the Water Decade it is necessary to proceed with the water projects rather quickly. The drilling methods used in a well-drilling project are therefore particularly topical at the present moment.

When starting up a well-drilling project, the question of what equipment to use arises. The final decision depends on many factors:

- how many wells should be drilled
- what the geological formation is like
- who is going to do the drilling
- in what time perspective the project is run, etc.

In many cases drilling equipment is brought from the technologically highly developed countries, designed specifically for their good infra-structure, well-developed service organizations and well-educated personnel. Coming to Africa the conditions are different and the rigs might not work as well as in their countries of origin since there is often a lack of spare parts, fuel shortage, access problems etc. Technical sophistication does not necessarily lead to drilling efficiency.

Most bigger drilling projects in Africa are monitored by a governmental institution often in cooperation with a sponsoring country. The drilling equipment often ends up in the care of the ministry responsible for the water supply. On this administrative level other problems of a financial and organizational nature can occur.

A parallel study of the best way to implement a water project financially and organizationally with the title "Well-drilling in Africa - a study of different investment forms and project management", was performed by Mr Torbjörn Arrland LiTH, 1985.

Purpose

The aim of this study was to look into the special operational conditions of drilling rigs in Africa and to investigate which equipment is most suitable for use by Africans in a rural water supply project.

This report is intended for officials in decision-making positions working in sponsoring organizations. Hopefully some aspects as to which equipment to buy when starting up drilling projects or sponsoring a water-producing establishment will be provided.

Limitations

The main interest of this study is in the drilling rig itself, by definition including auxiliary equipment as compressor and drilling tools. Other equipment necessary for the drilling, such as transport vehicle, is also considered.

Where well-drilling is concerned the trend seems to be moving towards increased activity in low technology schemes i.e. rural water supply projects which equip the bore-holes with a hand pump; consequently this forms the central theme of the present study.

Performance

The field studies and the main part of this investigation were performed in Zimbabwe. This country is particularly suitable because of the high number of well-drilling projects being carried out there. A variety of projects sponsored by various organizations using different kinds of drilling equipment can be found in the country, as well as a large number of drillers with experience from Zimbabwe and its neighboring countries. Some of these drillers were interviewed, as were people at different levels in the hierarchy. The interviews formed a knowledge base for the further study of the technical specifications of the rigs, their drilling records and some economical aspects such as running cost.

To broaden the study a shorter visit to Kenya was made. Here similar studies to those in Zimbabwe were carried out but on a much smaller scale because of time limitations.

Layout of report

This report begins with a theoretical section dealing with ground water and well-drilling in general to provide a basis for the second part which presents the actual study: the rigs, the parameters, how and why. In the third part the results are presented and finally the fourth part concludes with recommendations about well-drilling.

1. GROUND WATER

Water is one of the most important elements on Earth. The total amount of water is constant but the appearance changes between gaseous, liquid and solid.

Of all the water in the world approximately 97% is found in the oceans as salt water. Of the remaining three percent 77% is bound in solid phase in the polar ices and glaciers; 11% is hidden deep beyond the surface, unreachable for mankind; another 11% is closer to the earth's crust, the ground water; the rest can be found in lakes, rivers and in the atmosphere (Atlas Copco Manual, 1982).

The changes of the different phases of water are known as the *hydrological cycle*.

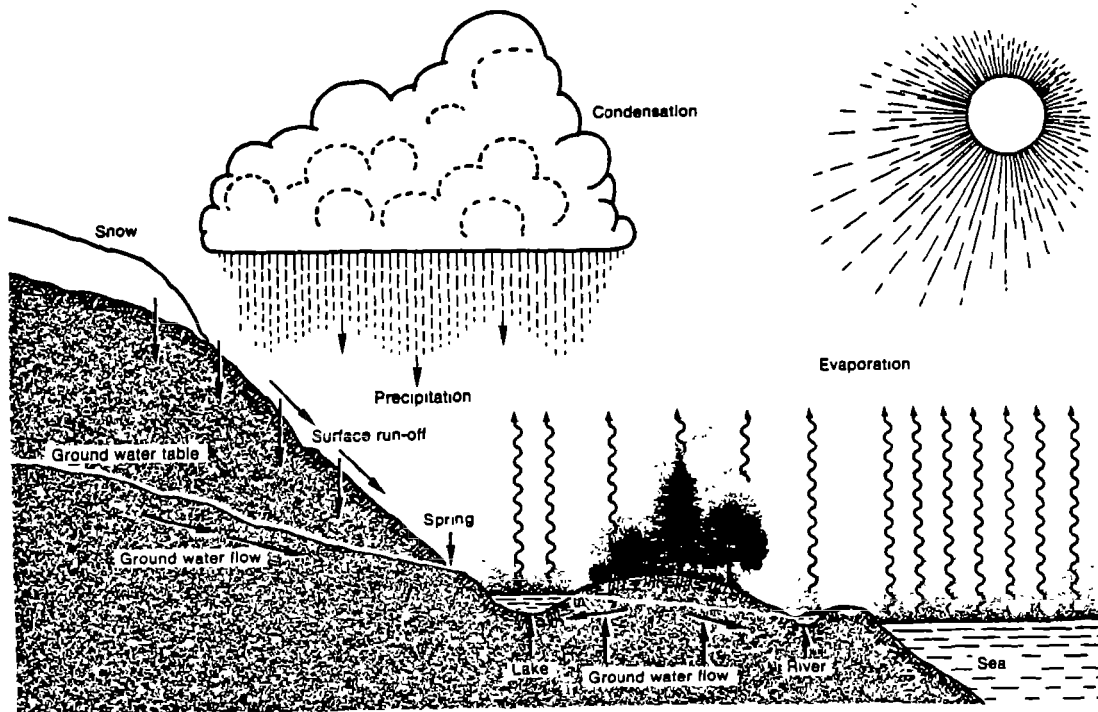


Figure 1. 1 The hydrological cycle (Atlas Copco, 1982)

Water infiltrating the ground passes through the unsaturated zone of the soil layers under the influence of gravity until it reaches the saturated zone. From now on the water moves with a lower water table. If the amount of water is large enough to serve as a water supply, the saturated geological formation is called an aquifer.

Important parameters for an aquifer are:

- permeability - the capability to transmit water and yield it to a well (m/day) or (cm/s)
- porosity - the total measure of the space among the grains or in the cracks that can be filled with water, (%).
- specific yield - the ratio of the volume of water that after saturation can be drained by gravity, (%).

These parameters are very much dependent on the grain size of the formation and whether the size is homogeneous or not.

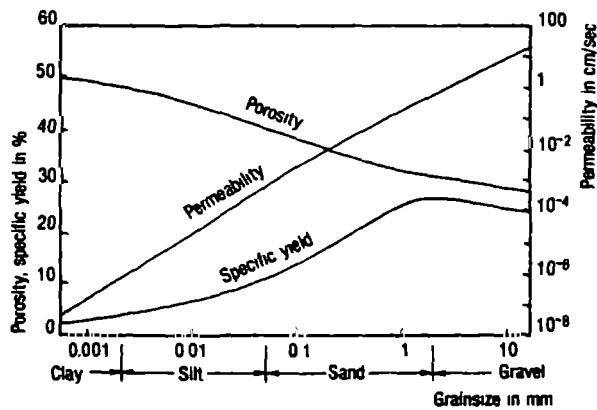


Figure 1. 2 Porosity, permeability and specific yield as a function of the grain size (Blankwaardt, 1984)

A good aquifer contains homogeneous material with high permeability, porosity and specific yield. As shown in the figure, coarse sand and gravel are the most suitable aquifers.

When pumping water from a well, the movement of the ground water can be described by a modified Darcy's law:

$$Q = \frac{\pi \times k \times (H+h) \times s}{\ln (R/r)}$$

where Q = well yield

k = permeability

H = saturated thickness

h = reduced thickness as result of pumping

s = draw down (H-h)

R = radius of influence

r = radius of the well

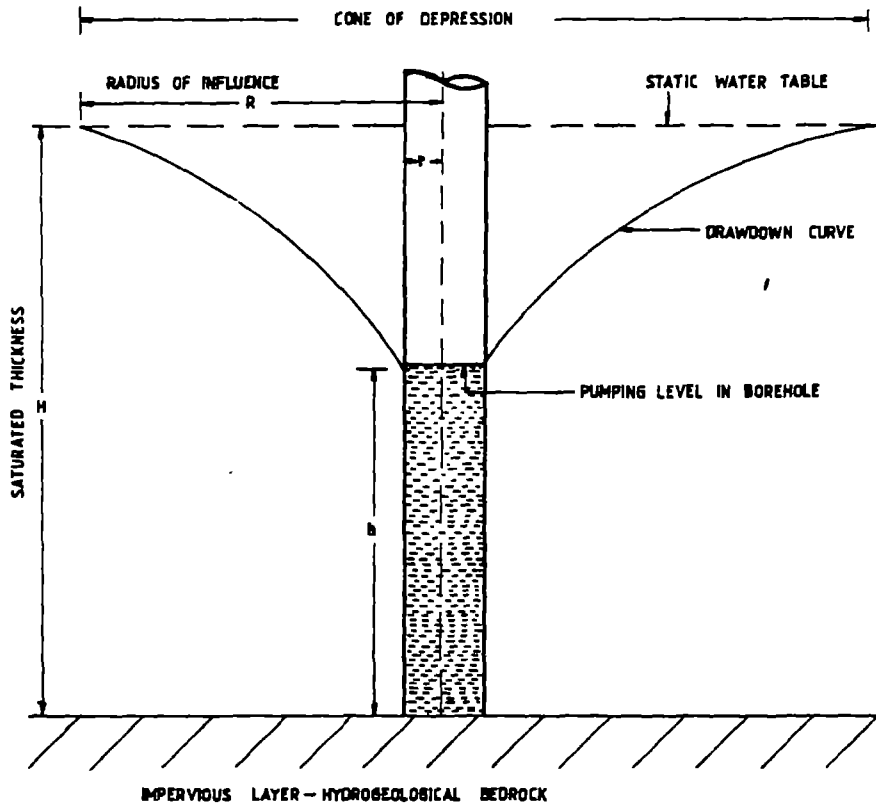


Figure 1. 3 Parameters controlling flow into a bore hole
(National Water Master Plan of Zimbabwe, 1985)

From this formula two important remarks can be made:

- The yield of a well is inversely proportional to $\ln R/r$. An increase of the well diameter only has a limited effect on the well yield.

For some common drilling diameters the relative increase of the yield is ($R=100$ m):

76mm(3")	101mm(4")	127mm(5")	152mm(6")	203mm(8")
100	104	108	111	116

When deciding what drilling diameters to use the well yield should not be regarded as an important factor.

- The yield is directly proportional to the draw down, s , which means that a doubling of the draw down also doubles the yield of the well.

It is obvious that for getting the maximum water production the aquifer should be fully penetrated and the bore hole should be screened all through the saturated zone.

There is usually a clear connection between the rainfall in an area and the level of the water table. In the dry season the level decreases. This gives another reason for drilling the fully thickness of the aquifer.

2. HYDRO-GEOLOGY

2.1 Overburden

By definition the overburden consists of the formations above the bedrock. In areas with basement rock there is a soft soil layer at the top, turning into a more consolidated weathered zone as the depth increases. The water table usually rests on the hard rock at the bottom of the overburden.

2.1.1 Soil

The occurrence of ground water in soil depends on:

- the grain size and homogeneity (i.e. porosity and permeability)
- the terrain and climate
- the surrounding soil types and/or rock types

The water yield therefore shows wide variation.

Soil consists to a great extent of weathering products such as sand, clay and gravel.

The fine-grained sand and clay is not regarded as a favorable formation either from the water-producing or the drilling point of view. It yields very little water and the drilling can be very complicated, particularly if boulders are present. Areas with coarse-grained sand or gravel are more preferable.

In soil well diameters can be very large, even more than 600 mm (24"). The well is usually cased to the full depth and screens and gravel packs are very common.

2.1.2 Weathered zone

Between the soil and the bedrock there is usually a zone of weathered rock. The degree of weathering can vary a great deal and so does the water content of the formation. Particularly in tropical and subtropical areas the weathered zone contains clay which reduces the permeability.

Knowledge about the thickness of the formation gives valuable information about the expected success rate of finding water and the capacity of the aquifer. If the thickness is not adequate, digging a well can be an alternative to the drilled bore-hole.

Both uncased open bore-holes and cased- and screened- well constructions are used depending on the local conditions.

2.1.3 Drilling in overburden

Drilling through soils and weathered zones can be more complicated than in hard rock specially when using an air percussion drilling method.

- The unconsolidated formation can plug the bore hole, particularly if clay is present.
- Boulders in the ground can move into the bore hole and stop the drilling tool from being pulled out.
- The soft formation is more elastic which makes the drilling action less effective.

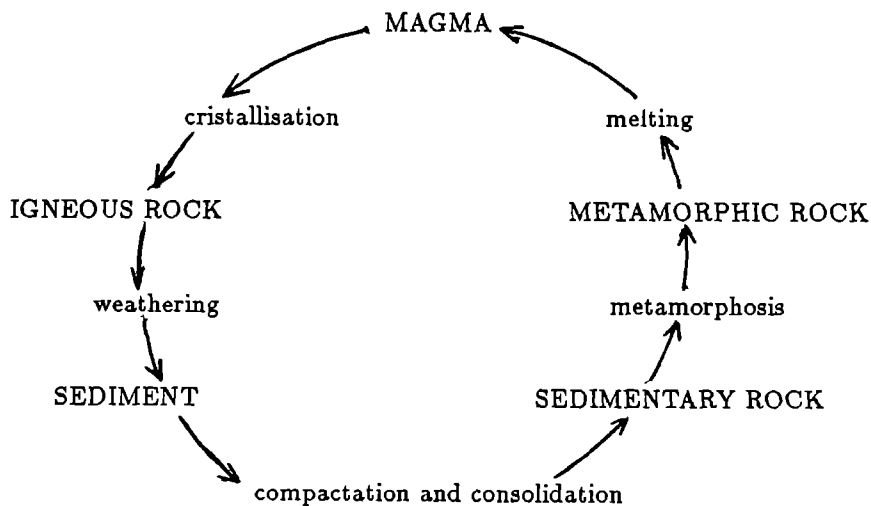
If an air percussion drilling method is used most problems are avoided by drilling with the eccentric ODEX-hammer. When rotary drilling a roller bit combined with mud flushing is preferable (See 3. 2 Drilling methods).

2.2 Rock Types

Geologists classify rocks in three major groups, due to their age and origin:

- Igneous rock
- Sedimentary rock
- Metamorphic rock

The different rock types are joined in a geological cycle:



The drillability of a rock is very hard to determine since it varies much depending on the grain size, the hardness of the included minerals, etc. The rock is more or less abrasive to the drilling tool which sets both the penetration rate and the costs of drill bits.

	Rock			Soil
	magmatic	metamorphic	sedimentary	
examples	granite basalt	gneiss quartzite	limestone sandstone	clay sand gravel
hardness	very hard—hard	very hard—hard	hard—soft	non-consolidated
aquifer potential and ground water occurrence	generally low yield, in cracks and joints	generally low yield, in cracks and joints	highly variable yields, usually moderate to very good in cracks and cavities	clay, very low yield sand, high to moderate yields gravel, very high yield
diameter of well	102—203 mm	102—203 mm	152—305 mm	203—810 mm
depth of well	25—150 m	25—150 m	25—300 m (or more)	25—300 m (or more)
casing tube	open hole or surface only	open hole or surface casing only	open hole or surface casing only	usually full depth
screen	none	none	depending on characteristics of formation	yes
gravel pack	none	none	none	yes or natural gravel pack
drilling tool	down-the-hole	down-the-hole	down-the-hole, Odex or roller bit	auger down-the-hole, Odex or roller bit
flushing	air or air/foam	air or air/foam	air, air/foam, water or mud	air, air/foam, water or mud

Figure 2-1 Well-design and drilling method for different formations (Atlas Copco, 1982)

2.2.1 Igneous rock

The oldest rock type is the igneous rock which is formed when magma from the great depths of Earth cools and solidifies. Magma solidified under the surface is called *plutonic rock*. This type is usually not porous and contains and transports very little water. Aquifers are found in fissures and fractures in the rock and occasionally in the upper weathered zone. The most well-known plutonic rock is granite, widely spread in both Scandinavia and Africa.

Magma cooled at or near the surface is called *lava*. This type can be very porous and contains good aquifers. The harder and consolidated types of lava are not considered as good water producers.

2.2.2 Sedimentary rock

When soft formations such as clay, sand, lime mud etc are compacted and consolidated because of heavy layers above, sedimentary rock is formed. Clay becomes shale, sand becomes sandstone, gravel becomes conglomerate and so on. The occurrence of ground water in these rock types is similar to the original unconsolidated sediment but due to the compaction, the pores are smaller and the water capacity less. Water can also be found between layers and/or in cracks in the formation. The drillability in sedimentary rock shows considerable fluctuation since the rock types include both soft and hard formations and there are big differences in grain size.

2.2.3 Metamorphic rock

The metamorphic rock is the result of long action at great depths of heat, high pressure and solutions upon igneous and sedimentary rocks. The crystalline structure is not changed since the rock never is melted. The metamorphosed limestone is called marble and it is the best water producer of this rock type. Others such as quartzite (from sandstone), slate (from shale) and gneiss (from granite) are usually poor aquifers. Some water can be found in cracks and fractures.

The rock is hard to penetrate and the well construction is similar to igneous rock. (Water Well Handbook, 1973)

2.3 Siting a bore hole

Choosing the right place for a well or a bore hole is one of the most important but also one of the most difficult activities when producing wells.

In the old days and in some places even today a divining-rod is used for locating the aquifer. This method is not recommended by the modern hydro-geologists though. They prefer a thorough investigation of the geophysics of the studied area. A variety of parameters are looked into such as the terrain around the area, the rock type, the kind of soil, rainfall etc.

For determining the existence of ground water in an area investigations are primarily made on existing bore-hole records, photo-geological studies, hydro-geological maps etc. The next step is to decide where to locate the actual drilling site and here geophysical methods are of great service. The common methods used in ground water exploration are:

- electrical resistivity method
- magnetic method
- electromagnetic method
- seismic method

To obtain the optimal success rate two or more methods should be combined, but usually only one is used at the time for economic reasons and lack of experience and personnel. The electrical resistivity method is the most versatile, cheapest and most applied method when locating where to drill a bore-hole and hence the only one described. The instrument is easy to carry around and relatively uncomplicated to use.

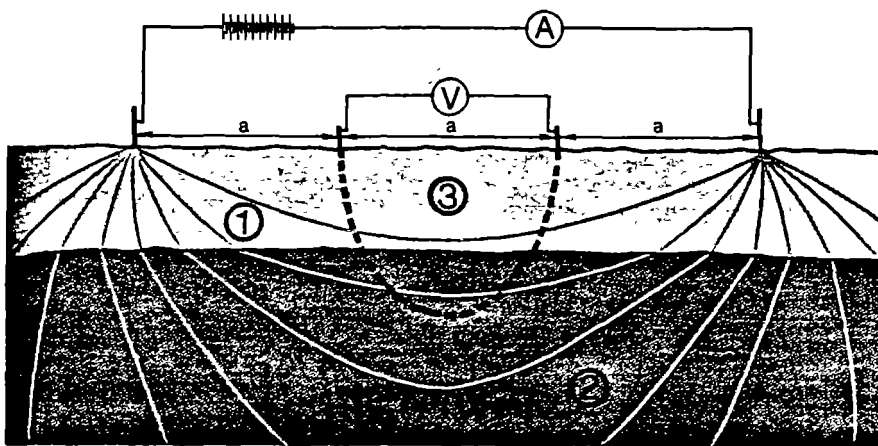


Figure 2. 2 Electrical resistivity method (Lundin, 1977)

An electrical current passes between two electrodes and the voltage drop is measured between another two interior electrodes (See fig). The resistivity of the formation can be calculated when the current and potential drop is known.

In unconsolidated formations the resistivity is determined more by the content and quality of water kept in pores and interstitials than by the resistivity of the dry formation itself. This electrical method can therefore directly be used for indicating the presence and quality of water, particularly in tropical areas where soil-covered bedrock is common.

The very best way of determining the optimal location for a bore-hole is to perform explorational drilling in the area. However, the method is too costly and slow to be used in rural water supply-projects.

3. WELL DRILLING

3.1 History

Fetching the life-giving water from the subsurface is a remarkably old activity that has engaged peoples' ingenuity all over the world throughout history.

One of the oldest well-known is Jacobs Well situated halfway between Jerusalem and Nasareth in modern Israel. The mysterious well was probably constructed long before Christ was born and is even mentioned in the Bible (John 4:6). It was hammered out by hand through the hard rock.

Further east in China, they produced wells in a much more efficient way:

a spring pole attached to lengths of bamboo was set into motion and with a chisel bit in the bottom of the bamboo string the rock was crushed to pieces. The very first *cable tool*!

Later the bamboo was exchanged with a cable and the chisel bit with a bit made of iron, but the principle is still the same.

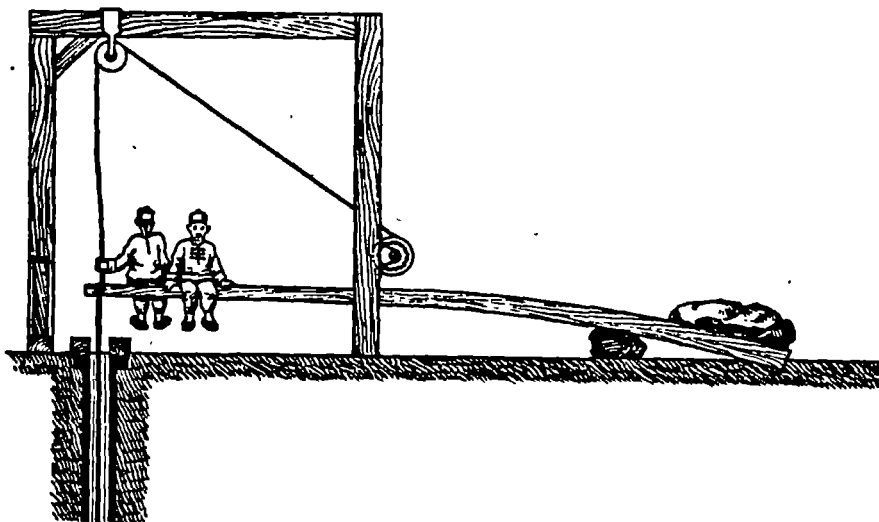


Figure 3.1 Chinese cable-tool drilling (Andersson, 1981)

The Europeans did not learn about this method until the 18th century but as soon as it was introduced it spread quickly. During the following century the percussion method was developed and improved, a steam engine was installed and the rig was made portable.

In the beginning of the 1900's when the growing oil-drilling industry needed better drilling methods, the first *rotary drilling rig* saw daylight. A modified rig more suitable for well-drilling with a smaller engine and a portable chassis was constructed and later on further developed. This rig dominated the scene for decades.

Not until the last twenty years has the *air percussion method* been used for well drilling. The technique originates from the mining industry and with some modifications it became the fastest and most versatile well-drilling method. Today the air percussion rig is gaining ground mainly at the expense of the rotary rig which has already overshadowed the cable-tool. Nevertheless the cable-tool is still going strong and playing an important part in well production, particularly in developing countries.

3.2 Drilling methods

In this study only current well-drilling methods capable of drilling through consolidated formations are considered. Alternative methods such as auger- and top-hammer drilling are left out. The remaining types are classified by the way the rock is destroyed and how the action is powered:

- cable percussion
- rotary crushing
- air percussion

The methods are more or less suitable in different kind of formations which the figures below show.

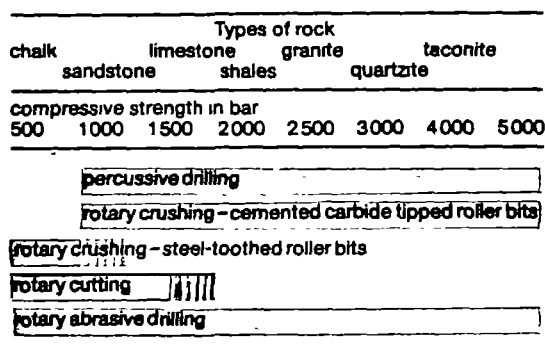


Figure 3.2 Rock drilling principles (Atlas Copco, 1982)

The principles of rock destruction are similar for the three drilling methods.

When breaking up the rock a force is generated in the drilling tool and the energy is transferred to the rock. In the contact point high stress is built up until the rock is crushed and a chip is released. The stress will disappear until the feed moves the tool, a new contact is made and the force is built up again.

The drill chips must quickly be removed from the destruction zone to prevent *secondary cutting*. This unnecessary crushing of the chips increases the wear of the drill bit and decreases the penetration rate. More energy is required for the drilling action when using a tool that is not sharp.

A *flushing media* is used to transport the cuttings away from the destruction zone and up to the surface. Air, water, foam or mud are used for flushing, depending on the current drilling method and formation.

3.2.1 Cable-tool

The ancient percussion method used by the cable-tool might not be the fastest way to drill a bore-hole but it certainly is a versatile method dealing with most formations in an economical way.

Working principles

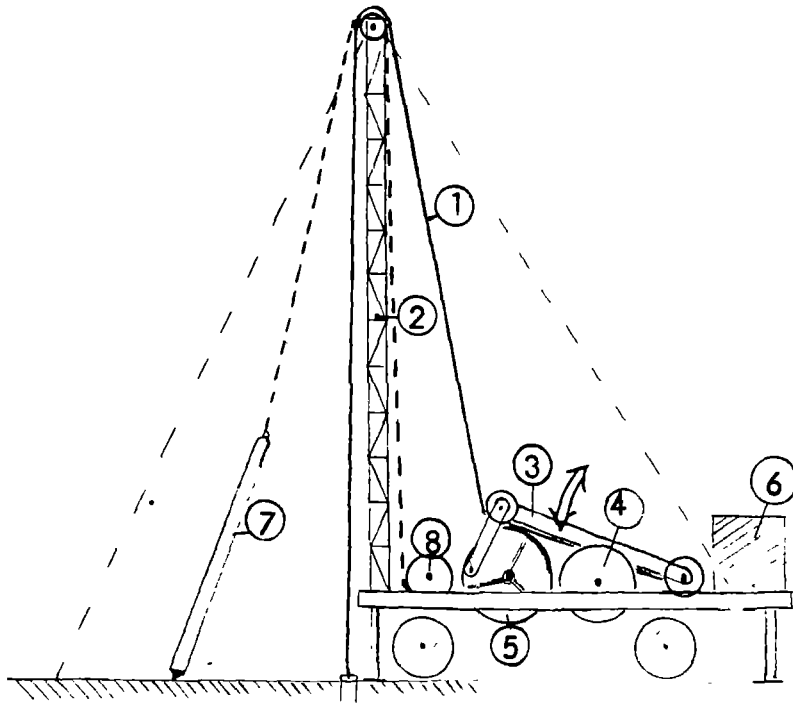


Figure 3.3 Schematic cable-tool

The percussion action of a cable-tool is generated by lifting and dropping a heavy drilling tool.

A wire (1) connected to the drilling tool runs to the top of the mast (2), down passing the spudding beam (3) and is stored on the bull reel (4).

It is the spudding beam that generates the up and down action of the wire and the tool. A pitman (5) connected to a crank gear and driven by the power unit (6) causes the movement. About 20 to 40 strikes per minute is common and the weight of the drilling tool varies between 500 and 2000 kg.

The rig is powered by a diesel engine and the different functions are applied from the back of the rig through clutches and brakes.

In the bore-hole crushed and loosened rock is mixed with water to a slurry, which is periodically removed using a bailer (7). In the bottom of this long pipe there is a check valve which allows the slurry to fill the pipe and be lifted by a second hoist line pulled by the sand reel (8). The drilling action has to be stopped and the drilling-tool lifted out before the bailer can be lowered and the slurry removed.

In very soft formations where collapses happen easily, casing can be driven down directly and the mud is bailed out afterwards. The drilling can also be stopped every second metre and a casing is installed.

When the rig is transported, the mast is lowered and taken apart. This is a rather time-consuming job taking several hours. The moving- operation of the rig is slow, rarely less than one day.

General

The construction of a rig is very simple, strong and sturdy. Most of the repair work except for major breakdowns can be done at the drilling site by the crew without any supervision. Even though a cable-tool is considered simple to operate compared to the modern hydraulic rigs and less training is required for the crew, a great deal of skill and experience is needed for drilling in the most efficient and safe way.



Figure 3.4 Cable-tool drilling in Zimbabwe

As the rigs are constructed today the working conditions are not the best; wires and moving parts are unshielded and the heavy tools can easily be dropped. One man must hold the wire centered in the bore-hole all the time to secure strait drilling and feel when the tool should be lowered.

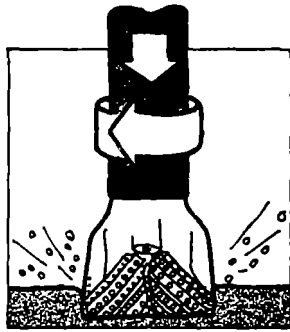
The crew is usually made up of one driller and 2-5 helpers. Particularly when moving the rig to a new site and when the drill bit is changed manpower is needed.

Dressing the bit is another time consuming task requiring great skill.

Since relatively small quantities of water are used for drilling and only one fuel-consuming engine is operating on the rig, very little support is required from a supply organization. If the rig is mounted on a trailer the crew can be left at the site and supplied only when needed. Naturally some kind of vehicle or communication radio must be on site for safety reasons.

driven by hydraulic motors.

An alternative to the rotation head is the *rotation table* (8b). A square kelly hangs in a swivel and fits through a hole in the rotation table. This method is common on bigger and more powerful rigs.



A drill bit is pressed down by the weight of the drill pipes and/or by the hoisting chain. It is rotated by the top driven rotation head/-table.

Figure 3. 6 Rotary crushing (Atlas Copco, 1982)

These two factors, feed force and rotation speed, together with torque and lifting force determine the capacity of the rig.

A third important factor is the *flushing media* that is pumped through the hollow pipes and jetted out of the roller bit.

This media has many functions:

- remove the cuttings from the destruction zone
- cool the drill bit
- serve as lubrication
- transport the cuttings to the surface
- seal off the formation walls to prevent caving and water loss

It is of great importance to have the right velocity and viscosity of the flushing fluid. The most common fluid for rotary drilling is mud and water usually mixed with bentonite but foam can also be used. The heavy mud pump can either be mounted on the truck or be transported separately.

If very wide diameters are drilled, the velocity of the mud gets too low for bringing up the cuttings to the surface. *Reverse flushing*, where the fluid is pumped down between the formation and the casing and pushed up through the pipe, can be used in these cases.

General

Hydraulic rotary rigs tend to be rather big, complicated and expensive machines. Only an experienced driller with the assistance of 2-3 helpers can handle the operation of the rig. The maintenance and regular service can be done on site but if a major breakdown should occur an experienced mechanic must be brought or the rig transported to a workshop. The most frequent breakdown is on the hydraulic system. Unfortunately the locally made spare parts are often of such a poor quality that they can not meet the high standards of a drill rig. Most spare parts are therefore imported.

Rotary drilling is mainly used in stable formations where a casing can be inserted after the drilling of the bore-hole is finished. The drill fluid supports the bore-hole walls with its higher pressure and stabilizing components. Drilling in soft formations with boulders present can be very problematic.

Relatively wide drilling diametres can be managed, especially when using reverse circulation, ranging from 100mm to 500mm (4"-20"). The maximum drilling depth depends on the hoist capacity of the mast and the power unit as well as the capacity of the mud pump. Depths of 300m are tackled with bigger machines.

Since the rotary rig is highly mechanized, the working conditions are better than on a cable-tool. The noise from the engine and pumps is high though and there is still some heavy lifting of the tools, pipes and casing.

The relative safe rig can be improved by using safety locks on all hydraulic connections and covering moving parts with safety shields.

The output of a rotary rig is high. One bore-hole (<100m) can be drilled in one day, including transportation. The efficiency of the rig is highly dependent on the support organization, since it has to be supplied with fuel and mud (water) for continuous drilling.

The use of hydraulic rotary rigs in rural water supply schemes is small since the main use of the machine is for drilling holes with larger diametres. Access problems can occur with the relatively big and heavy vehicles, particularly in the wet season.

A rotary rig can also be used for *auger drilling* in very soft formations. The torque forces a tool similar to a corkscrew through the ground. Only shallow holes less than 25m can be drilled.

3.2.3 Air Percussion Drilling with DTH

The most modern and technically advanced drilling method is the air percussion method. It is very fast, specially when drilling through hard rock, and can compete with other methods in almost any formation.

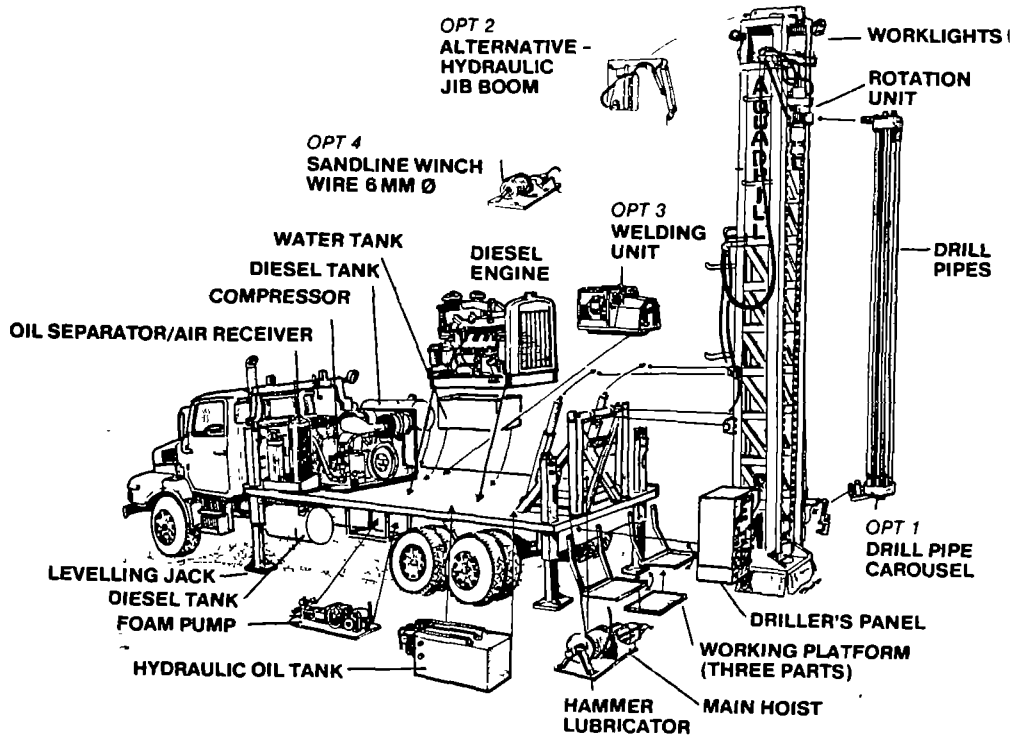
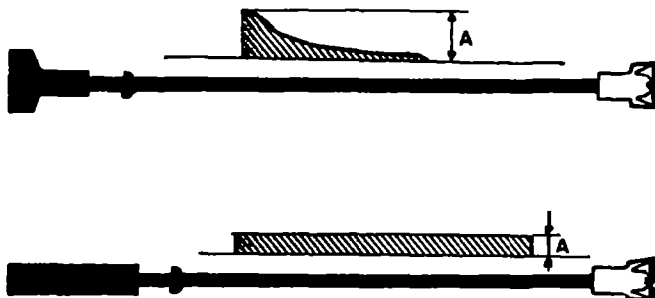


Figure 3. 7 Air percussion drilling rig (Atlas Copco Energy AB, 1985)

Working principles

The air percussion drilling method uses the same equipment as the hydraulic rotary. The main difference is that the compressor that has to be added.

The hitting action is caused by a hammer placed down in the hole with the self-explanatory name *DTH-hammer*, Down-The-Hole. Compressed air supplies kinetic energy to a piston in the *DTH-hammer*.



When the piston strikes the bottom bit, the energy is transmitted in the form of a shock wave, which is finally converted into drilling work in the contact area between rock and drill bit. Some energy is reflected in the drilling rod.

Figure 3. 8 Transmitted energy in the drill-steel (shaded areas) (Atlas Copco, 1982)

The hammer uses the rotation function of the rig to slowly rotate the drilling bit. A new area is therefore struck at each stroke. The normal frequency of the strikes is approximately 50 blows/sec and the rotation is about 80-160 rpm, depending on the hardness of the rock. The harder formation, the slower rotation.

The penetration rate is determined to a great extent by the air compressor. The pressure delivered to the hammer controls the striking frequency and the airflow is used as flushing media with the ordinary functions to remove and transport the cuttings, cool the drill bit, etc .

It is important to keep the air pressure and free air delivery at the correct level:

- the continuous air stream must clean the hole quickly to prevent secondary cutting.
- the velocity of the air must be high enough to carry the cuttings to the surface.

If the area between the bore-hole and the drill pipes is too wide the velocity gets too low and the cuttings might clog up the hole. Raising the hammer produces a strong flow of air, which hopefully removes the clogging. Foam or mud flushing is preferable under these conditions. A water pump with foam injector is usually mounted on the rig and sometimes also a mud pump.

The drilling machine is limited in depth by:

- the lifting capacity of the rig

It must be able to lift the long and heavy rod string out of the hole.

- the maximum air pressure of the compressor

Particularly when the bore-hole is filled with water, the pressure at the bottom of the hole works against the air pressure powering the hammer. If the external pressure is high enough the hammer stops working.

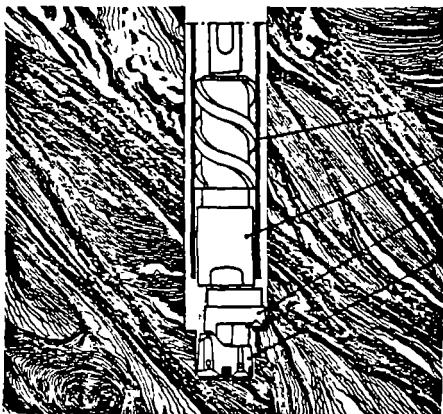
- the airflow,

from the compressor, through the rods, down to the hammer. Decreases with greater depth due to friction losses etc.

The hammer must be balanced with the pull-up and pull-down functions of the rig to get the right feed force on the bit. Too strong a force causes irregular drilling and excessive bit wear, but on the other hand, too weak a force results in vibrations and bad penetration rate.

The bottom bit is dressed with a pneumatic grinder, preferably with the same spherical shape as the hard metal buttons. Grinding is usually done on site.

Both hard-rock formations and soft soil can be drilled with the air percussion method. The more consolidated formations the better. When drilling through overburden problems can occur with collapsing bore-holes. A method called *ODEX-drilling* can be used in these cases:



An eccentric reamer swings out when drilling and gives room for a casing to be installed simultaneously. When the direction of the rotation is changed, the reamer swings in and the tool can be pulled out through the casing.

Figure 3.9 Principle of the ODEX method (Atlas Copco, 1982)

The method is very convenient but quite expensive and requires a well-trained driller. Common drilling diameters are 100-500mm (4"-20") and the drilling diameters go down to 500m for the bigger machines.

General

The air percussion drilling method requires even more support from a supply organization than the rotary rig, since the compressor consumes considerably amounts of fuel. If water, foam or mud is used as flushing media, large quantities of water must be brought as well.

The crew of 2-5 people can carry out the ordinary maintenance but a breakdown must usually be repaired by an experienced mechanic. The compressor has to be serviced by an authorized workshop. Not many spare parts can be made locally. Unless a large stock of common spare parts is kept, the rig must wait for components to be delivered from abroad. The delivery times are rarely less than two weeks and can occasionally be as long as one year.

The transportation of the drilling unit can be solved in many ways, for example:

- the rig and compressor mounted on separate lorries
- the rig and compressor mounted on separate trailers
- the rig mounted on a lorry and the compressor pulled behind on a trailer
- the rig and the compressor mounted on the same lorry

There are a number of auxiliary machinery and other equipment such as the camp that have to be transported and taken into consideration when planning the transportation.

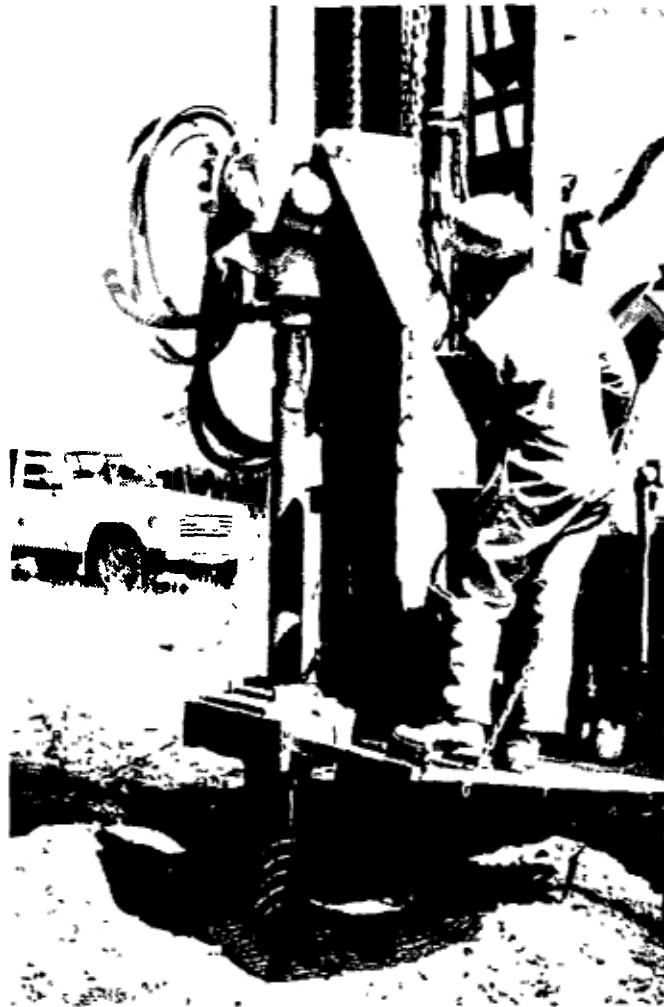


Figure 3. 10 Air percussion drilling

The working conditions on an air rig are considered good and relatively safe. The drilling is noisy and can be very dusty when drilling in dry formations.

The air percussion drilling method is the most modern one and its use will probably increase among well-drilling rigs.

The trend is moving towards more advanced maneuvering systems, to speed up the operation time and reduce the number of men working on the rig. This development is less interesting for the poorer countries where labor is cheap but good mechanics rare.

3.3 Organization

The organization of a well-drilling project in rural areas is one of the most important parameters for the efficiency of the drilling. The downtime for a machine is, for example, to a great extent related to organizational problems. No matter how fast the machine can drill, the output still depends on whether there is enough fuel, sharp bits, casing, etc at the drilling site, as well as experienced mechanics and supervisors close by.

The organization varies a lot depending on the project; who is running it and in what time perspective. In this study three different methods organization are described. All of these projects were run in Zimbabwe and are further mentioned in chapter 4.

-mobile base camp (MEWRD, Resettlement program)

-permanent base camp (DDF Water division)

-mobile main camp (Krush Programme)

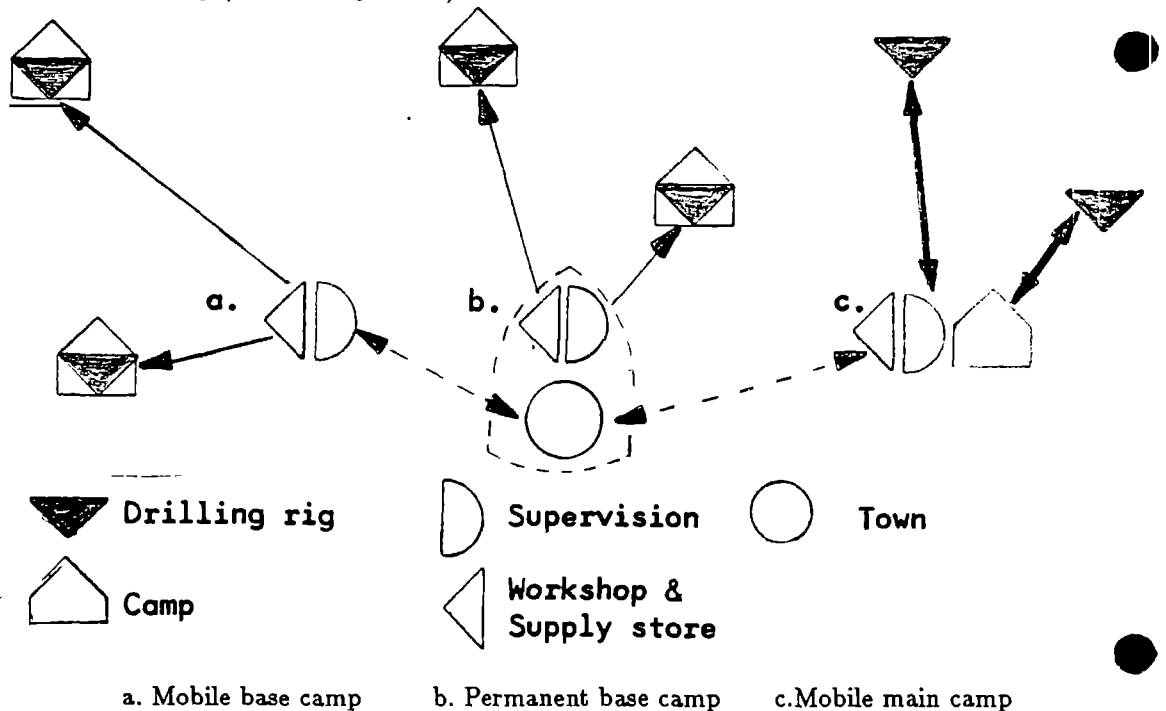


Figure 3.11 Organization types

There are some common factors in these types though: Starting from the bottom, the drilling team contains one driller and a number of helpers, often 2-4. The helpers usually have a secondary task as cook, driver, bit-sharpener, etc. A drilling manager is responsible for the teams in the project. A hydro-geological supervisor commutes between the rigs, giving advice on how deep to drill, what flushing media to use, casing, screening etc. An experienced mechanic usually takes care of the regular service and minor breakdowns.

A *mobile base camp* is set up in a strategic place close to as many sites as possible. The camp serves as a fuel, spare parts and supervision depot from where the project is run and where a smaller workshop is placed. The drilling crew is at the drill site all the time but stays in close contact with the base camp. The smaller drill camp is moved with the rig to the new site and the base camp is moved only when a new district is to be reached. The supervisors and the manager also have to maintain contact with the coordinators and main workshop in town.

The base camp can also be *permanent* and situated in the town, which is preferable if the sites are spread over a large area. The transportation cost and time is much higher, however, and it can be hard for the manager to communicate with the teams. It is therefore harder to maintain the same efficiency in this organization.

An alternative to the base camp is to set up a *mobile main camp* where all the personnel stay. Even regarding the transportation aspect it can be an advantage to have the drilling crews camping at the same place:

- it is easier for the drilling manager to get daily reports, to plan and supervise
- transportation from site to site is quicker since no camp has to be brought
- a good atmosphere is achieved among the workers and information is exchanged in a natural way
- better facilities (cooking, washing, etc) for the crew.

One disadvantage is the watchman who has to guard the rig at night.

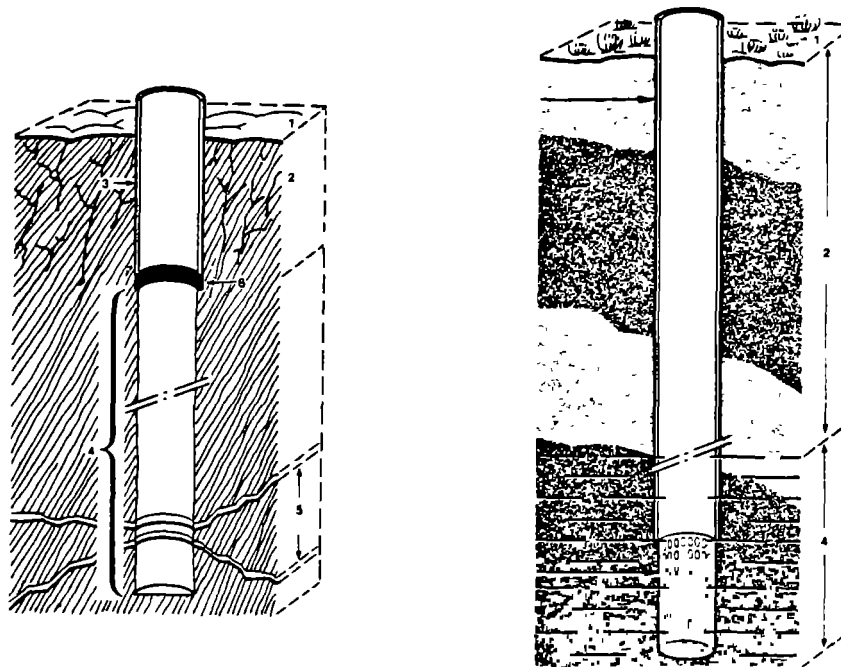
Particularly when drilling with the modern fast rigs it is a matter of discussion whether the total transportation is longer or not. The supplies required can be brought with the crew instead of by separate transports.

Regardless of the organization, an extra vehicle or a communication radio should always be available on site, mainly for safety reasons. A jeep often proves to be very handy for bringing extra casing, water etc.

One major problem for the project managers is to find experienced personnel. It can be hard to employ licensed drivers or well-trained drillers, for example. Looking at the wage system, a set monthly wage topped with a bonus system based on drilled metres seems to increase both the efficiency and the care of the machines.

3.4 Well Construction

The construction of a well is far from ^{completed} when the drilling tool is pulled out of the bore-hole. If the formation is unstable a casing must be inserted with a screen on certain depths and usually also a gravel pack. A hydro-geological supervisor should be present to advise the optimal well constructions. The well yield is determined by test pumping and finally the hand pump is installed.



a. Open bore-hole

b. Cased and screened bore-hole

Figure 3.12 Bore-hole construction (Atlas Copco,1982)

3.4.1 Open Bore-Holes

In consolidated and hard rock formations the bore-hole walls remain stable and there is no need for casing to the full depth. A sanitary seal, i.e. a short casing tube (1-2 m) and/or a concrete plug, is installed at the top of the well to seal off the surface water and prevent it from contaminating the well.

3.4.2 Cased and screened bore-holes

When drilling in collapsing formations casing must be inserted to the full depth. Using the ODEX-method (see air percussion drilling) can be very convenient as an alternative to mud- or foam-flushing or to driven casing tubes (cable-tool).

At the water-bearing zone a screen is installed through which the water can flow into the well. The choice of screen design and where to place it is one of the most important factors determining the well yield.

If the aquifer consists of fine sand it may be uneconomical or technically impossible to provide a well-screen that prevents the sand from entering the well. A gravel pack can be installed in these cases. Sieved sand and gravel fills up the space between the formation and the screen and serves as a filter. The well can as a final step be developed to prevent the well from silting up and to further increase the well yield. The medium-sized to fine particles are removed from the zone and provide an easy path for the water to follow into the well.

It is of great importance to choose correlating casing and drill bits. The drill bit must provide good room for the casing to be inserted. A smaller bit that fits inside the casing should afterwards be able to continue drilling in harder formations.

A well-welded spiral casing or a plain steel casing with threaded endings is a good alternative to the corrosive resistant and light PVC-casing.

A sanitary seal is installed in the same way as for an open bore-hole.

3.5 Test Pumping

When the well is developed the water yield is measured by test pumping. The amount of water, the time and the draw down are recorded by special test pumping equipment.

If the bore-hole has been drilled by a cable tool the bailer is used for test pumping. The draw down is measured as the water is bailed out of the hole.

When drilling with the air percussion method the compressor can be used for doing a simplified test drilling:

The water is blown out of the bore-hole by air and the time for filling up a barrel is measured.

3.6 Well Protection

To prevent unnecessary contamination of the well and the surrounding area a so called "head works" is constructed at the bore hole.

A platform keeps the the hand pump fixed and collects the spill water to a spill water outlet. A water trough for the cattle can be made in connection to the spill water outlet but the water should finally lead to a soak-away pit filled with coarse gravel and stones.

platform

The hand-pump area should be fenced in to prevent cattle from coming close to the pump. An example of head work construction is shown below.

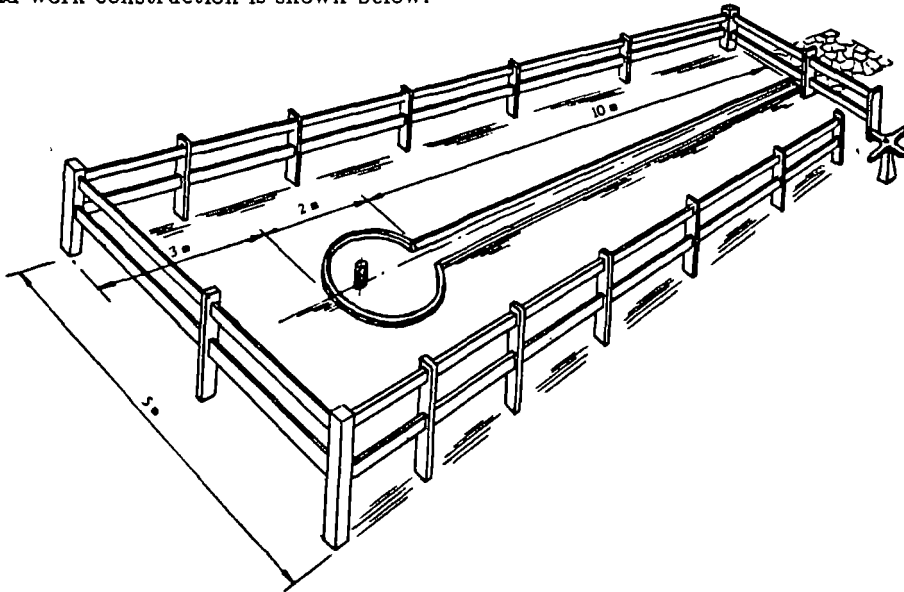


Figure 3.13 Head works design (DDF Report, 1984)

Which hand pump to use is a question of tradition and practical consideration as well as technical judgement. The India Mark II is very common in both India and Tanzania. In Zimbabwe the use of the so called "bush-pump" is widely spread.

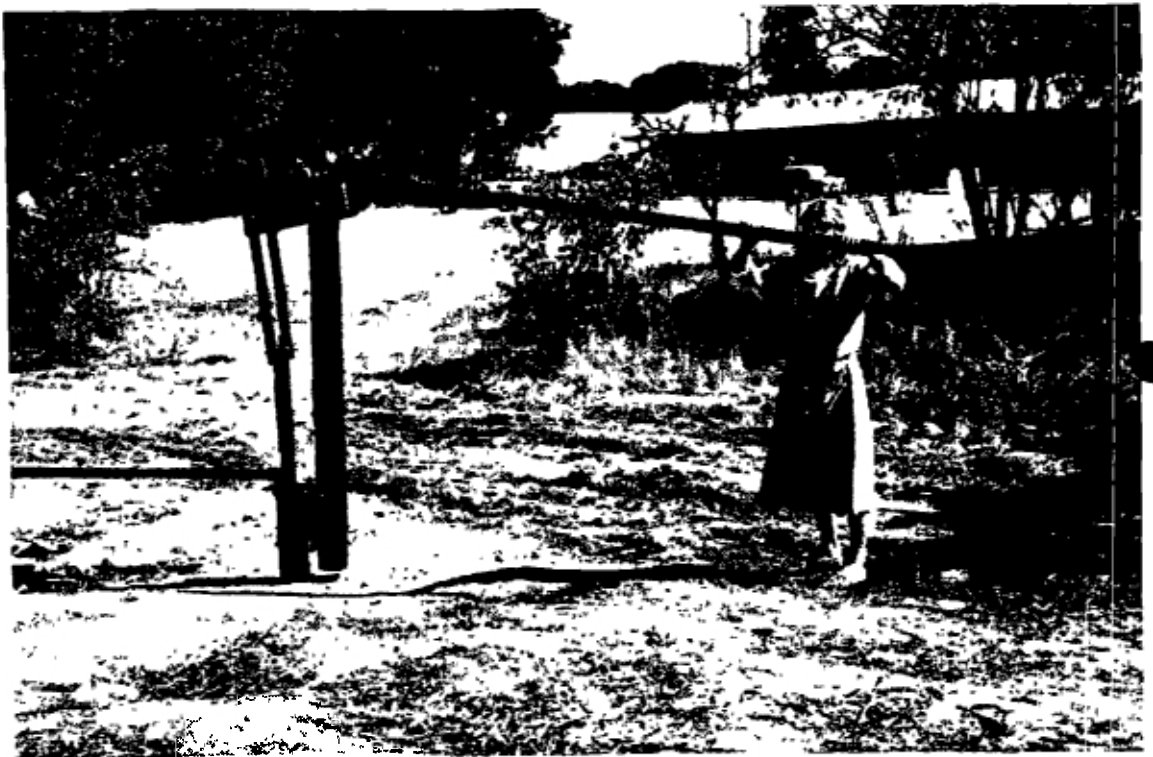


Figure 3.14 Bush-pump and the author

4. PRESENTATION OF THE COUNTRIES

The fieldwork of this study was performed over a period of seven weeks in Zimbabwe and two weeks in Kenya. All the data collected and used come from projects carried out in Zimbabwe, so the emphasis in this brief presentation is on that country. In Kenya the well-drilling projects, geological formations and common organizational forms were studied and some comparative studies were made on the productivity of the projects.

4.1 Zimbabwe

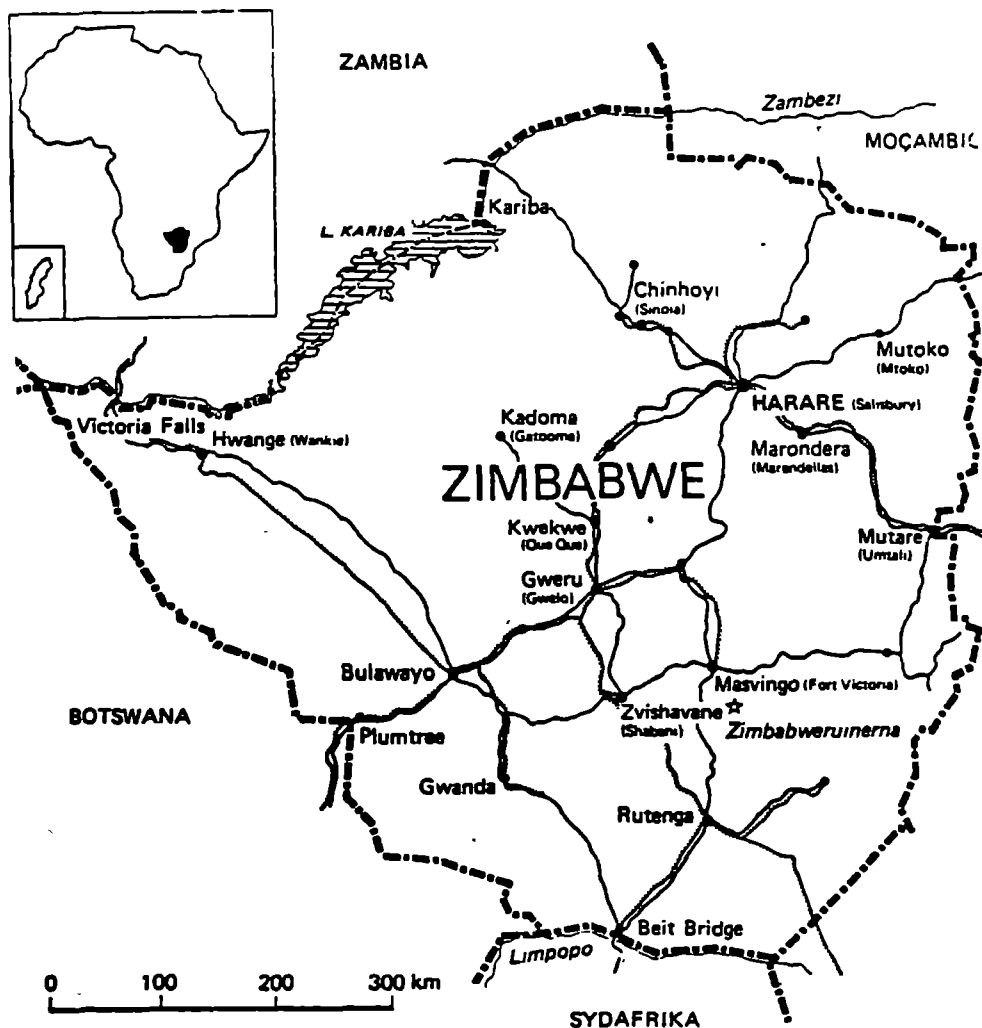


Figure 4.1 Zimbabwe (Utrikesdepartementet, 1985)

Some historical events and facts about Zimbabwe are included in Appendix 2.

4.1.1 Geography and climate

Zimbabwe is situated at the 20th latitude south of the equator in the tropical zone. The climate is, however, more subtropical due to the high altitude of the country, 80% is above 610 metres.

The *Highveld* area, ranging diagonally from the northeast to the southwest corner, forms a plateau. The landscape here is dominated by open grassland and savannah woodland. In this area the most productive farmland is found; the commercial farms, the bigger towns and industrial areas.

Going downwards at both sides of the ridge, the *Middleveld* is reached (915-1200m). In this area most of the Communal lands, former Tribal Trust land, are situated. Farm productivity is lower here partly due to the small scale and traditional farming.

The hot and dry *Lowveld* (below 915m) is sparsely populated.

The climate of the country has distinct seasonal changes and varies also depending on the altitude.

In the "winter", from April to August, the weather is mild and dry; frost can occur.

September to early November is the hottest time of the year, followed by the rainy season from November to March. The rainfall is ranging from 2000mm/year in the Eastern Highlands down to 350mm/year in the Southeast areas. (Sida Landanalys, 1980)

4.1.2 Ground water

The geology of Zimbabwe can be divided into two main parts following the same diagonal line as the high plateau.

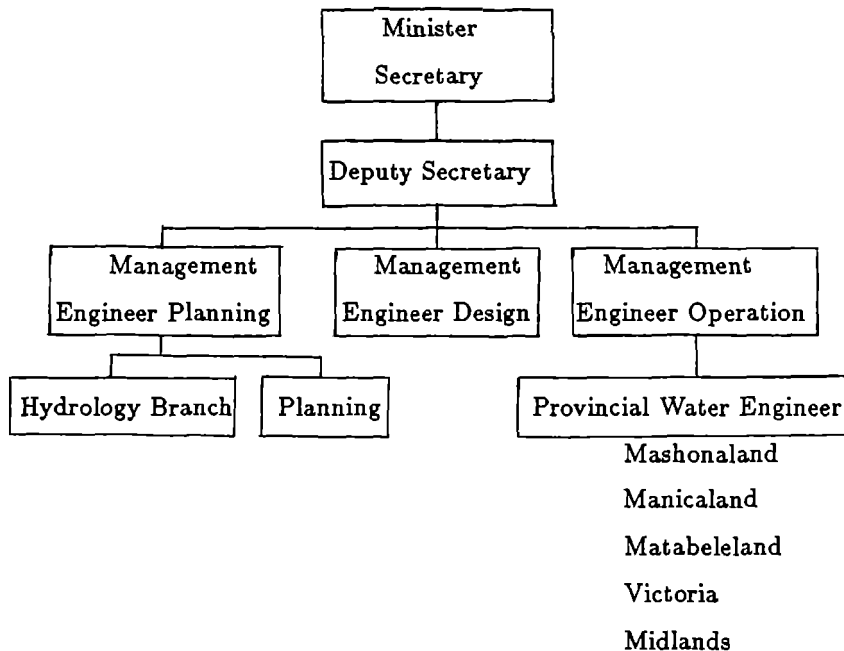
The area south of this southwest-northeast line, the *Basement Complex*, consists mainly of granite and gneissic rock. This type of rock covers 60% of Zimbabwe and occurs frequently in communal lands. Ground water is found in weathered zones and yields of 10-50 m³/day can be expected. The bore-holes are relatively shallow, 40-50m, which makes the area suitable for implementing low-technology schemes.

North of the line the rock is younger, the occurrence of granite and gneiss is low and the rock is mainly of sedimentary type. The occurrence of ground water varies greatly but is in general considered good. The expected bore-hole depth is more than in the basement region but rarely goes beyond 100m. (Master plan, 1985)

4.1.3 Well-drilling activity

There are a number of institutions dealing with well-drilling in rural areas of Zimbabwe. Most of the drilling activity is financed by donating countries or organizations.

The Ministry of Energy and Water Resources and Development, MEWRD, is responsible for the evaluation and development of the water resources in the country. The drilling is carried out by both their own teams and hired contractors. It is organized as follows:



The *Provincial Water Engineers* in the five provinces monitor a number of drilling rigs for rural water supply drilling. In August -85 they had four lightweight drilling rigs (LWD 200) at their disposal and some cable-tools.

The *Hydro-geological Branch* also performs drilling but mainly for ground water research purposes. A new air percussion rig (Aquadrill B-80/22) was given to them earlier this year and some drillers have been trained to run it.

The MEWRD also meets the water-supply requirements of other ministry departments using mainly cable tools. The Ministry of Land Resettlement and Rural Development is, for example, supplied with bore-holes in a *Resettlement Programme*. Four cable tools (Dando 400) and one small air percussion rig (Hands England 200) were working in this scheme in July -85. Further support from a bigger Japanese rig (Tone Top 200) was expected.

The Norwegian Development organizations, NORAD, sponsors large-scale projects under the auspices of MEWRD. One of the projects is a *National Master Plan for Rural Water Supply and Sanitation* for the whole country. They are also running a so called "*Krash Programme*":

400 bore-holes are produced in Mashonaland by a contractor, head works are constructed,

hand pumps installed and a *Community Participation Programme* have been introduced. The aim is to supply increase the participation of the inhabitants in the villages in the construction and maintenance of the bore-hole.

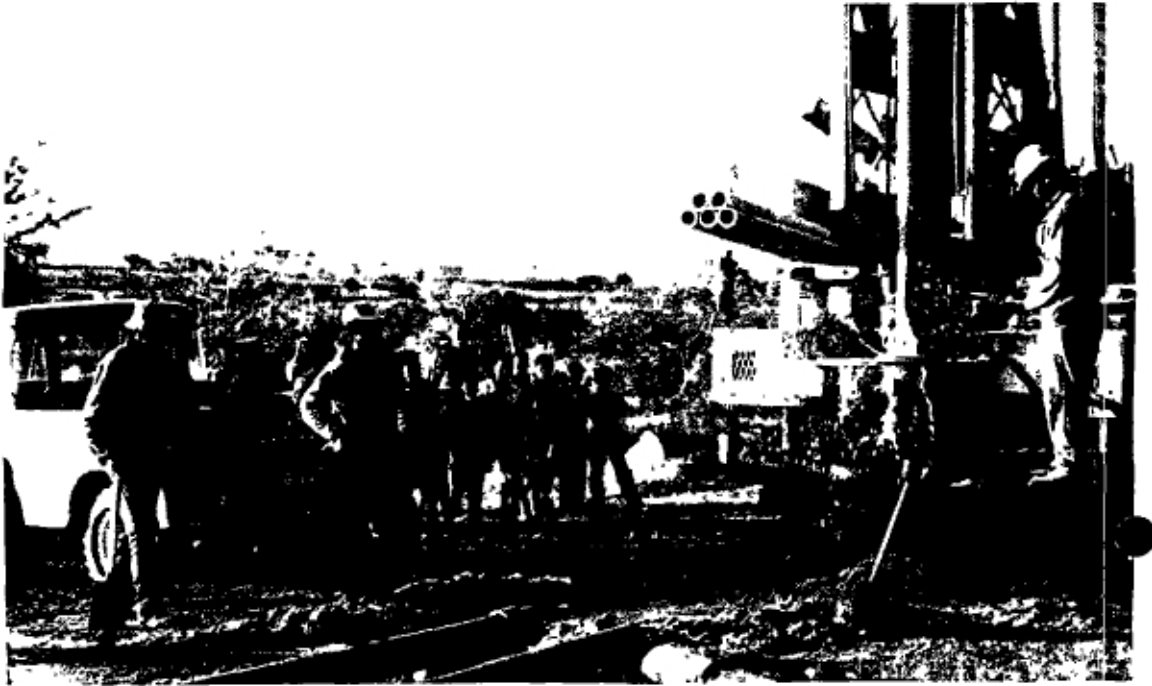


Figure 4.2 Successful well-drilling in the Krash programme.

Similar *relief projects* were carried out in Victoria province by the EEC and in Mashonaland by JICA (Japanese International Cooperation Agency) but with the major difference of not having any Community participation plan. The Japanese drilling rigs were donated to MEWRD when the projects were finished but the EEC contractor from Botswana reclaimed the rigs afterwards.

The long-term success rate of this kind of relief programme can be remarkably low partly due to lack of experience and technical knowledge in the villages. Community Participation Programmes are preferable.

The District Development Fond, DDF, is a semi-autonomous department under the Ministry of Local Government and Town Planning. Their responsibilities include construction and maintenance of the infra structure in the Communal Lands.

The *Water Division* supplies villages with bore-holes and will also in the future construct dams. NORAD is sponsoring the drilling and well-construction in the DDF.

Ten lightweight rigs (LWD 200), geophysical instruments, etc. were given to the DDF at the end of 1983.

Two drilling supervisors and two hydro-geological supervisors were employed as project leaders and instructors. An organization for training personnel, carrying out hydro-geological surveying, drilling bore-holes, constructing the head works and also for doing repair and maintenance on the equipment (including the hand pumps), has been formed. The project manager and drilling supervisor are still working on the project. Apart from them the DDF Water division is run by Africans.

Other governmental departments taking part in the water schemes but not in the actual drilling are the Ministry of Health and the Ministry of Women's Affairs.

The Krash Programme, Provincial Well-drilling and the DDF Water division are also discussed in the report "Well-drilling in Africa -a study of different investment forms and project management" by Torbjörn Arrland, 1985.

4.1.4 Special conditions

Running a rural water supply project in Zimbabwe or in another African country can be quite complicated. There are a number of factors pertaining to a young country like Zimbabwe that seldom occur in the well-established western world.

Seen from a historical point of view advanced technology was introduced into Africa quite recently. Attaining a widespread basic understanding for technical functions takes time. It is very optimistic to expect this knowledge to be distributed to the population within a few decades.

This generally low level of technical know-how affects the water-producing projects in many ways:

- There is a high demand for education of personnel on all levels. Most of the education and training today is on a trainee-basis, performed during ordinary working hours.
- It is harder (but not impossible!) to find experienced personnel such as good mechanics for service and repair work and licensed drivers for the transport vehicles.
- The step from being a driller on a cable tool to becoming an operator on an air percussion rig is big - additional training is required but rarely given.
- Repair work is often delayed or even made impossible by lack of tools and machines and/or skilled personnel in the workshop.
- The manufacture of quality equipment is small or non-existent; DTH-drill bits are not made in the country and the locally-made hydraulic components are of poor quality.

Another dominating factor affecting the drilling in Zimbabwe is the lack of foreign currency. The negative trend in the balance of foreign payments is a serious problem for the country but the situation has improved since the drought came to an end. Some consequences of well-drilling are:

- Hardly any rigs or equipment can be purchased from abroad unless supported by a donating country
- It is difficult to buy drilling accessories such as casing and hammers inside the country
- There is a constant lack of spare parts since only small quantities can be kept in store at the resale companies. Most of the spare parts have to be imported with long delivery times and much down time as a result.

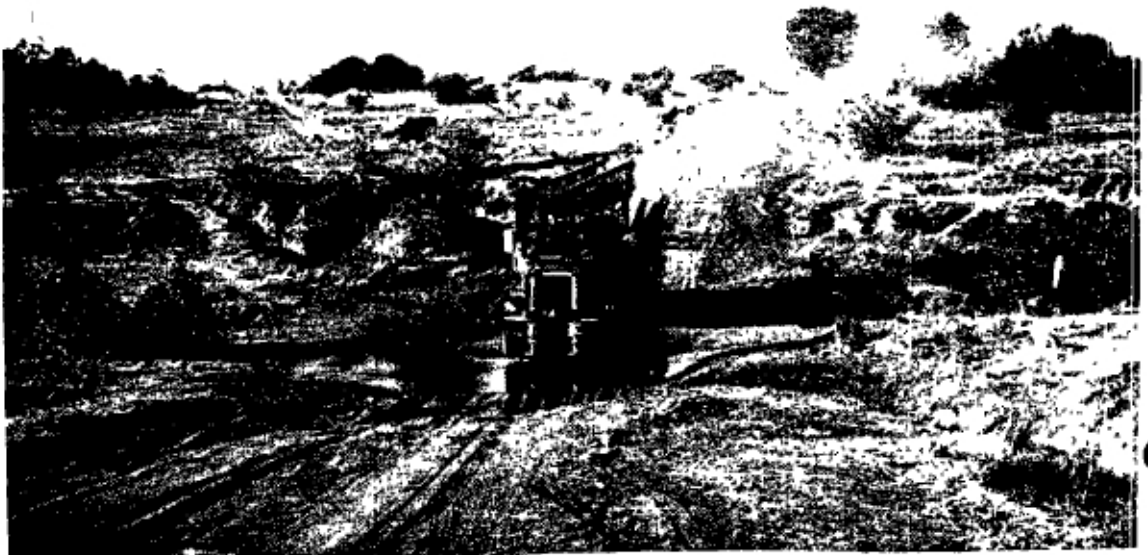


Figure 4.3 Accessibility problems

The delivery times are also affected by the major bureaucracy of the country. The purchasing procedures in the governmental departments are slow and the waiting time for getting goods through the customs can be very long.

The infra-structure of Zimbabwe is relatively good compared to the neighboring countries but is still not satisfying in the sparsely populated areas. Bad roads cause access problems and vehicle breakdowns which results in higher costs and lower production, particularly in the rainy season.

One problem in Zimbabwe, as well as in many other countries receiving financial help and machinery from western countries, is the wide variety of drilling equipment stocked by the Ministry of Energy and Water. The range of different makes, types and sizes of the rigs, compressors, trucks, etc complicates the planning and organization of the work greatly and has an adverse affect on productivity.

4.2 Kenya

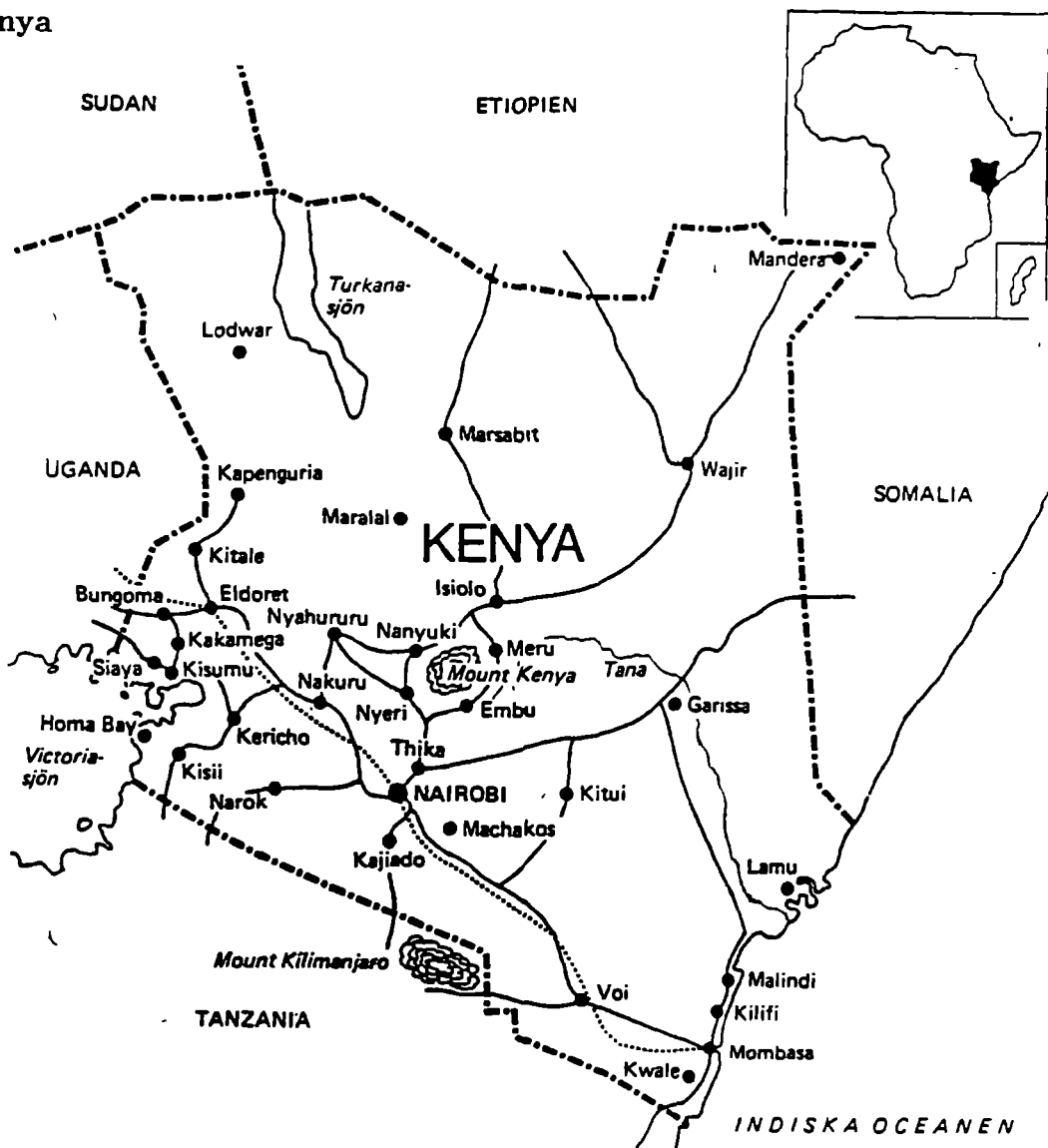


Figure 4.4 Map of Kenya (Utrikesdepartementet, 1985)

4.2.1 Geography and climate

Being situated right on the equator Kenya has a tropical climate. At the coastal lowland both temperature and humidity are high and stable. The land slowly rises towards the central parts and forms a plateau in the western half of the country. In the middle of Kenya the second highest peak in Africa rises - Mount Kenya, 5 200 metres above sea level. Through the high plateau, in a north-south direction, stretches the Rift Valley. It causes a low, dry interruption in the good farmland of the plateau. Tea and coffee plantations are plentiful in the highlands. The northern areas are arid or semi-arid.

The climate is influenced by the position relative to the equator and by the monsoon changes. From December to March the monsoons are directed south-east, which later on in June to August causes a rain period in most of the country. From September to November the wind direction changes to east.

The rain returns in October staying until December.

4.2.2 Ground water

The geological structure of Kenya is relative simple, except for the Rift Valley. Old and stable bedrock dominates the western and central parts of the country. At the coast sedimentary rocks of both marine and continental origin occur. The Rift Valley is a complex mixture of bedrock and volcanic rock formed in one of the earth's most spectacular geological phenomena. A thick overburden is common.

The unfavourable conditions in Kenya necessitate a careful siting of the bore-holes. Only in a few areas is the ground water level shallow enough for implementing low-technology projects. Drilling for water can be the only alternative, though, in arid and semi-arid zones.

In the eastern regions particularly, salty ground water occurs and causes problems for the water-producers.

4.2.3 Well-drilling activity

The *Ministry of Water Development*, MWD, monitors most of the well-drilling in Kenya. They drill for both town- and village water supplies, as well as irrigation schemes. Their hydro-geological section do the bore-hole siting for themselves and for external drillers.

The organization of MWD involves high concentrations of personnel. The crew on one drilling rig can be as high as seventeen people, including a driller, mechanic, watchman, driver and workers! In addition each rig has its own hydro-geological supervisor and nearly all have an inspector. A senior instructor coordinates all the projects and is assisted by expatriate advisor. There are a number of people employed by sponsoring organizations but who are working for the MWD. They serve mainly as co-ordinators, project managers or drilling supervisors.

The MWD has a central workshop and a central store in Nairobi where repair work is done and the spare parts and equipment are kept.

The Scandinavian countries are the main sponsors of water supply activities in Kenya. The Finnish development organization, Finnida, finances a rural water supply programme in western Kenya. The project is run by an agency, Kefinco, which consists of:

- a contractor performing the drilling, well construction and pump installation
- a consultant doing hydrological surveys and also dealing with a community participation programme, similar to the one in the Krash programme (chapter 4.1.3).

The target is 200 bore-holes/year supplied with hand pumps. Production between November -83 and

June-85 rose to 235 wells drilled with two air-percussion rigs

SIDA is investigating the water situation in the East Province, concentrating on the Kwale district, with an aim of starting up a rural water supply programme for low-technology schemes. A training programme for drilling supervisors is another sphere of activity in the drilling section of MWD.



Figure 4.5 Well-drilling in Kenya

The Christian churches in Kenya supply rural areas with water in small local schemes. They usually hire a private drilling contractor but can also drill with a rig and personnel of their own. One interesting alternative is found in eastern Kenya where the Associated Christian Churches lease out their own rig to a private contractor who performs the drilling. These projects are often very successful, particularly in the long term. The churches continue to maintain the water plant after the water pump has been installed.

4.2.4 Special conditions

A comparison of Zimbabwe and Kenya shows many similarities as, for example, the problems posed by foreign currency allocation, lack of experienced drillers, mechanics, drivers, etc., imported spare parts with long delivery times and customs difficulties, organizing the drilling-activities, bad quality tools.

In Kenya the MWD seems to be less organized, both at the administrative and the operational level, than the MEWRD in Zimbabwe:

- No set plans or schemes for water production exist, which makes it difficult for the Senior Inspector to organize the work.

-The transportation of both staff and supplies is also badly organized and productivity is limited because of this additional factor.

-The drilling-records are neither satisfactory filled in nor processed. Attempts to improve data collection have so far failed.

There are slightly fewer problems getting spare parts in Kenya and the delivery times are sometimes shorter since the shipped goods are delivered directly to the country.

The geological formations are more complex and varying in Kenya and the rest level of the wells are low, which makes it more difficult to implement low-technology schemes all over the country. Alternative methods such as dam-construction and spring-protection must be considered in some areas.

5. PRESENTATION OF THE INVESTIGATION

In this chapter the method of analyzing used in the study is presented. It is made in two steps; first a division of existing well-drilling rigs and secondly an identification of interesting parameters.

5.1 The groups of drilling rigs

When making a comparison between well-drilling rigs a division must be made with respect to different aspects of the rigs.

First a difference is made between the ancient percussion-method performed by the cable-tool and the modern drilling-methods of the hydraulic rigs. The air-percussion method using a DTH-hammer is dominant among well-drilling rigs of today. In this study the rigs are divided by size. Many parameters accompany the size such as weight, drilling capacities, fuel consumption.

The study of the groups concerns not only the actual rig but also the accessories, compressors, lorries, etc.

The following groups may be noted:

5.1.1 Cable tool

This method, described in Chapter 3.2.1, is still used all over the world mainly because of its cheap and simple way of drilling. In developing countries many single contractors use them but they are also purchased for larger water programmes run by governments. Their main advantage is that they can be manufactured and repaired locally. Only one simple motor is required and it uses relatively little fuel. It is simple to handle, the bits can be dressed at the drilling site and most of the work can be carried out by a small number of people without assistance. Very little supervision is required and the training period is not long.

The disadvantages of the cable tool are the slow drilling rate and the long time it takes to set up and dismantle.

In this study a Dando 400 is investigated. It operates in the Resettlement programme in Mashonaland East where Mr. Sharp is the Project Manager and Mr Robert Mutepha Drilling Manager. Transport: trolley-mounted rig, pulled by a tractor or lorry(longer distances).

(Appendix 4)

5.1.2 Lighter drilling rig

As an solution to the access problems in rural areas, the lightweight drilling rig was developed. The aim was to build a rig that could be pulled by a jeep or a tractor which did not have access problems because of their light weight.

The drilling diameter was set to 5" - 5 1/2" overburden and 4" - 4 1/2" in hard rock and the theoretical depth: 120 m. Drill pipes 3 m. Odex-drilling was to be used

The compressor is also trolley mounted and pulled behind a truck. This rig is operated by a minimum of three people, one driller and two helpers. They need to be served by mechanics doing the maintenance and repairing breakdowns.

The lightweight rigs used here are:

- **LWD 200** manufactured by Welldrill Systems AB, Gothenburg and operated by DDF-Water Division. Project Manager is Mr Lars Carlsson and Mr Ragnar Hurtig, Drilling Super Intendant.

Compressor: Sullair 300 HH DP, lorry mounted

Transport: Trolley mounted rig, towed behind a lorry (2x4, Nissan Diesel).

(Appendix 5)

- **Hands England 200.**

A small drilling rig mounted on a Land rover with a separate compressor. The hydraulic system is powered by PTO from the car engine. The rig is operating in the Resettlement Programme monitored by MEWRD.

Co-ordinator for the project is Mr Sharp and Mr Robert Mutepha is Project Manager.

Compressor: Ingersoll Rand P375/5 D

(Appendix 6).

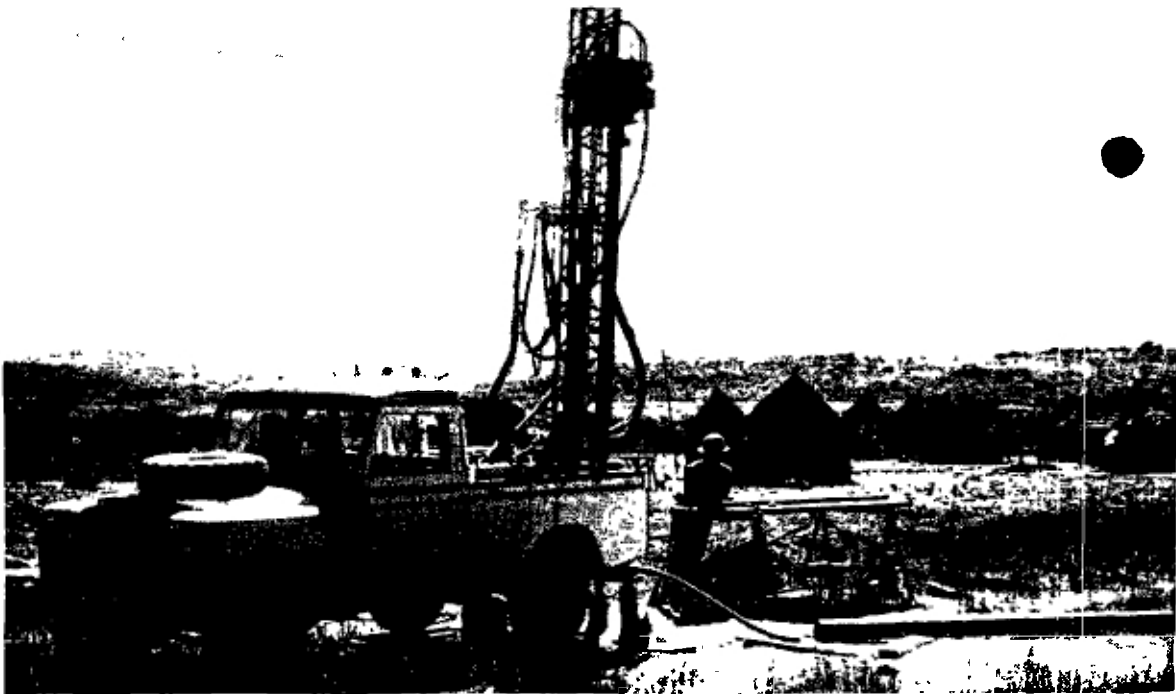


Figure 5.1 Hands England 200

5.1.3 Medium-sized drilling rig

Moving on to bigger drilling rigs the actual number of machines operating as well as the number of different brands increases explosively. In this group units with different combinations of drilling methods, compressors, flushing etc. are found and they are manufactured in most parts of the world. The weight varies between 8-15 tons, the maximum drilling diameter is about 10" (overburden) even though 8" and especially 6" is more common. The drilling depth goes down to 250 m and the pipes can be 3 or 6 m long. For the most part roller bits or DTH hammers are used, but they do manage rotary drilling as well. A water pump is often mounted on the rig and is used for water or foam injection. The crew on a medium-sized rig is similar to that of the lightweight rig: one driller, 2-3 helpers and some supervisors and mechanics in close contact.

Three rigs were studied:

- Scorpion

A locally made rig operating in the Krash programme by the contractors, Geotest Ltd.

Drilling supervisor: Trevor Corrigan

Some of the technical specifications are approximate since the rig is locally manufactured and no tests have been made.

Transport: Both the rig and the compressor are truck mounted (2x4).

Compressor: Ingersoll Rand XHP 750

(Appendix 7)

- Aquadrill B-80/22

Manufactured by Atlas Copco AB in Sweden and specially delivered to operate for MEWRD Hydrology Branch.

Drilling supervisor: Mr. A. Riesberg.

This rig is also prepared for exploration drilling (diamond-drill) and therefore has some extra equipment, but the main purpose is to drill for water.

Transport: Both the rig and the compressor are trailer mounted as specified by MEWRD Hydrology Branch when ordering the machine.

Compressor: Atlas Copco XRH-350 dD

(Appendix 8)

- Tone Top 200

This Japanese rig was first used in a water programme run by the Japanese government and afterwards donated to the MEWRD.

Project coordinator: Mr. Sharp

The rig is technically very sophisticated and in western countries can be operated by one person. In Africa, though, the complex hydraulic and pneumatic manouvres are not fully utilized.

Transport: The rig is lorry mounted

Compressor: Atlas Copco XRH-350

(Appendix 9)

5.1.4 Heavy drilling rig

The most flexible but also the most complex machine in this study is the heavy drilling rig. Like the medium-sized drilling rig the brands, manufacturing countries, technical specifications etc. vary greatly. With a good driller and the right ancillary equipment, this kind of rig should be able to cope with any geological formation and also drill wide bore-holes. The drilling depth reaches as far down as 500 metres. The most common set-up is a lorry-mounted rig with a separate compressor.

The major problem with this kind of rig operating in Africa is the difficulty in getting to the sites. In rural areas with bad roads, particularly in the rainy season, transportation can be very difficult and sometimes even impossible.

The crew of a heavy drilling rig is usually not more than 3-5, but additional supervision is often required from hydro-geologists and mechanics since the rig is very complex.

Rig studied:

- **Ingersoll Rand TH-60**

Operating in the Krash programme by Geotest Ltd.

Drilling supervisor: Trevor Corrigan

This heavy rig consists of only one single truck (4x4) where the actual rig, the compressor, a mud pump and a rod-rack are mounted. The lorry engine powers all the machinery by the PTO-shaft.

(Appendix 10)

5.2 Performance

The search for an appropriate well-drilling rig is a vague and subjective undertaking. Many factors must be taken into consideration even though they do not affect the actual drilling machine. For example, consider the kind of project the rig is operating in:

- is it private or governmental?
- is it run by experienced expatriates or mainly by Africans?
- is there a set number of holes to be drilled within a time-limit or is it a long-term scheme?
- where do they get the spare parts from? Imported, stocked, locally-made or donated by an aid-organization?

Different kinds of projects keep different kinds of records and some projects keep hardly any records at all, which also complicates the survey.

Thus the study must be based on both

- an *interviewing section*, where people at various levels in the drilling organization have been questioned,
- a *data basis* where the figures are based on available drilling records and technical specifications from the manufacturers.

5.2.1 Interviews

During the course of this study a large number of people, listed in Appendix 11 and in the List of References have been questioned. They work mainly as drillers, drilling supervisors or project managers, but directors in the biggest companies dealing with well-drilling equipment have also been interviewed.

The interviews serve basically two purposes:

- to provide a knowledge base for the whole study; to present ideas and aspects of well-drilling
- to gather opinions about the actual rig that the person is working at.

The results of the interviews are found in many parts of this report, both in the introductory theoretical part and in the evaluation of the rigs.

The standard questions are listed in Appendix 12.

5.2.2 Data collection

The figures used in the evaluating part of the study have been taken from various sources:

- the technical specifications of the rigs from the manufactures

-purchasing costs from buying documents registered at the Water department or the Swedish Embassy

-drilling data from Daily Drilling Records (DDR) where the driller reports for every days work. An example of a DDR is shown in Appendix 13.

The DDR keeps very different standards and the reliability of the figures can sometimes be doubtful. They are the only available records of the drilling though, and they are used for both economic and statistical calculations by project managements. A more consistent reporting and better follow-up would be preferable for every aspect of well-drilling.

5.3 Analysis

The analysis is presented in three separate parts:

- Technical aspects
- Economic calculations
- Miscellaneous

In each of the parts a number of parameters are chosen that reflect important aspects of a well-drilling rig operating in a rural water supply scheme. The rigs are compared and a ranking is made for each parameter.

The final summary is given for the parts separately, since the concepts are too different to be compared in a fair way.

5.3.1 Technical aspects

The technical aspects of a drilling rig are really the result of decisions made by the manufacturer and the ways of influencing them are small. One way is to simply change rigs and another is to use the modern system of components that some manufacturers keep.

The technical specifications of a rig must be chosen with regard to the bore hole specifications of the project. In this study low-technology projects with relatively simple bore hole construction and "hand pump-demands" are assumed.

For the analysis the data from each one of the rigs have been gathered (Appendix 14) and secondly representative figures have been chosen for the groups.

To achieve a better basis for evaluation the parameters are graded on a scale from 1 to 5, depending on the importance of the parameter regarding the above mentioned assumptions (5 -most important). The last step is to rank the rigs in order. The rig that meets the standards best ("the winner") gets 4 points and the last rig gets 1 point.

When the grade of importance and the rating are joined, a comparative figure is achieved.

The following parameters have been considered for each of the groups. Since three of the four groups are of air percussion type some of the parameters have been chosen to reflect their advantages and disadvantages.

1. Weight of the unit (ton)

Perhaps the most interesting parameter of a drilling rig operating in rural Africa is the weight of the rig fully equipped. From this figure conclusions can be made about the size of the rig, the drilling capacity, the essential accessibility in rural areas and several other factors. The same kind of rig or compressor can be mounted on different vehicles but it is the total weight of the vehicle

that is of importance and which is shown here. The figures are taken from technical specifications of rigs, compressors, lorries and trailers. Accessories such as casing and drilling bits are not included. Scale: 5

2. Drilling methods

The different kinds of drilling methods a rig is able to use provide valuable information about the versatility and limitations of the machine. Manageable geological formations, drilling diameters, depths and penetration rate are some of the factors which vary greatly according to drilling method. The drilling methods are further described in Chapter 3.2.

In the evaluation the actual drilling methods for the different rigs are used -not possible drilling methods. Scale: 4

3. Maximum drilling diameter (mm, ")

The flexibility of a rig is to some extent determined by the drilling diameter. If only a small diameter is possible, the rig is limited to operating in low-technology projects and can not, if required, be used in bigger irrigation schemes or drilling for town water supply. However, the common drilling diameters of a rural water supply project (115-200 mm) usually present no difficulty. Scale: 4

4. Maximum depth (m)

As mentioned in the hydro-geological part of the report, it is essential for getting the optimal water yield of a well that the aquifer is fully penetrated. It is obviously of great importance that the rig is capable of drilling to this depth. Looking at the parameter in the aspect of low-technology projects the depth-requirement is approximately 70 metres (limited by the hand pump).

Determining the maximum depth can be done both in a theoretical way by calculating the pull-up force or estimating from previous experience of actual drilling. In the last case factors such as free air delivery and torque are taken into consideration as opposed to the first-mentioned case where only the weight of the rods is compared with the lifting capacity (see #6). It is essential that the rig manages to fully penetrate the aquifer to get the optimal well yield (see Chapter 1). Scale: 5

5. Length of rods and casing (m)

This length is determined by the height of the mast. Common lengths are 3 and 6 metres. The shorter rods and casing that are used, the longer the drilling and casing takes, particularly if the operational system of the rig is inefficient. The bigger rigs naturally have a higher mast and longer rods, and sometimes also a very fast and appropriate system. Scale: 1

6. Maximum lifting force (kN)

The maximum lifting force (pull-up force) is the main limiting parameter on a drilling rig regarding the drilling depth. It is obviously unwise to drill deeper and put more drill rods into the hole than the rig is capable of pulling out.

The engine powering the hydraulic systems is the basic limiting factor, but others such as the strength of the mast also affects the maximum lifting force. Scale: 3

7. Torque (Nm)

Like the lifting force, the torque from the rotation head depends on the capacity of the hydraulic system. When using a roller bit or an odex-hammer, the torque is of great importance, but when operating with a DTH-hammer the rotation is only for moving the drilling bit.

If the hammer gets stuck due to muddy or unconsolidated formations, it is necessary to have enough torque (and pull-up force) to be able to move the hammer inside the bore hole. Scale: 2

8. Maximum air pressure (bar)

The penetration rate of the bottom bit depends to a great extent on the maximum air pressure delivered by the compressor. The hitting frequency and force vary with the air pressure in an air-percussion hammer and it is therefore specified for operating under a certain pressure. The penetration rate will decrease and the bottom bit wear will increase if the air pressure is too low. Scale: 3

9. Free air delivery (l/s)

The free air delivery determines the velocity of the flushing media (see Chapter 3.1). The right relationship between drilling diameter, rod diameter, weight of the crushed material and free air delivery is required for getting the right velocity of the flushing media. Diagrams can be used for finding this important parameter but usually the driller is capable enough of determining it by experience. Scale: 3

10. Drilling capacity (m/h)

Drilling capacity is here specified by average drilled metre per hour, i.e. the penetration rate of the rig. The figure is delivered from drilling records of at least three months of work or, if drilling records are missing, from figures given by hammer manufacturers and drillers operating the rig.

The drilling capacity is dependent on many factors:

- the geological formation,
- the pull-down and pull-up capacity, which puts the the weight on the drilling bit (balancing),
- the sharpness of the drilling bit, facilitated by proper dressing,
- the right rotation speed,
- the maximum air-pressure of the compressor,
- the skill of the driller,
- the drilling method.

Since all the rigs in this comparative study have been working in an area with similar geological formations during the time of the investigation, the first factor is eliminated. Scale: 4

5.3.2 Economic calculations

Despite the importance of technical specifications, the financial situation of a well-drilling rig to a great extent determines the choice of rig. It is hard to make a fair comparison between different brands, types and methods of drilling rigs and it is also hard to get hold of accurate and reliable data. The figures used here, therefore, originate from different sources as mentioned in the text, and the calculations have been made in a somewhat unusual way. The aim is to get a good comparative figure that reflects the financial conditions of the different types of rigs.

The costs are expressed in Zimbabwean dollars per bore metre (Zim\$/bm).

1. Investment cost

The first and most obvious expense when planning a well-drilling project is the costs of investment. The high-value machines such as drilling rig, compressor and lorry are usually paid most attention but also the cost of spare parts and accessories is worthy of close attention. How much money that is spent on these necessary but additional parts varies a lot between different projects depending on the total budget, the number of rigs purchased, standardization, etc. When the output of the rigs is considered along with the purchasing cost another picture of the investment appears.

This parameter includes the investment cost for rig, compressor (air-percussion rigs) and tools necessary for drilling. Since the equipment is purchased in different years and at different currency, the cost is compensated for 25% inflation and converted to Zim\$ at the current exchange rate. The total of drilled metres for each rig during its depreciation time is provided by the penetration rate and the efficient number of drilling hours. A depreciation time of five years is used for the modern rigs but for the long-lasting cable tool it is set to 20 years to emphasize the advantage of this rig. No tax is included in the investment cost (see Appendix 15). The cost of spare parts is discussed as a separate parameter.

Source: Purchasing documents and data from manufacturers.

2. Running cost

The cost for running a drilling rig is basically a matter of fuel expenses. The modern rigs with powerful compressor engines consume considerable amounts of fuel and are rather expensive to run. When weighed against with the output, again the costs have to be reconsidered.

The figures used here are both theoretical ones, taken from fuel consumption diagrams of the engines and data taken from Daily Drilling Records. The reported figures are too approximate to serve as the only source and that is why theoretical values have been added (Appendix 16).

3. Cost of Personnel

The crew required for running a drilling rig varies with the complexity of the rig. In the manufacturing countries a more sophisticated rig is run by a smaller crew . This is not the condition in the young African countries though, where labour is cheap and the modern rational way of thinking has not yet penetrated the organizations. It is rather the opposite situation: complicated systems on the rigs tend to need more personnel serving as supervisors and more mechanics supporting the crew.

The drilling rate and wages are connected with each other, which the bonus-based wage system of Geotest Ltd. shows. Therefore the wages of each project are connected with the rig and crew respectively. The support team often serves many rigs so the number of people in the team is shared between the rigs. The number of people in the crew is determined from the particular situation -which in some cases is not the minimum number.

Source: Interviews and Management documents

4. Down time cost

Down time is by definition "non productive time" -a parameter reflecting how efficient the rig is and what output can be expected. The cost for down time depends greatly on the project organization. A well maintained rig with skilled mechanics doing regular service and a good support organization providing supplies and spare parts can together with good logical planning keep the down time very low. It is not impossible to run such a project -even projects in this study touch on the description-but so far they are rare in Africa.

Studying the DDR is the only way of getting a fair idea of the down time over a limited period of time. The figures here simply compare the number of drilling hours with the the total working time (transportation time included).

When a rig is non-productive the the costs are basically profit-loss and depreciation cost. Only the last factor is considered here: the down time cost is affected by the investment cost, calculated as the first parameter, and a comparative figure is delivered.

The first-mentioned factor, profit-loss, is to a great extent connected with the actual project and also very hard to determine.

5. Spare parts cost

The last economic parameter is the spare parts cost. None of the project managers included in this study had any records of either the kind of spare parts used or their cost. Another method has therefore been used to give some idea of the parameter.

When a drilling rig is purchased a set of spare parts is usually included. It is the manufacturer that makes the spare parts list from experience and statistics from rigs operating in the area. The spare parts set is usually meant to last for at least one year of 8 hour per day production. The cost of the set can vary between 5 and 15% but 10% is a very common value.

The absolute cost of spare parts is divided with drilled metres in one year, which gives the resulting figure.

5.3.3 Miscellaneous

Miscellaneous parameters are a collection of very important aspects of a drilling rig that unfortunately are very hard or even impossible to measure.

Evaluating them is based on the interviews and my own observations.

Like the technical part, the importance of the parameters is graded on a scale from 1 to 5 and a rating is made between the rigs as a second step. The figures are multiplied together and a total figure for each group is obtained.

Following parameters are considered:

1. Drilling Organization (working days/bore hole)

This parameter was formed to get an idea of the actual efficiency of the drilling rigs including such factors as:

- the technical specifications
- the need of support from supervisors and supply organizations
- the transportation aspects
- the down time

The figures are worked out from the total number of working days of the examined period and the number of drilled holes during the same time. Source:DDR Scale: 4

2. Transport time

A well drilling rig is often transported and since this is unproductive time it should be reduced to a minimum. Included in the transport time is:

- the rigging up and down
- the time the actual travelling takes, here described as maximum speed on unpaved roads

The rating takes both aspects into consideration. Source: Technical specifications and interviews
Scale: 3

3. Accessibility

Closely connected with the transport time is the accessibility of the rig. A good and well-working rig must reach the drilling site without any major problems, even if there are no roads and/or the terrain is very wet.

The weight of the rig, the mounting (trailer, lorry, etc.) and the transport vehicle (tractor, lorry 2*4/4*4, etc.) are the main factors determining the rating of the rig beside the opinion of the people interviewed. Scale: 5

4. Training requirements

"A true driller is a born driller" (Mr D. Ferreira, 1985),

-this saying surely has something to say about the difficulty of finding good drillers and also the problem of training people to become good drillers.

The opinions about minimum training periods among those questioned varied so much that no fair figures could be obtained. The consequence is that also here a rating is made among the groups.

This rating mainly reflects the complexity of the rig, particularly regarding integrated technical systems which can be very hard to fully understand. Scale: 3

5. Working conditions

Good, safe working conditions are becoming an obvious requirement in the western world while the poorer countries can still not afford this way of thinking. It is necessary to take into consideration the working conditions of a drilling rig though, when choosing equipment.

Primarily the safety on the rig is considered:

-are there moving unshielded parts?

-is it easy to drop things by accident, etc.

and secondly the working environment is considered:

-heavy lifts,

-noise,

-dirt,

-attention required from the driller, etc.

The scaling and rating of this parameter is based on my own observations and interviews.

Scale: 4

6. RESULTS

The results of the analysis are presented here as a summary of the figures calculated for each group of well-drilling rig. The results are accompanied by a comment after each part in this chapter and the discussion is further developed in the final chapter of recommendations. Additional information can be found in Appendix 14-16.

6.1 Technical aspects

Table 6-1 TECHNICAL SPECIFICATIONS FOR THE GROUPS

GROUP	Unit	Scale	1	2	3	4	
1.Weight	kg	5					
rig			4800	2500	12000	28000	
compressor				2000	10000	(one unit)	
2.Methods	-	4	cable-tool	air-perc.	air-perc. rotary	air-perc. rotary	
				foam	mud,foam	mud,foam	
3.Diameter	mm, "	4	300(12")	115(4,5")	216(8,5")	305(12")	
4.Depth	m	5	250	100	200	350	
5.Rods/casing	m	1	6	3	6	6	
6.Pull-up	kN	3	25	25	60	100	
7.Torque	Nm	2	-	2300	8500	7000	
8.Air pressure	bar	3	-	10	14	17	
9.Free air	l/s,	3	-	160	350	280	
delivery	(m3/min)			(9,5)	(21)	(17)	
10.Penetration	bm/h	4	1,0	4,2	12,5	8,0	rate

Note: Representative figures for the groups

Table 6-2. RATING AND SCALE FIGURES.

GROUP	1	2	3	4	max
Parameter	rating x scale = sum				
1.Weight	3x5= 15	4x5= 20	2x5= 10	1x5= 5	20
2.Method	4x4= 16	2x4= 8	1x4= 4	1x4= 4	16
3.Diameter	4x4= 16	1x4= 4	4x4= 16	4x4= 16	16
4.Depth	4x5= 20	4x5= 20	4x5= 20	4x5= 20	20
5.Rodas.	4x1= 4	2x1= 2	4x1= 4	4x1= 4	4
6.Pull-up	2x3= 6	1x3= 3	3x3= 9	4x3= 12	12
7.Torque		1x2= 2	2x2= 4	3x2= 6	6
8.Air pressure	**12**	1x3= 3	2x3= 6	3x3= 9	9
9.Fr.air.del.		1x3= 3	3x3= 9	2x3= 6	9
10.Pen.rate	1x4= 4	2x4= 8	4x4= 16	3x4= 12	16
Total	93	73	98	94	148
Ranking	*3*	*4*	*1*	*2*	

** An average figure is delivered and added since a cable-tool has neither compressor nor rotation head.

Comments on technical aspects

Looking strictly at the technical specifications of the groups the modern and heavier rigs show their advantages with powerful, high capacity equipment.

The cable-tool is a good competitor though, a consequence of the high flexibility of the rig. It can handle almost any formation, drilling diameter and depth. But it takes time.

The "loser" here is the light rig with its weaker construction and lower capabilities. The high value for the bigger rigs may not be necessary for drilling in a low-technology project with skilled personnel.

6.2 Economic calculations

Shown below are the key figures for derivating the cost parameters. and the results of the calculations. Once again it must be noted that these figures must only be used in a comparison between the rigs, not as absolute costs.

For additional information about the figures and calculations see Appendix 15.

Table 6-3 INVESTMENT COST

Group	Unit	1	2	3	4
Penetration rate	bm/h	0,96	4,2	12,5	8,0
Depreciation time	years	20	5	5	5
Total drilled metres during depr.time		14 540	15 920	47 370	30 320
Investment cost, Zim\$(1985)		123 300	181 100	367 900	395 000
Investment cost per bored metre	Zim\$/bm	8,50	11,40	7,80	13,00

Note: bm = bored metre

Table 6-4. RUNNING COST

GROUP	Unit	1	2	3	4
Fuel consumption	l/h	4,3	25,4*	55,4*	70,5
Fuel cons. per bored metre	l/bm	4,5	6,5	4,4	8,8
Fuel cost per bored metre	Zim\$/bm	2,25	3,25	2,20	4,40
Extra 5% oil exp.	Zim\$/bm	0,11	0,16	0,11	0,22
Total fuel cost per bored metre	Zim\$/bm	2,35	3,45	2,35	4,65

Note : Diesel price (July,1985): 0,50 Zim\$/litre

Table 6-5. PERSONNEL COST

GROUP	Unit	1	2	3	4
Drilling crew*					
Number		3	3	3	3
Cost	Zim\$/month	850	675	930	910
Supporting team**					
Number		3 1/5	2 1/5	2 3/4	3 1/4
Cost	Zim\$/month	810	620	925	800
Total personnel					
cost	Zim\$/month	1660	1295	2455***	3067***
Bored metre per month		40	146	583	644
Personnel cost per					
bored metre	Zim\$/bm	41,2	8,9	4,2	4,8

Note : * Driller and helpers

** Drivers, Supervisors, Mechanics, etc.

*** Including bounus (0.5 Zim\$/bm) for the rigs operating in the Krash Programme.

Table 6-6. DOWN TIME COST

GROUP	Unit	1	2	3	4
Drilling hours		506	2198*	241	356
Total working hours		864	8416*	711	864
Down time	%	41	74	66	59
Investment cost	Zim\$/bm	8,50	11,40	7,80	13,00
Down time cost per bored metre	Zim\$/bm	3,50	8,40	5,10	7,70

Note : Down time = (tot. work hours)-(dr. hours) / (tot. work hours)

The drilling and total working hours for the period studied are shown.

* Total hours for eight rigs

Table 6-7. SPARE PART COST

GROUP	Unit	1	2	3	4
Spare part cost	Zim\$	7 190	9 400	25 630	30 000
Bored metres*		788	3 180	9 460	6 060
Spare parts cost					
per bored metre	Zim\$/bm	9,10	3,00	2,70	4,90

Note: * Total bored metres during depreciation time for the spare parts,
i.e. one year of operation (757 h).

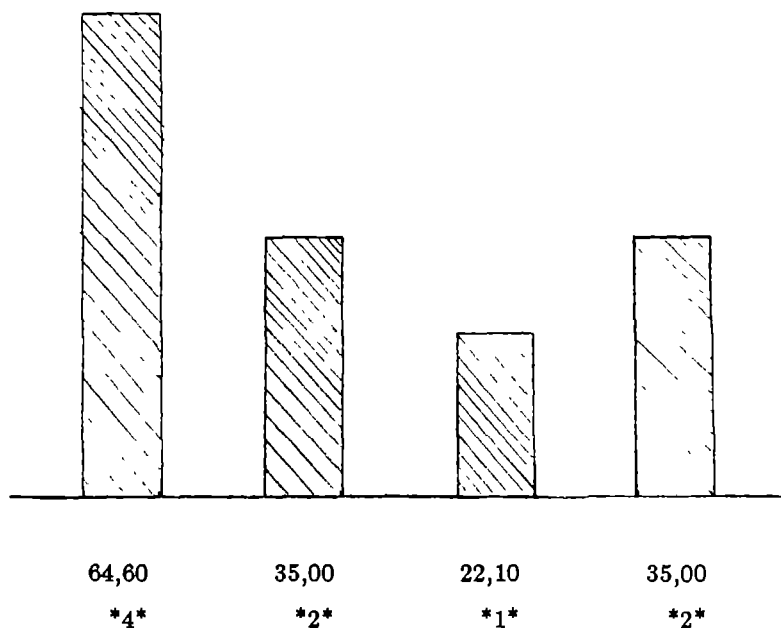


Figure 6.1 SUMMARY OF COST CALCULATIONS

Comments on cost calculations

Group 1. Cable tool

The remarkably high cost of the cable tool originates from the personnel cost, where the low efficiency of the rig gives an interesting figure. The high number of grinders supporting the rig studied is a minor additional factor to the high cost. Also the spare part cost is relatively high due to the low output of the rig.

Group 2. Lighter drilling rig

The smaller rig stays well in competition with the bigger rigs despite the fact that the penetration rate is only half of the others. The weaker construction results in higher down time and also a relatively heavy cost.

Group 3. Medium-sized rig

The high output of the third group gives a low total cost despite the high absolute investment cost and running cost. The difference between absolute cost and a result-oriented calculation is clearly shown.

Group 4. Heavier rig

The compressor of the heavier rig is slightly weak which results in the lower penetration rate of the rig. The investment cost is very high as well as the running cost - not even the high efficiency of the rig can improve these figures. The investment cost also affects the down time cost badly, even though the actual down time is not relatively high.

6.3 Miscellaneous

There are not many figures to be shown in this part since the parameters are scaled and rated on a subject base. Some additional information about the different rigs can be seen in Appendix 14.

Table 6-8. MISCELLANEOUS PARAMETERS

GROUP	1	2	3	4
1. Drilling & Organization	1x4= 4	2x4= 8	3x4= 12	4x4= 16
2. Transport time	1x3= 3	2x3= 6	3x3= 9	4x3= 12
3. Accessibility	4x5= 20	3x5= 15	2x5= 10	1x5= 5
4. Training requirements	4x3= 12	3x3= 9	2x3= 6	1x3= 3
5. Working conditions	1x4= 4	4x4= 16	3x4= 12	3x4= 12
Total sum	43	54	49	48
Rating	*4*	*1*	*2*	*3*

Comments on miscellaneous parameters

These parameters which reflect on subjects hard to measure and to take into calculation when evaluating well-drilling rigs, show the big advantage of a small and handy rig compared to the bigger and more complex ones. The slow and old fashioned cable-tool is losing points when the modern requirements of efficiency and safety are brought up.

7. SUMMARY AND RECOMMENDATIONS

As already mentioned the requirements of a well-drilling rig are many and dependent on a number of factors. The appropriate rig does not exist as a single concept covering every occasion, but nevertheless some conclusions can definitely be drawn from the analysis of a well-drilling project instance.

The most important points in the problem analysis are summarized in this chapter, resulting in a list of requirements for a well-drilling organization and for a well-drilling rig.

From this list, the comparative study and the interviews a suggestion for an appropriate rig is given followed by some personal reflections and proposals about well-drilling projects in general and rigs in particular.

7.1 Problem analysis

The following notes highlight some of the overall problems possibly affecting a rural well-drilling project in Africa and what they entail.

- low level of technical knowledge

- ⇒ high demand for technical training
- ⇒ high demand for skilled personnel
- ⇒ difficulties in repairing and maintaining the equipment
- ⇒ little manufacturing of spare parts, tools, etc.

- lack of foreign currency

- ⇒ most of the drilling equipment has to be imported from or by a sponsoring organization
- ⇒ small stocks of spare parts, accessories, auxiliary equipment, etc.
- ⇒ high downtime of the rigs due to long delivery times of supplies, materials and equipment

-bureaucracy in the purchasing process

- ⇒ long delivery time
- ⇒ down time
- ⇒ planning more difficult

- infra structure undeveloped and in bad condition

- ⇒ access problems for both rigs and supervisors, particularly in the rainy season
- ⇒ heavy wear on the vehicles resulting in frequent breakdowns

- no standardization of the drilling equipment

- ⇒ downtime, since no spare parts, tyres, etc. can be shared

- bad communication systems

- ⇒ bad information flow
- ⇒ logistic problems
- ⇒ hard to make a project efficient

- lack of long term plans

- ⇒ hard to plan future projects in a strategic way

- *different cultural climate* (from western culture)
 - ⇒ less tradition in running and participating in a complex and efficient well-drilling organization
- *lack of vehicles for the personnel*
 - ⇒ hard to keep contact with the rigs
 - ⇒ hard to supply the rigs
 - *lack of statistical facts and follow-up*
 - ⇒ the actual costs of the drilling are unknown
 - ⇒ no checking of spare parts consumption -either quantity or kind
- *long distances between drilling sites*
 - ⇒ logistic problems with transporting and supporting the rigs

7.2 Requirements

From the problem analysis a number of requirements for a well-drilling project can be formulated.

Organizational:

- technical training in common with emphasis on well-drilling and maintenance.
- enough transport vehicles and good planning
- long term plans
- follow-up of drilling records, costs, spare parts
- self sufficient crew, i.e. little support from hydro-geologists, mechanics etc
- easier administration for purchasing and importing equipment
- better coordination between organizations and departments

A similar list can be made for a well-drilling unit. The requirements for a rig are divided into a technical part of common interest and an operational part for the actual drilling performance in a low-technology project.

Rig, general:

- easy to handle, repair and maintain
- small demand for spare parts
- many locally-made and/or standardized spare parts
- few personnel
- self sufficient rig, i.e. small demand for supplies, materials etc.
- cheap to purchase

Rig, operational:

- fast drilling
- fast handling

- fast up/down rigging
- good working conditions
- simple, clear indicators
- easy to check and refill materials (oil, for example)
- cheap to run
- drilling diameter: \rightarrow 150 mm (6")
- depth: \rightarrow 80 m
- pull-up force: \rightarrow 40 kN (air), \rightarrow 25 kN (cable tool)
- torque: \rightarrow 3 kNm

Compressor:

- pressure: \rightarrow 12 bar
- free air delivery \rightarrow 10 m³/ min
- easy to maintain
- easy to transport

Transport vehicle:

- good and sturdy
- good accessibility (particularly in wet seasons)
- fast transport speed
- cheap running cost
- standardized (particularly tyres and engine)

7.3 The appropriate well-drilling rig

The dominant goal of a well-drilling project is to produce water for the inhabitants of an area. As the situation is today there is a big demand for water-wells which means that the time factor is important. When planning water projects the output must be regarded in parallel with financial judgements and this is the main disadvantage for the cable-tool. No matter how efficient (low downtime) the cable-tool is, it is still too slow by itself to meet the demand for water-wells in rural areas. An extensive number of cable-tools could perhaps do the work but the organization of such a project would be far too complex. The results of the financial study show that the economic advantages are very small compared to a modern rig. The cable-tool should not be totally forgotten though. In an area with soft formations and shallow water-table it may be the best method of drilling, as too when a single bore hole in a remote area is to be drilled.

For other applications the comparative study points out that a **medium-sized air-percussion rig** is recommended.

The advantages of this rig:

- efficient rig -> high output
- good working conditions
- versatile, if used in other projects
- strong and sturdy
- not more complex than other air-percussion rigs
- can access most places
- small crew
- the operational capabilities meet the requirements

A major disadvantage is the demand for regular support and frequent transportations, which is a prerequisite the high output, resulting in logistic problems. A well-planned organization is a necessity.

An outline of a well-drilling rig with auxiliary equipment is presented below:

Rig: Medium-sized mounted on a 7-ton lorry, 4x4 drive.

Technical specifications as in the list of requirements:

- Drilling diametre -> 150 mm (6")
- Drilling depth -> 80 m
- Pull-up force -> 40 kN
- Torque -> 3 kNm
- Rod & Casing length -> 3 m
- Drilling methods -> DTH (ODEX and roller-bit optional)
- Flushing media -> Water, foam (mud-pump accessory equipment)
- the hydraulic motors powered by PTO from lorry engine.
- the hoisting mechanism driven by wires => easier to repair than a chain
- rod-rack attached to the mast.
- a proper platform at the back of the rig (on both sides of the break-out table).

Compressor:

Technical specifications

- Air pressure \rightarrow 12 bar
- Free air delivery \rightarrow 10 m³/min (170 l/s)

Transport

- towed on its own wheels behind a supply-lorry or mounted on the supply-lorry

Transport vehicles:

- two 7-ton lorries (4x4) are required for transporting the rig and camp.
- much effort must be made for using standardized tyres and engines.
- boxes for keeping tools, accessories and camping equipment is provided on the lorries.

Auxiliary equipment:

- a winch is mounted on the lorry - mainly for use when access problems occur.
- a water-injection pump is mounted on the lorry
- pneumatic grinder of spherical shape
- welding-set mounted on the lorry and driven by the hydraulic system
- water-tank either permanently mounted on the supply-lorry or
towed behind the lorry (depending on how the compressor is mounted).

7.4 Impressions and proposals

Coming to Africa with few prejudgements, participating in a number of different well-drilling projects and interviewing personnel together create a variety of personal impressions and ideas of possible improvements that can be introduced. Some of them are listed below:

- create one organization out of all the organizations sponsoring well-drilling, where information can be exchanged and coordination discussed.
- introduce a priority scheme for transactions dealt with by the bureaucracy, resulting in faster handling time (including customs).

- strive to locate the drilling organization close to the rigs, both in a physical and informational sense. The shorter the distance between top and bottom level the better.

The drilling manager should not be tied down with operational details though, but do the heavy logistic planning, the follow-up and, very importantly, analyze the drilling records. He should also do the strategic planning, looking at long term requirements for spare parts, transport vehicles etc.

An air percussion rig will always be dependent on suppliers of fuel and water. A good organization can, however, reduce this. The technical and geological advising could be minimized by training.

- in the rainy season of the year some access problems will always occur in some areas - no matter what kind of drilling rig used. Instead of struggling against this fact it can be advisable to accept it and plan for it. The time could, for example, be used for:
 - major annual service on all the equipment, particularly the drilling rigs
 - training and/or holiday for the personnel
 - performing drilling in drier or easy access areas

- training should be monitored by MEWRD, not only via practical training but also at the theoretical level containing some geology, the systems on a rig, different drilling methods and, of course, maintenance.

A course could be run at certain times in a year, for example in the rainy season.

- try to build up the local industry in spare-part manufacturing. Particular aid should be given to encourage the production of hydraulic and pneumatic components of high quality.
- since the spare parts will always be a problem as long as there is lack of foreign currency, attempts must be made to reduce the use of spare parts and also to find out what kind of spare parts are

used.

The following activities are suggested:

- training and continuous information flow
 - strict maintenance; service books should be kept
 - simple maintenance i.e easy-to-check oil level etc.
 - instruction folders with illustrations of maintenance and simple repairs
-
- good planning of the drilling unit (layout on lorry platform, etc)
 - ⇒ more equipment can be transported
 - ⇒ the unit will be more self-sufficient.

 - the rig should be easy and safe to handle, particularly the rod and casing handling. This could be solved in many ways and each rig should be specially checked for this. The handling system is more important than the hoisting speed. A rod rack is preferable even for medium-sized rigs.

 - manual switches are preferable to complicated hydraulic or electrical ones, even though it takes slightly longer time to manoeuvre.

 - working conditions Even though injuries at today's well-drilling rigs are relatively rare, further improvements in the working conditions and safety aspects of a rig must be made. For example:
 - ⇒ safety lockings on the hoses (hydraulic/pneumatic)
 - ⇒ strict use of safety clothing (helmets, boots, etc.)
 - ⇒ turn the control panel 90 degrees ⇒ avoid dirtThe panel should include necessary indicators and levers and should be very simple and clear

 - the engine size should be adapted to the required pull-up force and torque. Too large an engine consumes too much fuel; too small an engine cannot meet the standards.

Finally a constructional idea:

A rig mounted on a detachable platform on the lorry. The platform could be fixed to the lorry by the hydraulically manoeuvred jacks and easily detached when rigging-up. This requires, of course, a separate engine on the rig but the main advantage is that the rig and lorries are exchangeable. If any of them are being serviced or have broken down, drilling is not necessarily affected.

7.5 Concluding remarks

Well-drilling in rural Africa is a far more complex undertaking than just purchasing a well-drilling rig and starting to produce wells - this conclusion is unfortunately not obvious to everyone. The *organization* of a rural water supply project is as important for the output as the choice of the actual kind of well-drilling rig. But naturally, the more appropriate the rig operating in the project, the more wells will be drilled.

The complex situation many African countries are in underlines the importance of investing in *high quality equipment* from the start. The life length is increased, resulting in higher availability and also higher output in the long run.

As the projects are run today, a few very skilful, *indispensable, people* are monitoring the well-drilling projects. This situation can only be improved by training - and that takes time. So at least for the immediate future well-drilling projects in Africa will have to be dependent on a few experienced people, often - but definitely not always - expatriates.

In a longer perspective the general technical level will catch up with the applied technology and many problems will thus be solved.

But the thirsty people can not wait until then.



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Personal communication

Apart from the persons listed in Appendix 11:

Clifford, I., Hydro-Geologist, Interconsultant A/S, Harare.

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Holland, Ministry of Water, Energy Resources and Development, Harare.

Johansson, J-O., Welldrill Systems AB, Gothenburg.

Kruger, A., Project Co-ordinator, NORAD, Harare.

Lindgren, L-E., Project Coordinator, Ministry of Waters, Nairobi.

Spone, P., Project Manager, Interconsultant A/S, Harare.

Steiger, CEO, Ingersoll Rand Ltd., Harare.

BOREHOLE COMPLETION REPORT

Borehole Number

R2

LOCATION PLAN

Resettlement Scheme: Romsley... Rest water level: 22.15...mbgl
 Village/VSC: Vge 15... Measured on: 7.7.84...
 Grid reference: 1932 A/089910... First water: 26...mbgl
 Site elevation: 899.16... Main supply:
 Sited by: TC Swain... Specific capacity: 0.122 l/s/m
 Date completed: 2.3.84...
 Dig type/no: Dado 400 (D424)...
 Drilling method(s): PERUSSIAN...
 Other boreholes in vicinity:
 Additional information:

Appropriate Scale: 1km

DESIGN FOR INSTALLATION

Type of pump: Bush...
 Setting depth: 23...mbgl
 Date of installation: 2.3.84...

CONSTRUCTION

Clearcut:
 Diameter of existing casing:
 Original pumping equipment:
 Depth of sole after clearing:
 Casing installed:
 Screen installed:
 Gravel:
 Grout sanitary seal:

Drilled diameters:
 ..152 mm from ..9 mm to 39.96 m
 .. mm from .. mm to .. mm
 .. mm from .. mm to .. mm
 .. mm from .. mm to .. mm
 .. mm from .. mm to .. mm
 .. mm from .. mm to .. mm
 .. mm from .. mm to .. mm

Apron type: 2m x circular...
 Working slab:
 Cattle trough:
 Waste water disposal by: sewerage...

WATER QUALITY

T.D.S 645 ppm
 faecal coliform 0 col/100 21504

REMARKS

Method(s): Air Lifting... .. Raise Lifting...
 Name of actual development: 19... .. 5...

Drillers Log	Hydrogeological Log	Construction
0	Red brown soil ^{with some banded ironstone} Weathered gneiss ^{granite}	<p>Table 21.</p>
10	soft Weathered gneiss with clay clay decreases with depth Green-grey weathered gneiss	
20	Moderately weathered gneiss	
30	hard Fine dark grey weathered gneiss	
40	very hard Med grained weathered gneiss Fine grained, v hard fresh gneiss	
50		
60		

Depth below ground level (metres)

R.W.L. 22.5m 1st WY 26

QUANTITIES FOR COSTING

Item	Quantity	Rate	Cost	Item	Quantity	Rate	Cost
Dove Stone	1 no	150	150	Gravel pack	1 no	192	192
Bedding Course	35 m	57	1995	Groutings	1 no	80	80
Drilling 35 m	3.96 m	80	316.80	Development	1.7 hr	40	680
Clearing hr	Pump testing	4 hr	31	124
Casing	23.96 m	15	359.40	Pump installation	1 no	850	850
Screen	15 m	20	300	Wellhead	1 no	200	200

TOTAL COST \$ **5253.20**

B/L TEST

Volume of bailer: 27...l

Test No.	Soil Depth m	Gravel Depth m	WL before mbgl	WL after mbgl	No of bails	Time	Aquifer Yield
1st							
2nd							
3rd	39	N/A	22.15	26.6	29	20 min 54 sec	0.43

Appendix 1 261



FACTS ABOUT ZIMBABWE (Utrikesdepartementet, 1985)

AREA	390 000	sqr. km	
POPULATION	7 200 000	persons	(1982)
POPULATION GROWTH	3, 2	%	(1970-82)
AVERAGE LENGTH OF LIFE	56	years	(1982)
READ WRITABLE ADULTS	40	%	(1981)
GNP GROWTH	-4	% per year	(1983)

BALANCE OF FOREIGN PAYMENTS (1969 = 100)

1975	1979	1980	1981
94	64	79	88

OCCUPATION SECTORS

Agriculture	26	%
Manufacturing industry	18	%
Mining industry	6	%
EXPORT		
Agricultural products	38	%
Minerals	40	%
Industry products	22	%

HISTORICAL EVENTS (SIDA Informationsblad, 1980)

1300-1500 A. D	The kingdom of Great Zimbabwe
1889	Mr. C Rhodes forms British South African Company in Zimbabwe
1923	Zimbabwe becomes a British Crown colony
1953	Federation between South Rhodesia (Zimbabwe), North Rhodesia (Zambia) and Nyasaland (Malawi)
1950:s	Liberation movements take form: ZANU, ZAPU
1965	Rhodesia independent from Britain
1966	Guerilla activities start
mid 1970	Full-scale war
1979	Bishop Muzorewa becomes Prime minister
18 April, 1980	Independence



FACTS ABOUT KENYA (Utrikesdepartementet, 1985)

AREA	583 000	sqr. km	
POPULATION	17 800 000	persons	(1983)
POPULATION GROWTH	4	% per year	(1979)
AVERAGE LENGTH OF LIFE	55	years	(1980)
READ WRITABLE ADULTS	appr. 50	%	(1977)
GNP GROWTH per year	3, 7%		(1983)

TERMS OF FOREIGN PAYMENT	(1976 = 100)				
	1978	1979	1980	1981	1982
	106	97	89	77	73

OCCUPATION SECTORS

Agriculture	78	%
Industry	2	%

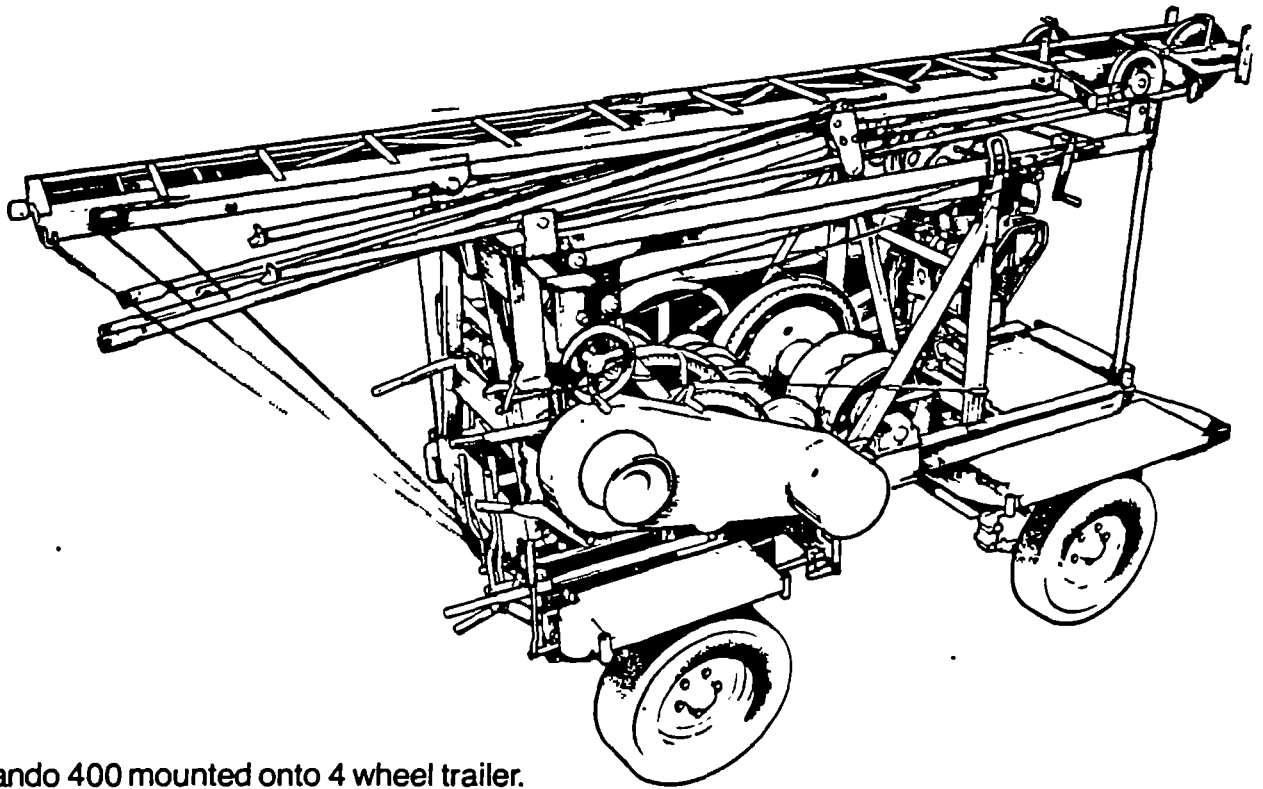
EXPORT

Oil products	16	%
Coffee	25	%
Tea	13	%

HISTORICAL EVENTS (SIDA Landanalys, 1982)

800-1700	The present inhabitants settled in the area
1300-1400	Swahili culture
1593	The Portuguese built Fort Jesus in Mombasa
1895	Kenya becomes a British Protectorate
1903	The railway to Uganda is finished
1946	Jomo Kenyatta forms Kenya African Union, KAU
1953	Liberation war, the Mau-Mau movement
12th December 1963	Uhuru (Independence), Kenyatta prime minister
1978	Daniel arap Moi becomes Prime Minister





Dando 400 mounted onto 4 wheel trailer.

Capacity Rating (for general guidance — average drilling conditions)

Depth range M	25	100	175	250
Diameter (Max) mm	380	300	250	200/150
Tool Weight Kg	800	730	665	600
Strokes-Effective Drilling	760mm (30ins) - 600mm (24ins) - 500mm (20ins)			

Reels Capacity and Speed	Bull Reel	Sand Reel	Casing Reel
Spooling Capacity (Max)	16mmx400M	8mmx300M	16mmx70M
Line Complement - Standard	16mmx250M	8mmx250M	16mmx50M
Line Pull - 1st Layer	2000Kg	600Kg	2700Kg
Line Speed - (Average - Max)	100M/min	140M/min	45M/min

● Last Height to crown sheave 11M Max load 8.500Kg

	Weight	Length	Width	Height
Trailer Unit Tyres 7.50x16x8 ply	4750Kg	7.08M	2.00M	2.70M
Shipment				
Trailer Only	4000Kg	3.80M	2.00M	2.70M
Skid Rig Only	3500Kg	3.80M	2.00M	2.55M
Mast	750Kg	7.08M	0.80M	0.45M

Note Weights and shipping specification for truck mounted unit available on request

Duke and Ockenden can supply all of the in-hole equipment required for all drilling projects with the exception of oil and gas

All DANDO drills are backed-up by a world wide sales and service organisation, with quality factory spares ready for shipment whatever the location. Contact us today and find out more about the drills that have 110 years of experience built-in.

Dando Drilling Systems Limited

Wharf Road, Littlehampton, Sussex BN17 5DN England.

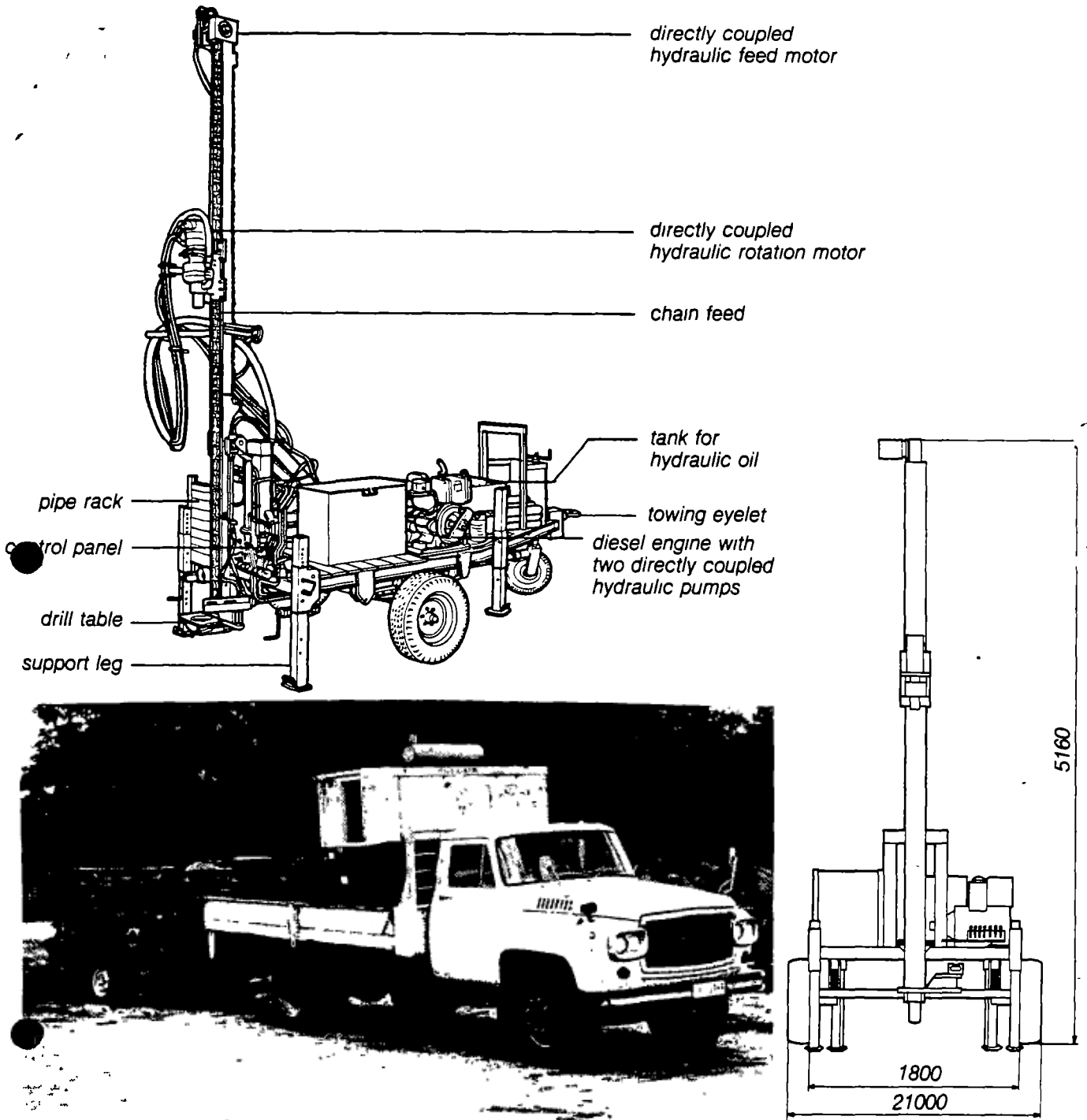
Telephone: Littlehampton (090 64) 23971. Cables: DANDO Littlehampton. Telex: 87543



A member of the Mowlem group of Companies

Descriptions contained in this leaflet were correct at the time of going to press and are subject to alteration without notice.





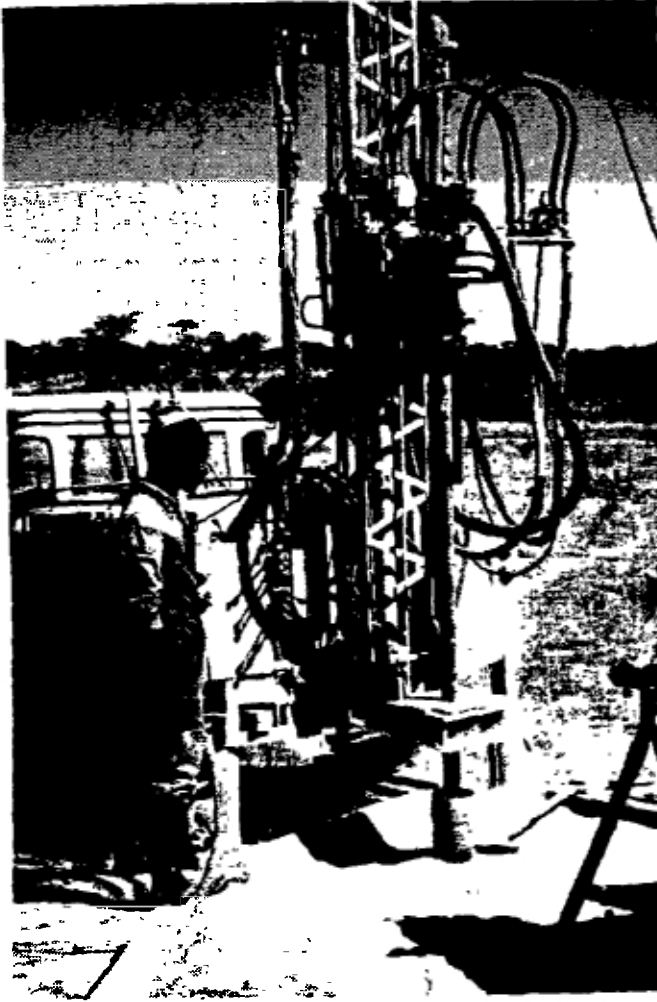
TECHNICAL DATA

Hole diameter	Rock 4 1/8"—4 1/2" (105—115 mm) Overburden 6" (150 mm)	Mast	Torque 200 kpm Lifting force 2500 kp Feed force 600 kp Feed/Hoist speed 0.3 m/s
Power unit	Diesel engine 7.4 kW (10 HP) Hydraulic system 40 l/min, 175 bar Rotation 12—40 rpm	Pneumatic system for DTH Drilling capacity	7—12 bar 120 m under normal conditions
		Weight	1700 kg

WellDrill Systems AB

Tagenevägen 21, S-425 90 Hisings Kärra, Sweden
Telephone 46-31 57 02 60. Telex 27329 WDRILL S





HANDS ENGLAND 200

Weight, trailer mounted	3 500	kg
Mast	3,5	m
Pull-out	2 000	kg
Pull-down	1 130	kg
Rotary speed / Torque	65, 119, 196	rpm
	/129	kgm
	23, 51, 91	rpm
	/258	kgm
Engine , PTO from Landrover		
Compressor :	Ingersoll Rand P375/5 D	
Weight, trailer mounted	1 920	kg
Free air delivery	375	cfm (177 l/s)
Operating pressure	100	psi (6,9 bar)





SCORPION

Manufactured in Bulawayo, Zimbabwe

Weight of rig, lorry mounted

8 500 kg

Drilling depth (maximum)

150 m

Diameter (maximum)

18"

Maximum length of rods

4,5 m

Engine : Forthtrader, 6-cyl. Diesel

Lorry : Thames Trader , 4x4

Compressor: Ingersoll Rand XHP-750

Optimum Pressure

17,6 bar

Free air delivery

354 l/2

Weight

4936 kg

Working pressure

12 bar

Weight lorry mounted

12 ton

Fuel tank capacity

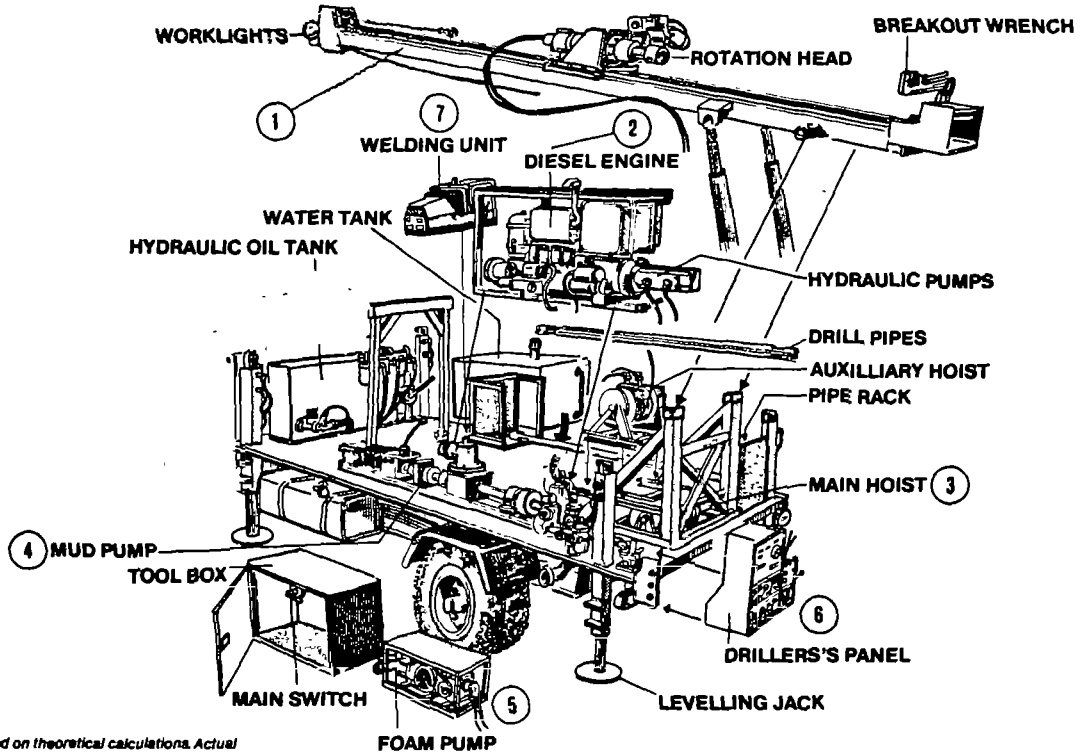
454 l



Atlas Copco

AQUADRILL B-80-22

A truck mounted water well drilling rig for rotary, hammer and auger methods. Most suitable for 4 - 8½ inch boreholes down to 250 metres.*



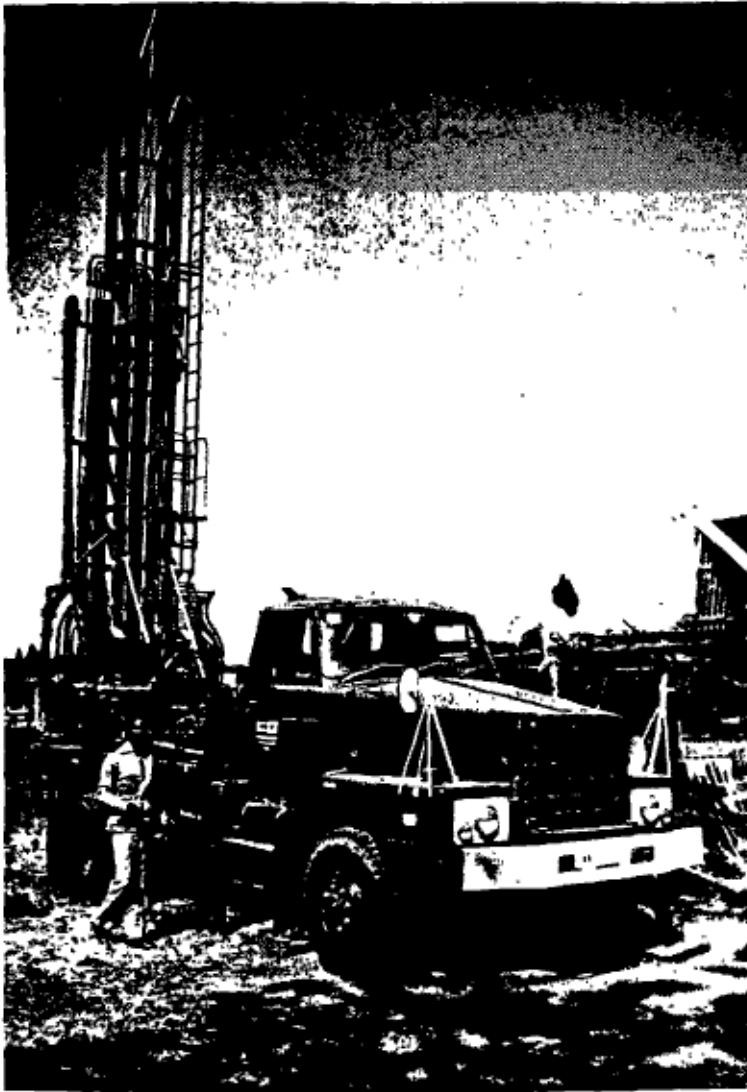
*) Drilling capacities are based on theoretical calculations. Actual capacities will vary according to specific drilling conditions.

ACE E 105029

**-AQUA
DRILL-**

- 1 Heavy duty hydraulic operated drill feed unit with slow/fast feed, 66 kN pull-up capacity and 50 kN pull-down, with top head rotation (0 - 362 r/min, max torque 8 100 Nm, 6.7 m stroke). The feed unit is mounted on 10 m steel mast with hydraulic raise/lower. Mast has breakout table (max opening 12 inch) and hydraulic break-out wrench for 76, 89 and 114 mm drill pipes.
- 2 Deutz air-cooled F6L 912, 70 kW 6 cylinder diesel engine with 240 litres fuel tank giving 8 hours continuous running, with automatic shut-down in unlikely event of high engine oil temperatures. Engine drives a triple direct-flanged hydraulic pump (max pressure 175 bar). The system includes 420 litres hydraulic oil tank, three oil filters, and oil cooler. A handpump, for direct filling from hydraulic oil drum, is standard fitting.
- 3 Hydraulic operated main hoist (lifting capacity 52 kN, with 30 metres wire rope), and hydraulic auxiliary hoist (lifting capacity 11.5 kN, with 30 metres wire rope).
- 4 Hydraulic operated duplex mud pump (max output 568 l/min at 21 bar).
- 5 Hydraulic operated foam injection piston pump (minimum capacity 25 l/min) with pulse pump. 250 litres water tank and 25 litres foam concentrate container.
- 6 Driller's panel with all operating levers, gauges, switches, control valves and emergency stop grouped for safe and efficient drilling. When not in use the panel is covered by raising the driller's work platform.
- 7 Welding/generating set with 14 kW diesel engine, 20 litres fuel tank, for casing/repair work. Welding current 250 A at 60% intermittent. 5 kVA, 220V for external power/extra worklights.
- 8 Atlas Copco XR 350 Dd screw compressor with free air delivery 350 l/sec and a maximum pressure of 12 bar. Compressor is driven by a Deutz air-cooled F10L 413F 167 kW, diesel engine. 560 litres fuel tank gives 8 hours continuous operation. Compressor has safety shut-down devices for high discharge air temperature and low oil pressure.





Tone Top 200

Manufactured in Japan

Drilling methods:	DTH, air/mud rotary, reverse circulation		
Max Load capacity	6 000	kg	
Pull-down	6 000	kg	
Feed stroke	7,5	m	
Weight, lorry mounted	14 500	kg	
Power required for PTO	75 ps at 1800	rpm	
Mud pump	600	l/min	
	25	kg/cm ³	
Rating speed range	low	0 - 45	rpm
	high	0 - 135	rpm
Draw works, max single pull	3000	kg	
spooling capacity	100	m	
Drilling depth	(drillpipe size, 3½")		100- 150 m

Atlas Copco XR 350 Dd, 4-wheel trailer-mounted two-stage oil-injected screw compressor, with F 10L 413F air-cooled 167 kW 10-cylinder Deutz diesel engine. 560 litres fuel tank giving 8 hours continuous running, with automatic shutdown in unlikely event of high engine oil temperatures. Direct-flanged by flexible coupling to compressor screw element. Free air delivery 350 l/sec at 12 bar.





TH-60 Cyclone water well drill specifications



DIMENSIONS

Overall length (derrick down)	33' (10 m)
Overall height (derrick down)	12' 6" (3.8 m)
Overall height (derrick up)	38' (11.5 m)
Width	8' 0" (2.43 m)
Derrick (standard)*	28" x 36" x 33' (0.7 x 0.9 x 10 m)
Gross weight (depending on options)	42,500 lb. (19, 318 kg.)

TRUCK AND ENGINE

International F-5070 truck

Engine is GMC 8V-92T (430 hp) when 750-cfm air compressor is supplied; 8V-71T (350 hp) with 600 cfm.

POWER TRANSFER CASE

Capacity	500 hp at 2100 rpm
----------	--------------------

CAROUSEL CAPACITY

4½" O.D. x 20' pipe	7 pcs. 140' (42.4 m)
3½" O.D. x 20' pipe	9 pcs. 180' (54.5 m)

PULLDOWN and HOLDBACK

Pulldown (standard)	32,000 lb. (14,500 kg)
(optional)	37,000 lb. (16,800 kg)
Holdback (standard)	24,000 lb. (10,900 kg)
(optional)	30,000 lb. (13,600 kg)
Derrick rated capacity	45,000 lb. (20,455 kg)
Drilling feed rate	0-21 fpm (6.4 m/min.)
Fast pullout rate	84 fpm (25.6 m/min.)
Fast feed rate	252 fpm (76.8 m/min.)

ROTATION

Standard head	
Rotation	0-100 rpm
Max. torque	60,000 in.-lb. (692 kg-m)
Optional high-speed head	
Rotation	0-160 rpm
Max. torque	39,000 in.-lb (450 kg-m)
Optional high-performance head	
Rotation	0-160 rpm
Max. torque	60,000 in.-lb. (692 kg-m)

SWIVEL AND PIPING

Swivel I.D.	2" (51 mm) std., 2½" (64 mm) optional
Piping I.D.	2½" (64 mm)
Swivel static load at 100 rpm	36,000 lb. (16,364 kg)

HYDRAULIC DRAWWORKS

Capacity, single line pull	16,000 lb. (7,260 kg)
Max. line speed	70 ft/min (21 m/min)
Spool capacity with ¾" (16-mm) cable	580 ft (177 m)

COMPRESSOR OPTIONS

I-R Spiro-Flo HL-750 Screw	750 cfm at 250 psi (21.25 m³/min. at 17.6 kg/cm²)
I-R Spiro-Flo HL-600 Screw	600 cfm at 250 psi (17 m³/min at 17.6 kg/cm²)

MUD PUMP OPTIONS (FOR AIR/MUD RIG)

Single 3 x 4 centrifugal	300 gpm @ 100 psi (1136 L/min. @ 7 kg/cm²)
Twin 3 x 4 centrifugal	300 gpm @ 200 psi (1136 L/min. @ 14 kg/cm²)
Single 5 x 6 duplex	228 gpm @ 300 psi (863 L/min. @ 21 kg/cm²)
Single 5½ x 8 duplex	314 gpm @ 400 psi (1188 L/min. @ 28 kg/cm²)

MUD PUMP OPTIONS (FOR MUD-ONLY RIG)

Twin 5 x 6 duplex	456 gpm @ 300 psi (1826 L/min. @ 22 kg/cm²)
Single 7½ x 8 duplex	598 gpm @ 180 psi (2264 L/min. @ 12.6 kg/cm²)
Single 7½ x 10 duplex	637 gpm @ 255 psi (2411 L/min. @ 18 kg/cm²)

The options shown under "air/mud rig" above are also available on the "mud-only" rig.)

HYDRAULIC PUMPS

Pulldown	Fixed displacement gear pump 2500 psi, 33 & 21 gpm at 2100 rpm (176 kg/cm², 125 & 80 L/min at 2100 rpm)
Rotation	Variable displacement piston pumps 2500 psi, 0-60 gpm at 2700 rpm (176 kg/cm², 0-227 L/min at 2700 rpm)
Mud Pump	Variable displacement piston pumps

Note: Ratings on hydraulic systems are calculated at 100% efficiency. Product improvement is a continuing goal at Ingersoll-Rand. Designs and specifications are subject to change without notice or obligation.

* Optional 38' (11.6 m) derrick is used for downhole drill, casing hammer or dual-wall pipe



LIST OF SUBJECTS INTERVIEWED

<u>Name</u>	<u>Title</u>	<u>Project</u>	<u>Drilling rig</u>
Mr L. Carlsson	Project Manager	DDF Water division	LWD 200
Mr T. Corrigan	Drilling Super Intendant,	Geotest Ltd, Gaboronne. Krash Programme	Scorpion Ingersoll Rand TH-60
Mr W. Hagström	Drilling Supervisor	MWD, Nairobi	Running: 8 Hydraulic rigs 8 Cable-tools 3 Survey drilling rigs
Mr Heinzen	Hydro-Geologist	MEWRD, Hydro division	Aquadrill B-20/22
Mr R. Hurtig	Drilling Super Intendant,	DDF Water division	LWD 200
Mr C. Johansson	Managing Director	Instapump Ltd, Nairobi	Cable-tools, LWD 200
Mr Luut	Drilling Supervisor	Geotest Ltd, Gaboronne Krash Programme	Scorpion
Mr Macloudy	Drilling and Engineering supervisor,	Geotest Ltd, Gaboronne Krash Programme	Ingersoll Rand TH-60
Mr Mishek	Driller	Geotest Ltd, Gaboronne Krash Programme	Ingersoll Rand TH-60
Mr R. Mutepha	Project Manager	Resettlement Programme, MEWRD	Hands England 200, Dando 400
Mr A. Riesberg	Drilling Instructor	Atlas Copco AB	Aquadrill B-20/22
Mr Sharp	Project co-ordinator,	Resettlement Programme	Hands England 200, Dando 400
Mr Zilawe	Driller & Mecanic	Atlas Copco Ltd, Harare	Aquadrill B-20/22, LWD 200



QUESTIONNAIRE

1. Title and tasks
2. What project are you working in and what type of rigs are you using ?
3. How **is** the project organized ?
4. Working area and geological formations ?
5. What is the minimum number of persons operating the rig ?
6. What is the minimum number of persons in a drilling team ?
7. Does the rig require much service, maintenance ?
8. What kind of maintenance/service is mostly needed?
9. How much downtime and breakdown does the rig have ?
10. Which spare parts are mostly required ?
11. What bore hole formations can be managed ?
12. What kind of different drilling methods can be used ?
13. Where and by whom is the service and maintenance done ?
14. Are specialized personnel needed ?
15. From where do **you** get the spare parts and how long is the delivery time ?
16. Can the spare parts be locally manufactured ?
17. Is the rig easy to start up, how much time is needed ?
18. Is the rig easy to finish off, how much time is needed ?
19. How good is the accessibility to the sites ?
20. What is the maximum speed on sealed roads and on "dirt" roads ?
21. What could be made to make the rig easier to transport and to increase the accessibility ?
22. How long time do you consider it necessary for educating a driller and mechanic respectively ?
23. Can a project be run by only Africans ?
24. How much is the (practical) maximum depth ?
25. What is the most common drilling diameter and what is the maximum ?
26. Should the diameter be increased ? (for further development)
27. What parameter limits the machine ?
28. What improvement can be made ?
29. For how long can the machine last ?
30. Have there been any injuries when drilling ?
31. What can be improved concerning the working conditions ?
32. What does the perfect machine look like meaning size, capacity, transport etc ?
33. Other comments .





GEOTEST

(Pty) Ltd.

GEOTECHNICAL, GEOPHYSICAL AND
GROUNDWATER CONTRACTORS

1900

DAILY DRILLING RECORD

JOB/CONTRACT No. RIG No. DATE.
HOLE No. LOCATION.

OPERATION	HOURS	METRES
MOB/DEMOB		Km
RIGGING UP		
RIGGING DOWN		
DRILLING mm		
DRILLING mm		
RUNNING CASING		
LING CASING		
DEVELOPING FLUSHING		
STAND BY		
WORK TIME		
REPAIRS		
OTHER		
TOTALS		

DEPTH START OF SHIFT metres
DEPTH END OF SHIFT metres
PROGRESS DURING SHIFT metres

MATERIALS USED

DIESEL RIG Litres
COMPRESSOR Litres
CASING metres mm
..... metres mm
..... metres mm
SCREENS metres mm
MUD BAGS FOAM Litres
CORE/BOXES/SAMPLE BAGS ETC.
.....

DRILLING/CORING SCHEDULE

FROM	TO	DIAMETER	METHOD	RECOVERY

SAMPLES

Sampling interval metres
Taken from metres to metres
Total No. samples

FORMATION DETAILS

FROM	TO	ROCK TYPE

WATER STRIKES

1st metres
2nd metres
3rd metres

DRILLER

SUPERVISOR



TECHNICAL PARAMETERS

	1).Lorrymounted	unit	Dando 400	LWD 200	HandsEngland 200	Aquadriill B-20/22	Tone Top 200	Scorpion	Ingersoll Rand TH-60
<u>Rig</u>	1.Weight, rig compr.	kg	4 750 -	1 700 2 000	4 500 1 900	12 000 11 000	15 000 ¹ 8 700	8 500 ¹ 12 000	28 000 (unit)
	2.Methods		cable-tool	air.perc. odex DTH foam	air.perc. DTH foam	rotary air.perc. DTH foam,mud	rotary air.perc. DTH foam,mud	air.perc. DTH foam	rotary air.perc. DTH foam,mud
	3.Drilling diametre	mm,"	300,(12")	115 (4½")	152 (6")	216 (8½")	254 (10")	216 (8½")	305 (12")
	4.Drilling depth	m	250	120	80	250	200	150	350
	5.Rod&Casing length	m	6	3	3	6	6	3	6
	6.Pull-up force	kN	27	25	20	66	60	-	109
	7.Torque	kNm	-	2 000	2 600	8 800	-	-	6 900
<u>Compressor</u>	8.Max Pressure	bar	-	12,2	6,9	12,0	12,0	17,2	17,3
	9.Free air delivery	l/s m3/min	-	140 8,5	180 10,6	350 21	350 21	350 21	280 17
<u>Unit</u>	10.Penetration rate	bm/h	0,96	4,2	4,2	(12,5)	(12,5)	12,0	8,0



MISCELLANEOUS PARAMETERS

Group:			-1-	-2-		-3-		-4-	
	unit	scale	Dando 400	LWD 200	HandsEngland	Aquadrill	Tone Top	Scorpion	Ingersoll Rand
1. Drilling & Organization The group:	days / bore-hole	4	12,88 = 12,9 =	5,55 = 5,4 =	5,33	-	2 = 2,0 =	1,15	1,7 = 1,7 =
2. Transport-time The group:	km/h , riggingh.	3	30/2 = 4 =	40/1 = 2 =	50/1	40/1	50/1 = 3 =	50/1	50/1 = 4 =
3. Accessibility The group	1-5	5	4 = 4 =	3 = 3 =	4	1	2 = 2 =	2	1 = 1 =
4. Education requirements The group:	1-5	3	4 = 4 =	3 = 3 =	3	2	1 = 2 =	3	1 = 1 =
5. Working conditions The group:	1-5	4	1 = 1 =	4 ⁻ = 4 =	4 ⁻	3	4 ⁺ = 3 =	2	4 = 3 =



ECONOMIC CALCULATIONSAvailability of the rigs

	Drillinghours/day	Drillingdays/Tot.days
Group 1	5,27	21,0 %
Group 2	-	47,5 %
Group 3	3,48	47,6 %
Group 4	3,70	82,0 %
<u>Average</u>	<u>4,15 h/day</u>	<u>50,0 %</u>

(source: Daily Drilling Records)

1. Investment costsTotal drilling hours per year: $4,15 \times 365 \times 0,50 = \underline{757 \text{ h}}$

	Depreciationtime	Drillinghours during depreciation
Group 1	20 years	15 150 h
Group 2-4	5 years	3 790 h

Purchasing CostsCompensation for inflation: $(1 + \frac{p}{100})^n$ p - inflation , 25 %
n - number of yearsCompensationfactor, n=1 : 1,25
n=2 : 1,56Group 1Dando 400

Rig	18 675 St.Pound (1983)
Wires	597
Drillingtools	+ 13 800
	<hr/>
	S:a 33 072

Compensated cost: 51 592 St,Pound (1985)

Exchange rate, Dec 1985 : 2,39 Zim \$ = 1 St.Pound

Equivalent cost : 123 300 Zim.\$



Group 2LWD 200

Rig	42 500	(trolley mounted)
Compressor	37 500	
Drillingtools	+ 23 000	

S:a 103 000 Zim.\$ (1983)

Compensated cost : 160 680 Zim.\$ (1985)

Equivalent cost : 160 680

Hands England 200

Rig	33 566	(not mounted)
Compressor	12 000	
Drillingtools	270	
Auxilliries	+ 8 208	

S:a 54 044 St.Pound (1983)

Compensated cost : 84 309 St.Pound (1985)

Exchangerate;Dec. 1985 : 2,39

Equivalent cost : 201 500 Zim.\$

Equivalent cost for the group : 181 100 Zim.\$

Group 3Aquadriill B-20/22

Rig	737 500	(trailer mounted)
Compressor	475 500	(trailer mounted)
Drillingtools	+ 423 390	

S:a \$ 636 390 SEK(1984)

Compensated cost : 2 045 487 SEK(1985)

Exchangerate,July 1985 : 0,18

Equivalent cost : 368 190 Zim.\$



Tonē Top 200

Rig	258 000	(truck mounted)
Compressor	134 000	
Drilling tools	+ 62 000	
	<hr/>	
	S:a 454 000	Zim.\$ (1984)
Compensated cost :	567 500	Zim.\$ (1985)
Estimated cost without truck :	500 00	Zim.\$
<u>Equivalent cost :</u>	500 000	Zim.\$

Scorpion

Rig	100 000	(estimated)
Compressor	115 000	
Drilling tools	+ 20 500	(estimated)
	<hr/>	
	235 500	Zim.\$ (1985)
<u>Equivalent cost :</u>	235 500	Zim.\$

Equivalent cost for the group : 367 900 Zim.\$

Group 4Ingersoll Rand TH-60

Rig	363 000	(truck and compressor included)
Drilling tools	+ 32 000	(estimated)
	<hr/>	
	395 000	Zim.\$ (1985)
<u>Equivalent cost :</u>	<u>395 000</u>	Zim.\$

source : Purchasing documents
 Ingersoll Rand, Harare
 DDF Report, 1984



2. Running costCalculation of fuel consumption

<u>Rig</u>	<u>Engine</u>		<u>Fuel consumption</u>			
	cylinders	power (kW)	(g/kW·h)	theoretical (l/h)	(l/bm)	from DDR (l/bm)
Dando	2	17,9	240	4,3	4,5	-
LWD,rig	1	7,4	255	1,9		
compr.	4	94,0	250	<u>23,5</u>		
total				25,4	6,0	5,8
B20,rig	6	70,0	225	15,8		
compr.	10	167,0	220	<u>36,7</u>		
total				52,5	4,2	
H&E						8,4*
Tone,rig	PTO	55,9	250	14,0		
compr.	10	167,0	220	<u>36,7</u>		
total				50,7	4,0	
Scorpion						
rig	6	70,0	225	15,8		
compr.	6	216,0	220	<u>47,2</u>		
total				63,0	5,0	11,6*
TH60 , PTO	8	320,0	220	70,5	8,8	11,3*

Summary

Group 1	4,5 l/bm
Group 2	6,5 l/bm
Group 3	4,4 l/bm
Group 4	8,8 l/bm

* Including transportation

DDR - Daily Drilling Records

source: Deutz Engines Characteristics

Daily Drilling Records

DDF Report 1984





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As this is the Water decade intense activity is being put into producing water wells in rural areas in Africa. Opinions on choosing the appropriate equipment, however, vary widely.

This report draws a comparison between some well drilling rigs suitable for operating in a low-technology project. Technical, economical and other aspects are considered. The well drilling process is described as are the well drilling activities in the countries encompassed in the study, Zimbabwe and Kenya. The report concludes with recommendations for appropriate well drilling rigs and for well drilling in general.

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