MINISTRY OF AGRICULTURE, IRRIGATION AND WATER DEVELOPMENT

Technical Manual - Water Wells and Groundwater Monitoring Systems

Second edition

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ACRONYMS AND ABBREVIATIONS

EIA	Environmental impact assessment
GIS	Geographic Information System
GPS	Global Positioning System
ID	Inner Diameter
MIS	Management Information System
MoWDI	Ministry of Water Development and Irrigation
OD	Outer Diameter
PVC	Poly Vinyl Chloride
RPM	Revolutions per Minute
VHWC	Village Health Water Committee
NWRA	National Water Resources Authority
WRB	Water Resource Board

1.0 BACKGROUND

1.1 INTRODUCTION

Groundwater resources in Malawi have for a long time been developed predominantly for domestic supplies. With Malawi's agricultural background, much of her population lives and works in rural areas and so the provision of potable water for domestic supply across the country is of special importance. It is clear that groundwater supplies are required to serve the majority of the rural population. It is therefore necessary to have an understanding of the occurrence of groundwater and its development potential for rural domestic and agricultural supplies.

The abstraction of groundwater requires good groundwater management principles to monitor the resource and for equitable resource distribution. The current national groundwater monitoring system comprise of 29 monitoring boreholes, which will be expanded by additional 100 boreholes over the next 5 years.

This technical manual describes borehole aspects associated with groundwater development mainly for rural domestic supply and groundwater monitoring boreholes and the associated groundwater monitoring or management aspects thereof. This manual is an update of the earlier manual by the Ministry of Water Development (MWD), 2001. Chapter 8 has been added to the previous document in addition to updates to the previous document.

1.2 GEOLOGY AND HYDROGEOLOGY

Four hydrogeological units have been identified in Malawi, based on the surface geology and the country's physiography:

1) Regolith aquifer
2) Basement fractured aquifer
3) Alluvial and fluvial aquifer
4) Sedimentary aquifer

Basement and regolith aquifers: A greater part of Malawi is underlain by crystalline metamorphic and igneous rocks of pre-Cambrian to lower Palaeozoic age commonly referred to as the Malawi Basement complex (Figure 1). In most parts of the country especially plateaus, the bedrock is deeply weathered and it is this saprolic or weathered material which forms the principle aquifer.

Alluvial and fluvial aquifer: In the rift valley area, large parts of the lakeshore and Shire River Valley are covered by Quaternary alluvial deposits comprising of consolidated and variable sand, silt and clay sequences. Along the lakeshore itself, the alluvium comprises interbedded lacustrine sands and clays of limited lateral and vertical extent.

Sedimentary aquifer: Occasionally sedimentary rocks have been deposited on top of the basement rocks (regolith included) and offer an alternative aquifer. Rocks of this nature and belonging to the Karoo Super Group (250 - 300 million years old) are preserved in a number of north-south trending basins. A major basin of Karoo sediments, up to 3 000 meters thick, lies below the Lower Shire Valley whilst another lies in northern Malawi, below the lake, extending over 100 km between Livingstonia and Karonga. Other smaller and usually fault-bounded blocks occur in various places in between.

Regolith and alluvial and fluvial aquifers are considered the principle aquifers in Malawi on the basis of their high groundwater potential and spatial extent. Adequate yields for domestic rural supplies are likely to be developed within these aquifers. However, groundwater monitoring boreholes will be developed within all the aquifer units of Malawi in order to characterise the aquifers.

The associated aquifer units within the country's four main physiographic regions are:

a) Plateau Areas - largely form basement aquifers covered by a thick mantle of saprolite (regolith aquifer).
b) Upland Areas - These comprise mountainous areas and smaller uplands which rise abruptly from the plateau. They form basement aquifers devoid of thick regolith in most instances.
c) Rift Valley Escarpment - These areas fall steeply from plateau areas and slopes are commonly dissected. The main aquifer units are basement aquifers.

d) The alluvial plains – associated with alluvial, fluvial and sedimentary aquifers within plains of the rift valley floor. They are gently sloping and of very low relief. They extend along the lakeshores around the lakes of Malawi, Chirwa and Chiuta and also along the Shire river valley. These areas have considerable potential for ground water development.

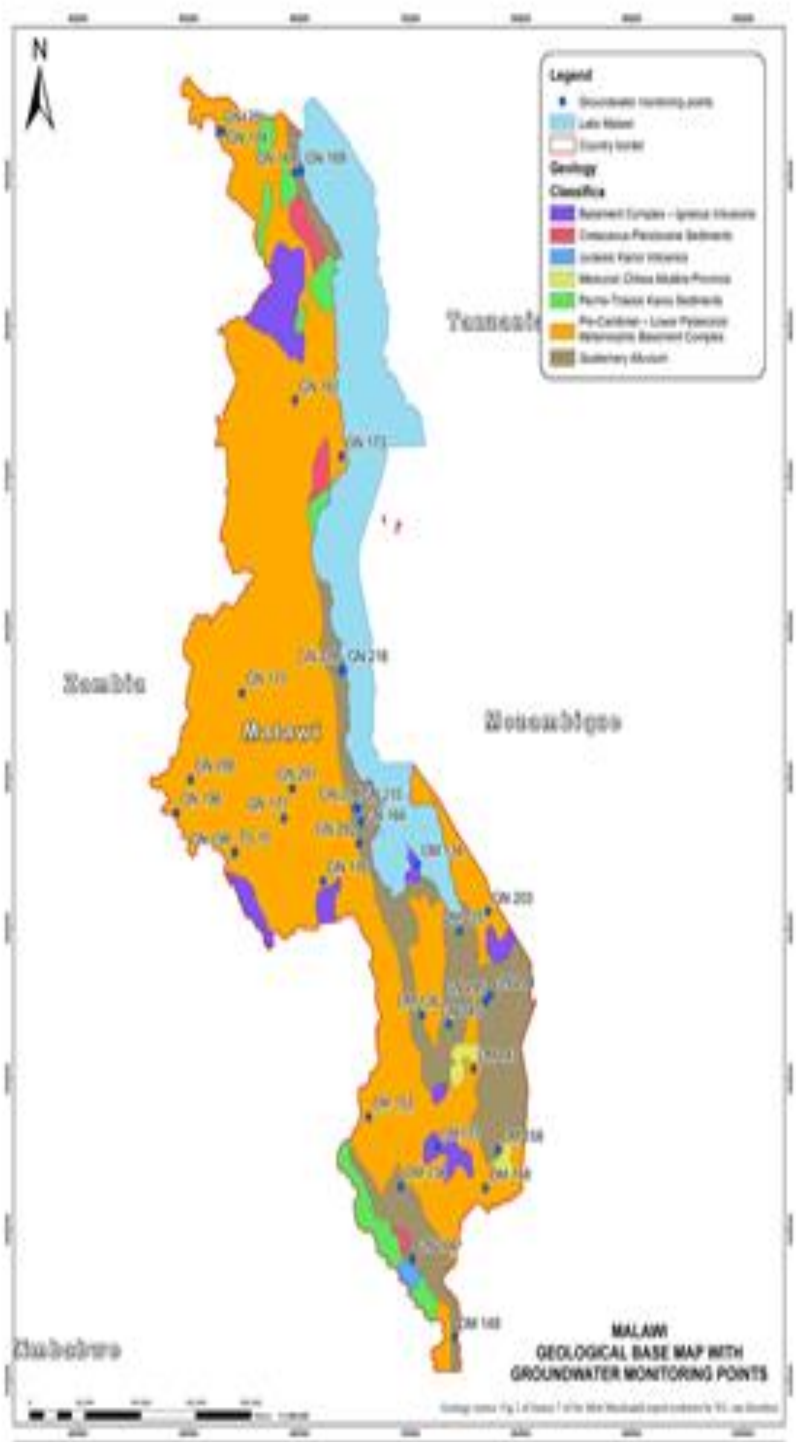

Figure 1 Hydrogeology/geology map of Malawi

Table 1 and Table 2 show the characteristics of the aquifers. The data will be updated during the proposed expansion of the groundwater monitoring network.

Table 1 Properties of Malawi main aquifers

Rank	Aquifer type	Regime	Hydrogeological characteristics	Area in Malawi	Sub-aquifer	Strike (%)	Av. Thick. (m)	Av. Yield (%)	Yield range (l/s)	Mobile silt potential	Vulnerability to pollution
1	Regolith	Plateau areas	Typically thick, degraded bedrock	Upland Districts	Saprolite	47	12	0.17	0 - 1.9	High	High
		Escarpment areas	Variable and often thin over parent bedrock	Lakeshore Districts	Saprock	55	16	1.6	0 - 15	Low to moderate	Low
1a	Basement	As above	Devoid of water except where dislocated	All areas	Bedrock (fractured)	47	na	0.6	0 - 4.4	Low	High – shallow and Low - deep
2	Alluvial, fluvial and colluvial	Lakeshore areas, major rivers, (Shire)	Thin to very thick sand, silt, clay with gravels	Lake shore and Shire River valley	Alluvial, fluvial and colluvial	-	-	-	low to high	High	High
3	Sedimentary	Ancient sedimentary basins, (Karoo Super Group)	Thought to be very thick, cemented sandstone, arkose, conglomerate	Extreme north and south	Fractured units	-	-	-	Not known	Low	Low to medium

Table 2 Basement and alluvium aquifer parameters (Department of Lands, Valuation and Water, December 1983).

Aquifer	T (m^2/day)	K (m/day)	Recharge (mm)
Altered basement	5 – 30	0.5 – 1.5	10 - 100
Alluvium	100 – 300	5 - 10	10 - 100

2.0 HAND DUG WELLS

Hand dug wells may be defined as water points that tap water from shallow water tables. As the name suggests, these water points are constructed manually using hoes, picks and shovels. Usually, hand dug wells have a diameter of not less than 1.5 metres and a minimum water column of 3 metres. The wells are lined using bricks or concrete rings; and fitted with a hand pump.

2.1 SOME PRINCIPLES OF DUG-WELL DESIGN

In principle, the hand dug well supplies water from storage. Where continuous pumping is planned, the rate of inflow to the well should be more than the rate at which the water is being pumped out. This will safeguard the pump from pumping the well dry.

The well storage acts as a “buffer” in providing water at peak pumping periods (such as early morning and late afternoon) when pump discharge can be higher than the rate of inflow to the well. For that reason a dug well is best sited in aquifers of very low permeability. In Malawi these are mostly “dambo” areas. Other areas are low lying.

2.1.1 WELL YIELDS

A hand dug well is designed to serve a population of 125 people at a rate of 27 litres per head per day which is equivalent to a discharge of about 3,400 litres per day. Therefore well storage of about this volume would be required and a total 24 hour inflow of this same volume would also be necessary.

Storage of the full daily requirement is not necessary but, the minimum storage should be more than half the daily pumping requirement. As a safety margin, an arbitrary figure of two-thirds of the full daily requirement should be allowed for. It is important to remember that rate of inflow is a function of “head” or drawdown and not dug-well diameter, unless the formation is fractured.

The dug-well diameter does not greatly affect the rate of inflow, but it does directly affect its storage. A dug-well of internal diameter of 1.5m after lining, has storage of about 1760 litres for each meter dug.

Therefore, the desired well depth can be calculated after determining the full daily required yield of 27 litres per person per day. 125 users would require 3375 litres per day (say approximately 3400 litres). Applying the safety margin the population of 125 users would need a well that will store at least two thirds of this full daily requirement which is about 2270 litres. One meter depth of a 1.5 meter diameter well has storage of about 1760 litres. To store 2270 litres, a water column of 1.3m is required in a 1.5m diameter well. The desired well depth will be 1.3m below the static water level of this example.

With 1m high concrete rings, at least three porous concrete rings should be installed if possible, with the top of the highest one at least 1m below the static water level. The inflow into the drained hole over 12 hours should be adequate to fill at least to the top of the third ring (i.e. a height of 3m of water). If the pump suction is to be significantly above the bottom of the well, additional depth must be added accordingly.

2.1.2 WELL WATER LEVEL

The susceptibility of the well to small changes in water level must be recognised. A fall in static water level could result in a major drop in both storage capacity and rates of inflow. In order to maintain acceptable water levels, the following should be observed:

a) Construct wells in the dry season when water levels are at their lowest.
b) Be aware of longer-term water-level fluctuations, if data is available, and dig to appropriate depths.
c) Be able to deepen the well fairly easily after completion should there be drastic drops in water levels.

2.1.3 DESIGN OF WELL DEPTH

The designed well depth should take into account both the average seasonal water level fluctuation and the desired storage as discussed in the last two sub sections. The time (season) of construction should also be taken into account:

a) Dry Season: It is usually adequate to allow for the desired depth of water column (storage).
b) Other Seasons: After allowing for the desired storage, add depth to allow for the seasonal water level fluctuation.

2.2 CONSTRUCTION PROCEDURE

The operational procedure outlined below is for a backfilled well and conventional wells.

2.2.1 SITING

a. The dug-well site will generally be in a valley (dambo margin) where water levels are in the range 1 - 4m below ground level and certainly no more than 6m below ground level.
b. Areas where groundwater levels are likely to be less than 1m below ground level are prone to pollution and should be avoided.
c. Similarly, particular care should be taken to avoid potential sources of pollution such as pit latrines, cattle kraals and rubbish pits.
d. The well site must be accessible all year round.

2.2.2 DIGGING

Digging equipment and tools include:

- 2m guide rod
- dewatering pump
- Shovel
- Pick-axe
- Hoe
- Wheel barrow
- Building trowels
- Chalk line

- Plump line
- 1 tripod (4 metal legs - 4m height, 100mm diameter.)
- 1 fixed pulley
- 1 movable pulley.
- 4 sisal ropes.
- 1 bucket.
- 1 helmet.
- 16kg hammer.
- 13kg hammer.

Set the well by drawing a 2 meter diameter circle on the ground using rope/string, peg and a stick/rod in order to mark the well diameter.

Commence digging the well using hoes and remove the soil using buckets (Figure 2). If relatively hard material is encountered a pick-axe is used. Dig the well as deep as possible ensuring that the well is 2m diameter throughout by rotating the guide rod horizontally. Digging should continue below water until either the water cannot be removed fast enough (a rate of inflow of over 1 bucket (20 litres per minute) or wall collapse starts to occur. If well starts to collapse cassoining method should be used otherwise continue digging to designed depth.

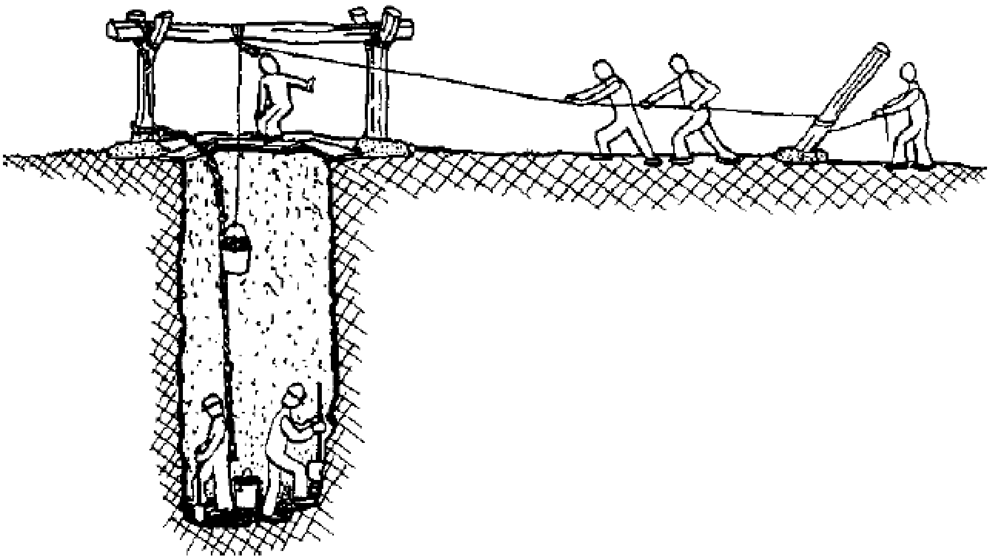

Figure 2 Digging a well (Brush, 1982)

When the required depth has been reached and approved by a Hydrogeologist or expert, the well is logged and then lined.

2.2.3 WELL COMPLETION

2.2.3.1 VARIATIONS IN WELL COMPLETION

Construction methodologies of hand dug wells depend on a number of factors which include, among other things soil formation, cost of the desired technology and time factor. There are three variations in hand dug well construction, namely:

i. Cassoining

This method is applicable in loose, unconsolidated, and highly unstable formations or where wall collapsing is envisaged. Concrete rings are moulded before construction commences. After making the construction diameter of 2m, the concrete ring is placed inside the circle. As digging progresses, the concrete ring sinks into the ground. When the concrete ring levels the ground surface, a second ring is placed on top of the first ring. The process continues until the required depth is achieved. It is advisable to start with a non-porous concrete ring and use porous rings thereafter and again finish with non-porous ring. However, logging sample should be collected as the digging progresses

ii. Dig a Metre – Pour a Metre

This methodology also applies where the formations are unconsolidated. However, in this case the formations are relatively stable. The methodology requires that you excavate progressively 1m deep of soil and then line immediately. This process continues until the required depth is reached. The walls are brick lined.

iii. Full Excavation and Line

In stable formations or where the regolith is relatively hard, digging can continue throughout until the required depth is reached. Well lining is then achieved after full excavation. In this case, either brick or concrete ring lining is possible.

Concrete Ring Lining

The porous concrete rings are inserted first. The rings are carefully lowered into the well and centred. Crushed stone is then lowered in a bucket to a man standing on the concrete ring who backfills the annulus around the ring to form a gravel conduit and to add structural strength and stability. The procedure is repeated for the next subsequent concrete rings, ensuring that they are all well centred.

It is preferable that enough concrete rings are installed to provide adequate storage, unless the aquifer is very permeable (e.g. alluvial sand). If the well is to be backfilled, the top slab should preferably be at least 1m below static water level, and even more if the well is not dug in the later part of the dry season. Overnight recovery in the drained well should be at least 3m of water.

The bottom slab is carefully lowered into the well using a rope passed through the loops, and fixed firmly in position with crushed stone around and over it.

110mm PVC pipe is inserted through the hole in the top slab towards the bottom of the hole and held vertically whilst crushed stone is used to backfill the well to the static water level, or 2m below ground level, whichever is the deeper, and then clay is used to backfill to the surface and above it to form a half metre high mound.

A stone wall with rocks and concrete mortar is built around the clay mound to support the top slab. The PVC pipe is cut and the slab put over the mound with the pump socket centred over the PVC pipe. The slab is cemented to the stone wall to give stability and protection against pollution.

The well is disinfected using one teaspoon of sodium hypochlorite per meter of depth of water. This is added through the PVC pipe. The socket pipe in the top slab is then capped to await pump installation.

Concrete rings may be used to line the full depth of the well so additional materials will be required. Rings above the water level, or for at least 2m below ground, whichever is deeper, must be non-porous to prevent contamination.

Brick lining

If the well is not to be backfilled, then 1,000 to 2,000 bricks will need to be supplied by the village to line the upper portion of the well. The brick lining would be carried out by a builder. A foundation is laid at the bottom of the well using large stones after levelling the floor. Bricks are laid in honey comb fashion with mortar against the water bearing formation. This allows water to pass through the space between the bricks. The upper part (impermeable material) is sealed off using cement plaster.

Concrete Ring-Moulding

The materials required are:

- crushed stone
- river sand
- ordinary cement
- moulds

The mixing and curing of concrete should take place in a position protected from the sun and wind, if necessary shade and windbreaks should be erected. Both heat and rain can affect both the cement and the curing process and thus the strength of the concrete.

Concrete is mixed using a 1:2:4 (cement: sand: aggregate) mix for the slabs and pillars and a 1:2:6 mix for the porous rings. If possible the aggregate should be cooled with water before mixing and the concrete mixing should be done early in the morning when temperatures are lower. The concrete is placed in either a slab or ring mould and compacted using a poker.

The porous rings are strengthened by using the normal 1:2:4 mix for the top and bottom 15m and the 1:2:6 mix for the centre section. Particular care must be taken during the handling and transportation of the porous rings as they are brittle and will break relatively easily.

The top and bottom slabs are reinforced with 8mm steel reinforcement mesh. The bottom slab is cast with four 8mm rod loops on its upper side (to assist in lowering it into the well). The top and bottom slabs are cast with a 110mm opening in the centre.

The moulds are removed after 24 hours and the structures are watered three times per day for the next seven days, before installation in the well.

If the concrete rings were to be cast in situ in the well only an inner mould would be required and the ring insertion process would be avoided.

Equipment for moulding Ring:

- 3 metal ring moulds (100cm height, 155 cm OD, 150cm ID)
- 2 metal bottom slab moulds (150cm diam., 8cm thickness)
- 2 metal top slab moulds (150cm diam., 6cm thickness)
- 2 wooden floats.
- 2 trowels.
- 2 shovels
- 2 metal or wooden pokers.
- 1 wheelbarrow.
- 2 metal pails.
- Mortar pans

3.0 HAND AUGERED (VONDER) BOREHOLES.

A vonder borehole is a tube well drilled with hand operated augers of 150mm diameter and installed with permanent casing of 110mm diameter. Vonder boreholes are drilled in unconsolidated formations (such as alluvial/sands) to depth of up to 20 metres. Apart from the drilling technology being hand operated, the standard of completion of the vonder well is similar to that of deep mechanically – drilled boreholes. A compressor is used to develop vonder boreholes after the installation of well screens and gravel pack. Figure 3 shows hand-augering using a Vonder rig.

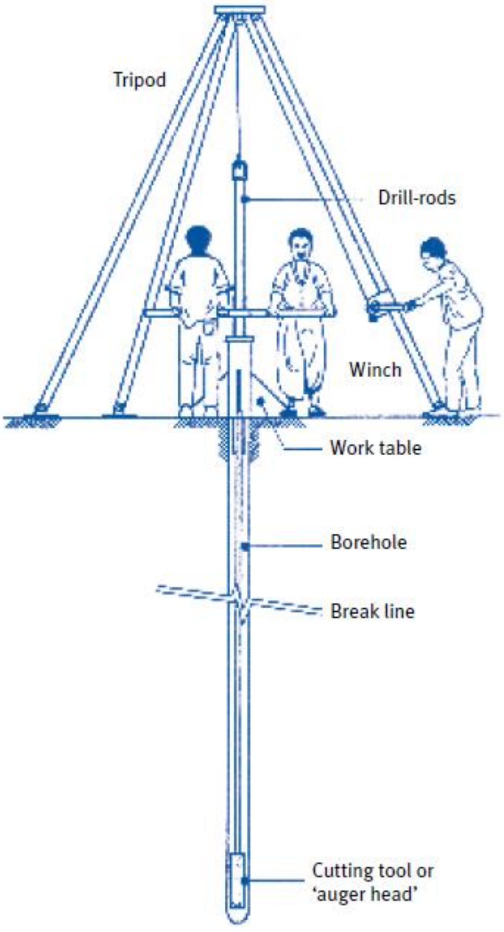

Figure 3 Hand augering using a Vonder rig (WaterAid, 2012)

3.1 PRINCIPLES OF HAND AUGERED WELLS

Hand augered wells are constructed in areas where the water table is moderate (between 6m and 15 m) and the formation is made up of loose material. The technology finds wide application in alluvial, colluvial and high weathered profiles. The commonly used augering equipment in Malawi is the vonder drilling rig; as a result water points constructed using this rig are referred to as Vonder Wells.

3.1.1 SITING

The well site should be located at a distance of not less than 100 metres from sources of pollution e.g. pit latrine, waste disposal sites, kraals, septic tanks and dip tanks. Unconsolidated materials are ideal locations for hand augered wells.

The Local Community are encouraged to select their own sites for hand augered wells with the assistance of a technical expert.

3.1.2 EQUIPMENT REQUIRED

a) Vonder rig, comprising the following:

- Worktable with plumb line for levelling
- Tripod with hand winch and cable
- Auger (for soft soils)
- Hole saw (for decomposing rock formations)
- Bayonet adaptor for augers
- Cross bar for turning stems
- Bailer (sand bailers, water bailers).
- 8 x 2 metre heavy duty drilling stems with acme threads
- Stem stand with oil can
- Heavy duty spanner for tightening stems
- Rock chisel

b) Bucket auger:

- Welding set/ welding back up
- Weir tank

- Well development tools (airline, surge blocks, jetting tools)
- 1 ton pick-up.
- Temporary Casing.
- Compressor

3.1.3 MATERIALS REQUIRED

- Gravel pack.
- 110mm class 10 PVC Plain Pipes.
- 110mm PVC Slotted Pipes.
- Cleaning Fluid.
- Solvent Cement.
- Quarry stone
- Bricks
- Ordinary Portland cement

3.2 CONSTRUCTION PROCEDURE

3.2.1 SITE ACCESS

The site must be cleared, including the access track or road. Fill in any gullies or potholes on the access track.

3.2.2 SETTING UP THE RIG

Once the site has been located, it is important to properly set up the worktable. A plumb line is provided for the purpose of maintaining accurate levels. If the levelling is accurate, the centre of the will come to rest on the edge of the barrel when slung over the top of the work table.

The tripod is then assembled and erected directly over worktable. In order to get an exact position for the tripod, the steel cable is lowered with the winch so that the stem linkage on the end of the cable falls exactly centrally within the barrel of the worktable.

The position of the worktable and the tripod can be adjusted slightly by chiselling away soil with a shovel from underneath the worktable or tripod respectively. The steel cable pulley and the threads for the drill stems should be oiled, and the worktable secured into position finally with the four steel pegs provided for the purpose.

3.2.3 TROUBLE SHOOTING AREAS

It is possible that the auger may meet hard rock before it meets the water table. In this case it is best to change location and try again. In many cases a change in location of about 5 or 10 metres may enable the auger to penetrate much more deeply into the ground.

In harder ground, it may be necessary for some people to sit on the cross bar to give the auger more "bite" and speed up the drilling process. One or two people on either side of the cross bar is enough. If the ground is too hard, and the rig is loaded with too many people, the cutters will bend, wear out or break.

The drilling rig cannot cope with every situation. If bedrock lies in the ground above the level of the water table, only a big mechanical drilling rig will be able to cope. It is important to establish the best areas in which the rig can operate.

The total depth of the hand augered well should have a minimum water column of 3 metres. Generally, wells are drilled to a depth of 15 – 20 metres.

3.2.4 DRILLING WELLS THROUGH COLLAPSING FORMATION

The problem of penetrating through mobile mud and sand formations has been overcome by a development of V & W Engineering in which a steel casing is allowed to penetrate the formation at the same time as the auger. The steel casing actually precedes the auger in this case. This additional piece of equipment includes a low work table. The work table is fitted with a clamp which secures a special length of steel casing used to support the stem guides, when the normal auger is used. The same work table also supports the specialised casing used to drill holes. When the steel casing itself is used for drilling, the work table clamp is loosened, and an adaptor fitted to the top of the steel casing, which enables it to turn with a cross bar. The first steel casing is equipped with a cutting edge similar to the hole saw.

The drilling procedure follows the normal pattern as with the standard rig, using the standard work table and augers as described in the previous section. This drilling procedure continues until a difficult formation like sand or loose mud is encountered. At this stage the standard worktable is removed and the lower level work table is fitted in its place.

The standard auger and bayonet is also removed. A specialised bayonet adaptor is now fitted to the first steel casing that has a series of cutting teeth at its lower end for drilling. The swivel bolt attached to the steel cable is attached to the T-shaped adaptor which allows the cross bar to pass through it. The T-shaped adaptor is lowered inside the bayonet and T-shaped adaptor, and a cross bar passed through both the bayonet and T-shaped adaptors. This enables the bayonet adaptor and the steel casings beneath it to the turned.

3.2.5 DRILLING SEQUENCE

(a) Lower the swivel bolt into the bayonet adaptor.
(b) Pass the cross bar through the openings in the bayonet adaptor.
(c) Attach the first steel casing fitted with teeth to the bayonet.
(d) Use the winch to raise the casing and cross bar.
(e) Lower the casing through the worktable, and clamp tight.
(f) Fit more lengths of casing until the sand layer is met.
(g) Use the cross bar to turn the casings into the sand or mud.
(h) Drill through the sand layer as far as possible.
(i) Clamp the casing.
(j) Remove cross bar and tee adaptor.

After the completion of the above listed tasks, the casing must be removed in order to scoop out the mud. This is usually done using the flap auger and the bailing technique.

3.2.5.1 FLAP AUGER

A specialised auger, narrow enough to fit within the steel casing and equipped with non-return flaps is lowered through the casing. This penetrates loose material, which passes through the flaps, but closes when the auger is pulled up.

3.2.5.2 BAILING TECHNIQUE

The following steps should be taken when removing loose material from the hole using a bailer.

a. Winch operator slackens cable.
b. Bailer operator activates cable by a sudden pull which allows the bailer to drop sharply.
c. This is repeated until the operator feels that the bailer is full.
d. When holding the string onto which bailer is supported, hands should be protected by gloves or a piece cloth.

It is important that the sand is loosened first within the steel casing before the bailer can operate. This is best achieved by first loosening the sand with a small 125mm diameter auger which will pass down inside the steel casing. The sand will rise more easily into the bailer once it has been loosened.

3.2.6 LINING THE DRILLED HOLE

Once the hole has been drilled to the acceptable depth and several metres of water have been achieved, the borehole is completed.

3.2.7 MAINTENANCE OF THE DRILLING RIG

The rig should provide a good service if kept clean and well oiled. Cleanliness is very important. When stems are not used they should be stored on the stem rack. The threads of the stems should be kept clean and oiled regularly. The tools should also be kept clean and the stem guides kept off the ground.

The cable may begin to fray after months of use and the frayed section should be removed and a fresh section of the cable unwound from the winch and connected to the stem linkage.

The cutters also wear out, and require sharpening from time to time. They may also break under strain. V & W Engineering can re-sharpen and repair cutters and hole saws, but there are suggestions that local engineering shops do the job. V & W Engineering supply new cutters with rivets, so that replacements can be made at the nearest workshop in the District. It is best to have spare sets of augers and hole saws.

4.0 HANDPUMPS

4.1 HAND PUMP SELECTION

There are 3 types of standardised hand pumps in Malawi:

- Afridev for deep well as at village level
- Malda for shallow water tables
- Climax, for deep water tables or institutional boreholes
- Life Pump, for deeper water levels (deeper than 30 m dynamic water levels)

4.1.1 AFRIDEV HANDPUMP

4.1.1.1 Specification

Skat Publication 1998 (Revision 3) gives the standard specification for the Afridev Deep Well Hand pump. A copy of this publication could be obtained from the following address: Skat Bookshop, Vadianstrasse 42 CH – 9000, St Gallen Switzerland. Phone No. 41 71 302585 Fax 41 71 224656 Tex 881225SKAT CII.

All down hole components must be straight and true.

4.1.1.2 Installation

- Prior to installation all components must be stored in such a way as to prevent damage and distortion.
- The pump shall be installed according to the manufacturer's instructions.
- The installation of the hand pump shall be done with the participation of the Village Health and Water Committee (VHWC). The installation shall serve as a practical training session for the VHWC and caretakers.
- All rods, couplings, pump heads shall be installed so as to ensure correct pump operation.
- Following installation the hand pump must be operated manually by the installer to provide a minimum of 450 litres of water in 30 minutes.

4.1.1.3 Pump Setting.

- In case of boreholes having a tested reliable yield less than 0.5l/s the setting for pump cylinder shall be 5m below tested dynamic water level to a limit of 40m.
- No hand pump cylinder shall be set deeper than 40m.

4.1.2 MALDA HANDPUMP

4.1.2.1 Specification

Skat Publication 1998 (Revision 0) gives the standard specification for the Malda Hand pump. A copy of this publication could be obtained from the following address: Skat Bookshop, Vadianstrasse 42 CH – 9000, St Gallen Switzerland. Phone No. 41 71 302585 Fax 41 71 224656 Tex 881225SKAT CII.

4.1.2.2 Installation

1) Prior to installation all components must be stored in such a way as to prevent damage and distortion.
2) The pump shall be installed according to manufacturer's instructions.
3) The installation of the hand pump shall be done with the participation of the VHWC. The installation shall serve as a practical training session for the VHWC and caretakers.
4) All pump components shall be installed so as to ensure correct pump operation.

4.1.2.3 Pump setting

5) In case of boreholes the setting for the pump cylinders shall be 5m below tested dynamic water level to a limit of 0.5m from the bottom of the well.
6) No hand pump cylinder shall be set deeper than 15m from dynamic water level.

4.1.3 CLIMAX PUMP

4.1.3.1. Installation

1) Prior to installation all components must be stored in such a way as to prevent damage and distortion.
2) The pump shall be installed according to manufacturer's instructions.
3) The installation of the Hand pump shall be done with the participation of the VHWC.
4) All pump components shall be installed so as to ensure correct pump operation
5) Pump Setting.
6) The setting for pump cylinders shall be 5m below tested dynamic water level to a limit of 1.0m from the bottom of the well.

4.1.4. LIFE PUMP

Water tables continue to drop due to climate change and increasing temperatures. Water is needed in many areas that groundwater development was previously avoided because of technological challenges and in cases where dynamic water levels are deeper. Standard hand pumps are not able to perform effectively at dynamic water level of more than 30m whereas the Life pump can perform at pump set depths deeper than such depths.

4.1.4.1. Specification

Handles:

- Heavy-duty aluminum with UV-resistant rotating grips

Gearbox:

2:1, 1.5:1, 1:1 gear ratio options available (see depth guidelines below)

- Heavy-duty anti-reverse bearing

Gearbox Mount:

- 304 Stainless steel
- Compatible with Afridev & India Mark II base

Base:

- Galvanized steel

Riser Pipes:

- 304 Stainless steel material
- 3 m length
- Square threads for hand tightening and reduced galling

Drive rods, couplers, and rollers:

- 304 stainless steel material with rolled threads
- 3 m length
- Stainless steel couplers with differential material hardness to reduce galling
- Polyethylene rollers

Rotor/stator assembly:

- Stainless steel and durable elastomer materials
- 7.6 cm maximum outer diameter
- 100 m and 150 m depth capacity models

Foot valve:

- Brass and stainless steel materials
- Heavy-duty and high-reliability foot valve
- Self-cleaning design

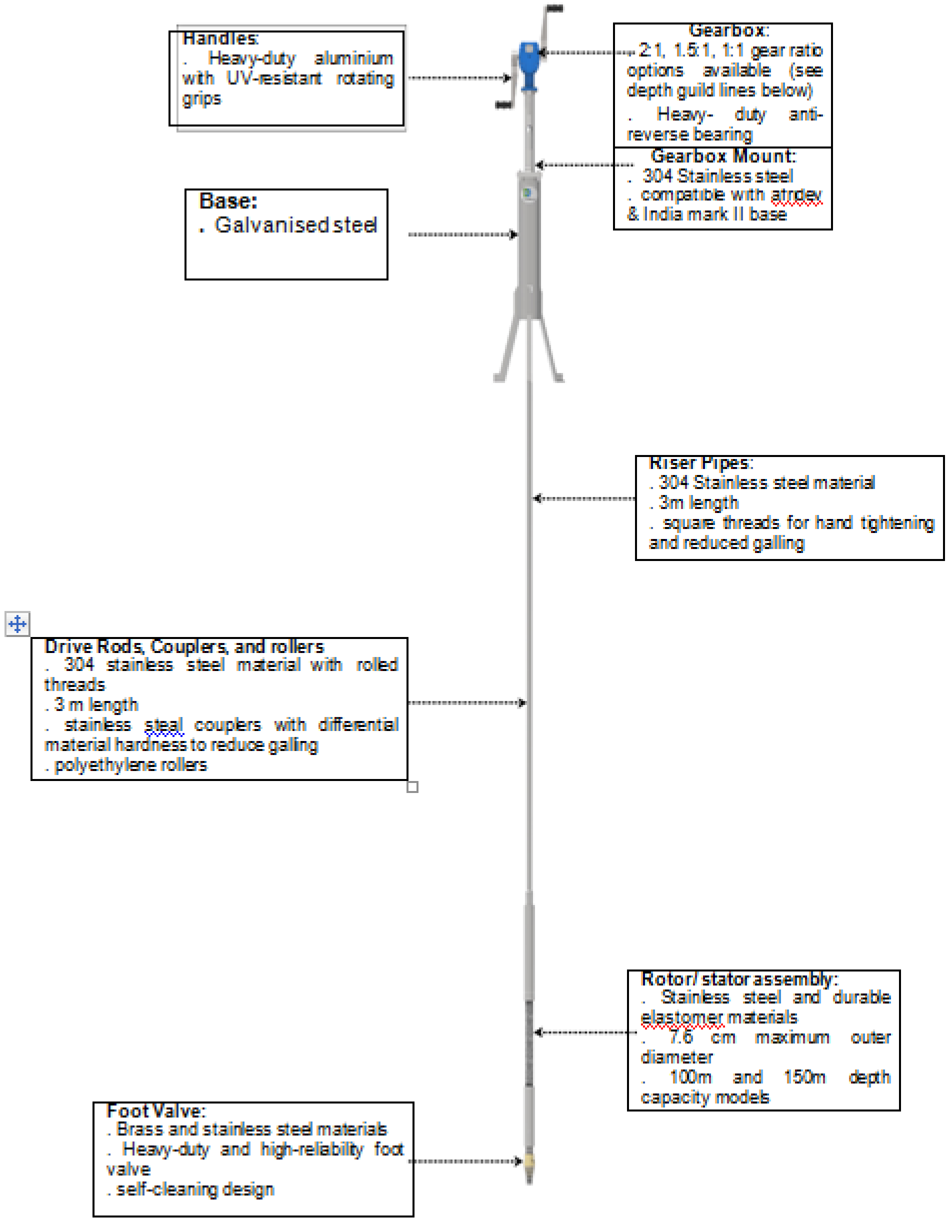

Figure 4: Life Pump parts

Table 3: Depth Capacity

Dynamic water level depth (m)	Gear box ratio guidelines	Lifepump stator
0 – 50	2 : 1	LifePump
50 – 100	1.5 : 1	LifePump
100 – 150	1 ; 1	Lifepump 150

4.1.4.2. Installation

1. Prior to installation all components must be stored in such a way as to prevent damage and distortion.
2. The pump shall be installed according to manufacturer's instructions.
3. The installation of the Hand pump shall be done with the participation of the VHWC.
4. All pump components shall be installed so as to ensure correct pump operation

4.1.4.3. Pump Setting

1. The setting for pump cylinders shall be 5m below tested dynamic water level to a limit of 1.0m from the bottom of the well.

4.2 CIVIL WORKS (HEADWORKS) CONSTRUCTION

Head works have been designed to provide an easily cleaned area around the pump. Owing to the heavy usage of the water points, contractors are required to take particular precaution over the standard of concrete to be used at sites. The primary intention of the design is to provide rapid water drainage away from the pump head. The contractor must take into full account the natural drainage at the site. At certain sites this may require modification of the basic design. In general it is envisaged that such modification shall take the form of an adjustment of the final through. These shall be applicable in those cases where the drainage water can be transmitted to a natural channel located within the normal design extent of the headwork. The under cutting of the headwork's edges shall be regarded as evidence that this requirement has not been fulfilled.

Head works shall be constructed in accordance with the drawing plans provided.

4.2.1 TOOLS AND EQUIPMENT REQUIRED

The following tools are required for construction of civil works: -

- Hoes
- Shovels
- Wheel barrows
- Spirit level
- Float
- Measuring tape
- Shutters
- Trowels

4.2.2 CONSTRUCTION PROCEDURE

1) Excavate site according to the specified dimensions and plan of the civil works
2) Mix concrete for the base using the 1:2:6 (cement: sand: quarry stone)
3) For the structures mix concrete using the 1:2:4 (cement: sand: gravel)
4) Mix well, adding water.

4.2.3 CIVIL WORKS CONSTRUCTION FOR AFRIDEV HANDPUM

4.2.3.1 The deep well option

The pedestal is set when grouting. The legs are set in the grout of the well with the well casing inside the pedestal. The legs will be submerged in the base concrete. Proceed to complete the structure.

After construction, the structure will be cured for 7 days before the pump is installed by flooding it with water.

4.2.4 CIVIL WORKS CONSTRUCTION OF MALDA HANDPUMP

4.2.4.1 The hand dug well option

The pedestal is set on the top slab. The wings of the pedestal are bound to the reinforcement mesh by the binding wire. The wire skeleton is set in the middle of the top slab mould on a hessian cloth. Concrete is then poured in the mould and allowed to set and cure for 7 days. Remove the slab and install on the well.

4.2.3 THE BOREHOLE APRON

Excavate a pit 20cm deep and 70cm in diameter around the well casing. Set the pedestal in the ground around the well casing on the reinforcement wire. Excavate for the apron and drain according to the specified dimensions. Proceed as specified above. Allow to cure before pump installation.

5.0 SPRINGS

5.1 INTRODUCTION

A spring is a naturally occurring output of ground water to the earth's surface, either from the force of gravity or hydrostatic pressure (Virginia Water Resources Research Center, 2012). Springs are usually found in low-lying areas, at the base of slopes, or along hillsides. In Malawi, most springs are low flow discharges, almost all from shallow formations in areas where the topography encourages shallow groundwater to discharge at the surface (Mott Mcdonald, 2003). The springs cannot be included in the national monitoring network since their water level information will only provide information on the fluctuation of shallow groundwater. However, where the aquifers are used to provide portable drinking water in rural communities, proper development, management and protection of the springs is recommended as described below.

5.2 FACTORS TO CONSIDER WHEN DEVELOPING SPRINGS

The following factors should be considered when developing a spring as a source of drinking water:

(1) Ensure the rate of flow is reliable throughout the year. Great fluctuations of spring flow indicate an unreliable source which may also be susceptible to contamination. Measure the flow rate of the spring by digging a 10L bucket into the slope of the spring and measure the time taken for the spring water to fill-up the container.

(2) Determine the water quality of the spring water to determine its quality for human consumption and ensure it can be efficiently and economically treated to make it safe for human consumption if it's of poor quality.

5.3 SPRING DEVELOPMENT PROCEDURES

Springs can be developed into a drinking water supply in two ways, depending on the type of spring – concentrated spring or seepage spring. Spring development entails collecting the spring water e.g. using a pipe and running the water into a sanitary storage tank. Proper spring development helps protect the water supply form contamination.

5.3.1 CONCENTRATED SPRINGS

A concentrated spring typically occurs along hillsides in mountain and piedmont areas at points where groundwater emerges from one defined discharge in the earth's surface e.g. where groundwater is forced through openings in fractured bedrock. It is usually less contaminated than other types of springs. A concentrated spring that occurs in valleys or other low areas is termed a low-area spring. This type of spring is not as easily protected as those located in higher areas where surface water naturally drains away from the spring.

The procedures for developing a concentrated spring are (Figures 5 and 6):

1. Dig upslope from the spring outlet to a point where flowing water is at least 0.9m underground or where rock is encountered.
2. Install a rock bed to form an interception reservoir.
3. On the downslope side, install a cut-off wall of concrete or plastic. The cut-off wall may not be necessary for a low-area spring, where the spring box may serve as the collector (Figure 5).
4. Insert a collector pipe low in the cut-off wall to guide water into the spring box. As much as possible, prevent water from backing up behind the wall.

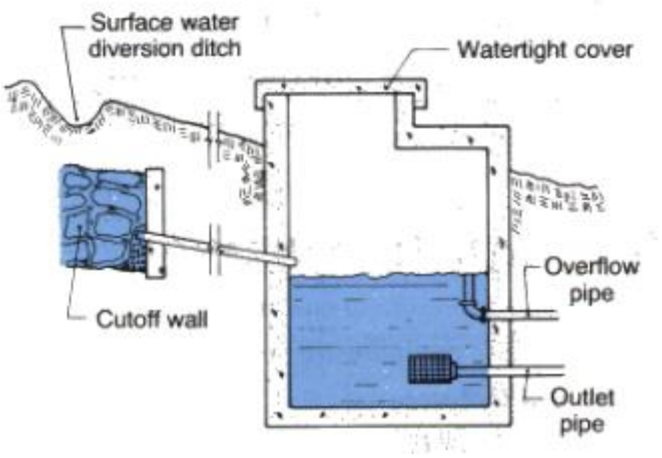

Figure 5 Cut-away view of a concentrated spring (Jennings, 2012)

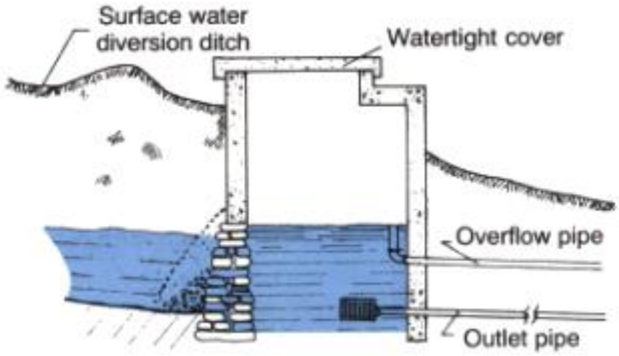

Figure 6 Cut-away view of a low-area spring (Jennings, 2012)

5.3.2 SEEPAGE SPRINGS

Seepage springs occur where groundwater "seeps" from the ground over large areas and has no defined discharge point e.g. occurs when a layer of impervious soil redirects groundwater to the surface. The development process for seepage springs consists of intercepting flowing groundwater over a wide area underground and channelling it to a collection point. Seepage springs are more difficult to protect from surface water contamination than concentrated springs.

The development steps for a seepage spring (Figures 7 and 8) are (Jennings, 2012):

1. Dig test holes uphill from the seep to find a point where the impervious layer below the water-bearing layer is about 0.9m underground. Water flows on top of this layer in sand or gravel toward the surface seep.
2. Dig a 45 to 60cm wide trench across the slope to a depth of 15cm below the water-bearing layer and extending 10 to 15cm beyond the seep area on each side. Install a 10cm collector tile and completely surround the tile with gravel.
3. Connect the collector tile to a 10cm line leading to the spring box. The box inlet must be below the elevation of the collector tile.

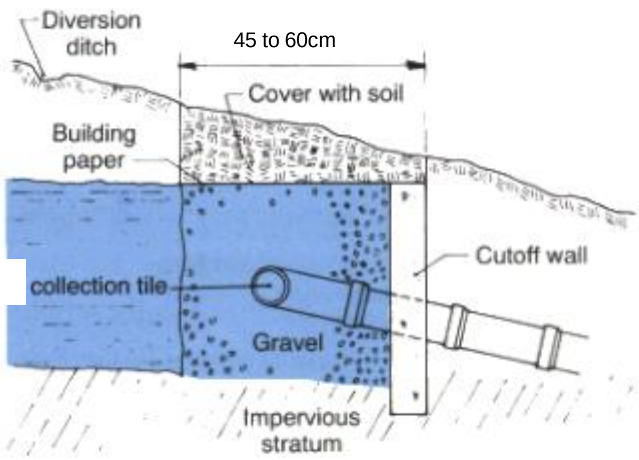

Figure 7 Cut-away view of a seepage spring (Jennings, 2012)

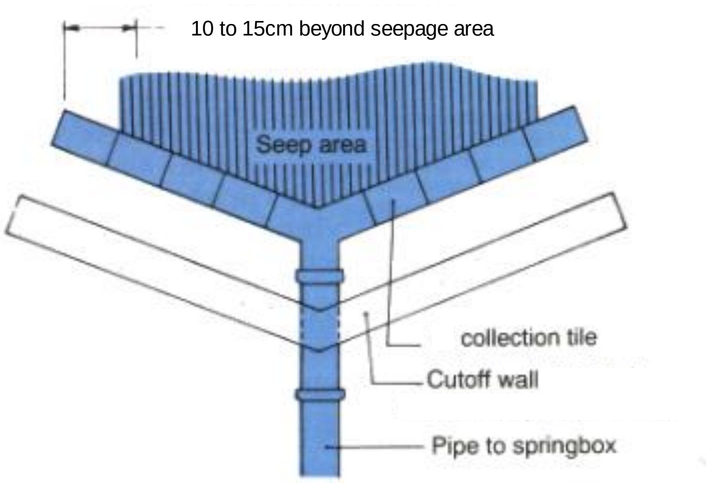

Figure 8 Over-head view of a seepage spring (Jennings, 2012)

5.3.3 SPRING BOX DESIGN CONSIDERATIONS

The spring box is a water tight structure, usually made of reinforced concrete, built around the spring to isolate it from contamination from surface run-off, animals etc. The following design considerations should be noted:

(1) It should be at least 1.2m in height and extend at least 30cm above ground level when buried.

(2) The size of the spring box depends on the amount of storage needed but should typically be at least a 90cm square, which would provide storage of 510l with water standing 60cm deep.

(3) The spring box should have an outlet pipe and an overflow pipe. The overflow pipe should be screened and located below the collector pipe or tile so that water will not back up behind the spring. The overflow may be a floating device connected to the outlet pipe.

(4) Install a drain for cleaning the box.

5.4 MANAGEMENT OF SPRINGS

Proper management of springs involves isolating all sources of contamination such as livestock, wildlife, agricultural fields, forestry activities, septic systems and fuel tanks on the spring recharge area. The following steps can be followed to protect springs (Jennings, 2012):

1. Divert all surface water away from the spring as far as possible. Do not allow flooding near the spring.
2. Construct a U-shaped surface drainage diversion ditch or an earth berm at least 15m uphill from the spring to divert any surface runoff away from the spring. Be careful not to dig deep enough to uncover flowing groundwater.
3. Construct an earth berm adjacent to the spring or a second U-shaped diversion ditch lined with concrete tile for added protection.
4. Fence an area at least 30m in all directions around the spring box to prevent contamination by animals and people who are unaware of the spring's location.
5. Avoid heavy vehicle traffic over the uphill water bearing layer to prevent compaction that may reduce water flow.
6. Spring water should be tested before and after heavy rains each year for bacteria, pH, turbidity, and conductivity to determine if surface-water contamination is a problem. If bacteria are found at any time in the water, properly disinfect the system and retest the water before using it again.
7. Most springs used for drinking water will require some type of continuous disinfection system e.g. chlorination to make certain that the water is safe for consumption.

6.0 DEEP WELLS

A deep well is defined as a borehole that is greater than 25 metres in depth and minimum diameter of 110mm. These are normally drilled using mechanical methods. Two classes of deep wells, namely production and monitoring boreholes, are presented in this section.

Construction of boreholes entails six distinct processes:

1) Site selection,
2) The actual drilling operation,
3) Installation of casing, screen and gravel pack, to ensure sand-free operation at maximum yield,
4) Well development,
5) Construction of sanitary seal and
6) Test Pumping

Two or more of these operations may be performed simultaneously, depending upon the borehole construction technique used.

6.1 BOREHOLE SITING

Complete hydrogeological desk studies should be carried out to target specific aquifers in specific areas and determine the best geophysical siting approach to use. The following analyses should be carried out during desk study:

1) Aerial and satellite imagery interpretations
2) Establish geological and hydrogeological set-up of the area
3) Evaluate applicability and effectiveness of previous geophysical siting approaches

A desk study report should be prepared spelling out the background hydrogeological data, the appropriate geophysical siting approaches, establish the survey locations and optimise borehole and test-pumping designs appropriate for the type of boreholes to be drilled in the area.

Major surface geophysics techniques to be used include:

1) Electrical resistivity

2) EM
3) Magnetics
4) Gravity
5) Seismic refraction and reflection

The applications of each of these surface methods are summarised in Table 4.

Table 4 Major surface geophysical methods for groundwater exploration (Modified after EPA, 1993)

Method	Description	Hydrogeologic Applications
Electromagnetic induction (EMI)	Uses a transmitter coil to generate currents that induce a secondary magnetic field in the earth that is measured by a receiver coil. Well suited for areal searches.	Can be used to map a wide variety of subsurface features including natural hydrogeologic conditions. Depth of penetration is typically up to 60 meters but depths to over 200 metres are possible.
DC electrical Resistivity	Measures the resistivity of subsurface materials by injecting an electrical current into the ground by a pair of surface electrodes and measuring the resulting potential field (voltage) between a second pair of electrodes.	Can be used to delineate water filled fractures/faults, water quality assessment, stratigraphic mapping
Seismic refraction and reflection	Uses a seismic source (commonly a sledge hammer), an array of geophones to measure travel time of the refracted/reflected seismic waves, and a seismograph that integrates the data from the geophones.	Can be used to define the thickness and depth to bedrock or water table, thickness of soil and rock layers, and map structures

Method	Description	Hydrogeologic Applications
Magnetometry	Uses a magnetometer to measure the intensity of the earth's magnetic field. The presence of ferrous metals can be detected by the variations they create in the local magnetic field.	Can be used to map bedrock and delineate structural features e.g. faults and dykes
Gravimetry	Uses one or more of several types of instruments that measure the intensity of the earth's gravitational field.	Can be used to estimate depth of unconsolidated material over bedrock on basis of density contrasts. Microgravity surveys may be able to detect subsurface cavities and subsidence voids.

Aquifer specific geophysical exploration is recommended for siting the 100 proposed monitoring boreholes and any new production boreholes. A list of some of the relevant geophysical techniques, from the classification in Table 3 above, and their applicability is as follows:

1) Lund imaging techniques to map bed rock, lithological and structural mapping and palaeo-channels within sedimentary sequences
2) Magnetic survey techniques to map bedrock and pick up dykes and structures
3) Electromagnetic profiling using the EM 34 instruments to map zones of deep weathering within rock units and thickness of deposits such as alluvial.
4) Resistivity sounding techniques to map the depth to deepest weathered unit

Geophysical siting is essential to avoid low yielding boreholes and proximity to pollution or interference effects from nearby abstraction boreholes. The distance from a pollution source will depend on the geological formation. However, as a guide the distance should not be less than 30m from a potential pollution source.

6.2 DRILLING METHODS

Drilled boreholes can be constructed using the cable tool “percussion” method or rotary method. The method selected will depend primarily on nature of the aquifer, type of terrain and economic implications. Anticipated size and depth of borehole and the geologic formations to be penetrated may also dictate which method is preferable.

6.2.1 CABLE TOOL DRILLING

The cable tool method of drilling wells is also referred to as “percussion,” “solid tool” and “standard” drilling. It is used for wells of all sizes and depths.

In this method, the hole is drilled by percussion and cutting action of a drilling bit. The bit is attached to the bottom of a heavy string of drilling tools located at the end of a cable that is alternatively lifted and dropped by suitable machinery (Figure 9 and Figure 10).

Figure 9 Cable tool rig in operation (Driscoll, 1986)

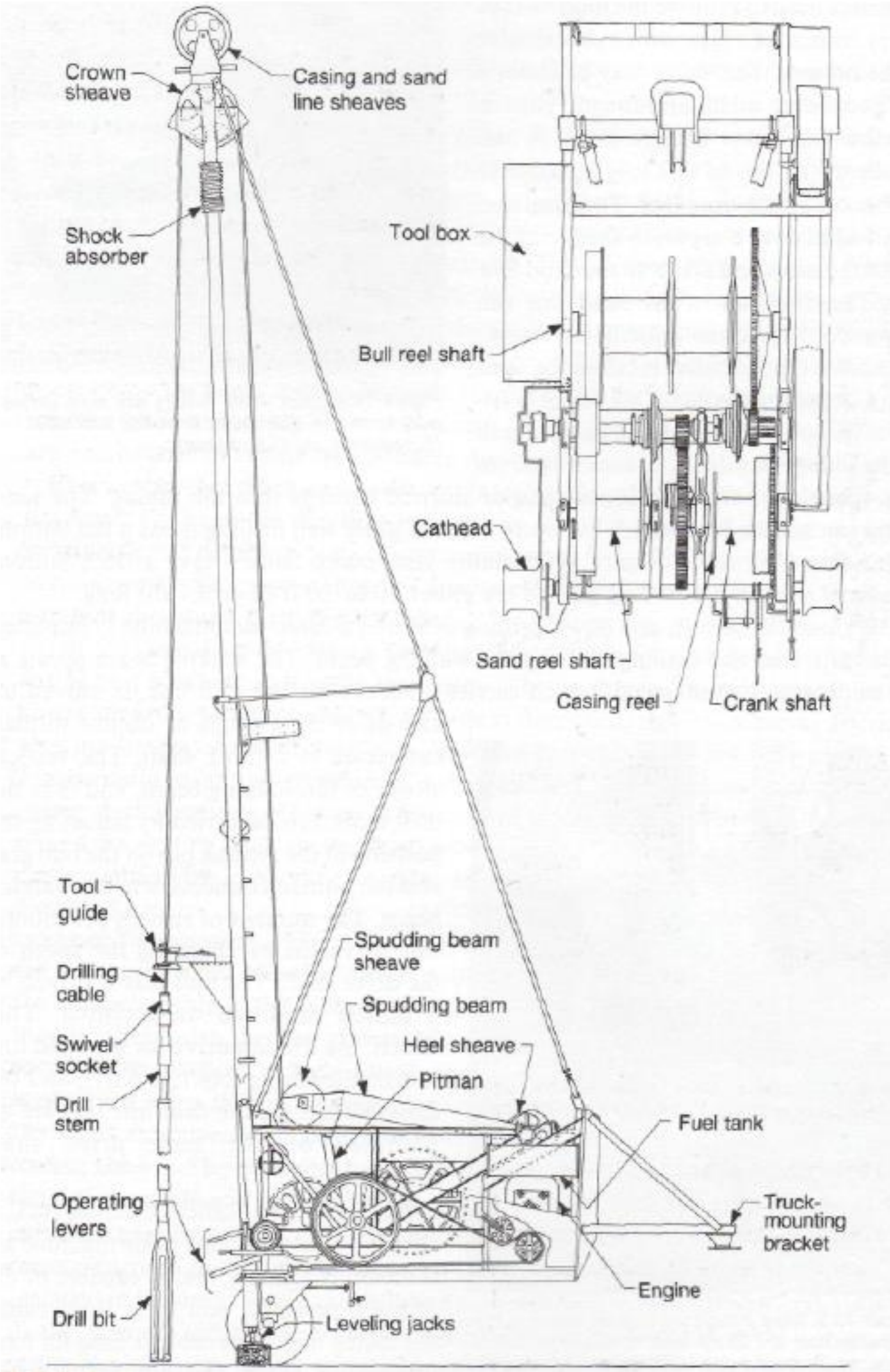

Figure 10 Engineering drawing of cable tool rig (Driscoll, 1986)

When working in hard formations, the drill bit breaks or crushes the hard rock into small fragments. In soft, unconsolidated formations, the bit simply loosens the material. The length of the drill cable can be adjusted so that the bit will strike with the right amount of weight. The driller assesses the “blow” of his tools, and based on his evaluation the length of the stroke can be regulated by controls on the rig. Several metres of hole are drilled at each “run” of the drill tools. After each “run”, the hole must be cleared of debris.

A slurry or sludge is formed in the borehole by mixing water with the dislodged material. If no water is present in the formation being drilled, the necessary quantity is added into the hole. If too much sludge accumulates in the hole, the fall of the tools will slow down and penetration will be retarded. Therefore, slurry is periodically removed by means of a sand pump or bailer.

The sand pump bailer consists of a section of tubing 3 to 5 metres long with a valve in the bottom for removing cuttings or sludge from the drill hole. It is smaller in diameter than the drill hole, allowing it to move up and down freely. After being lowered and raised within the hole several times to collect the material which has settled to the bottom, the bailer is brought back to the surface and the material collected (sludge or slurring) is dumped.

Drilling rate and efficiency are affected also by the following:

- Resistance of the formation
- Weight of the drill tools
- Length of the stroke
- Strokes per minute
- Diameter of the bit
- Clearance between tool joints and inside of hole

Whether or not temporary casing must be driven during the operation will also influence the drilling rate. In consolidated formations, open-hole can usually be drilled, but in soft or unconsolidated formations, temporary casing must be installed as the well is drilled to keep the borehole open and vertical. The temporary casing should be flush jointed (with no couplings protruding) for ease of installation and extracting.

Temporary casing is driven with the drilling tools, drive clamps, and a drive head that is, casing is driven down the hole by hammering as the hole is drilled. A drive shoe is attached to the lower end of the casing to keep it from collapsing or crumbling in formations where it may be damaged. The drive head or cap is attached to the upper end of the casing to protect it from the driving blows of the clamp. The drive clamp is attached to the drill stem, and as the drill is raised and lowered, the clamp dropping on the drive head forces the casing into the hole. Care should be taken not to force drive the temporary casing done the hole as this will cause problems during extraction.

Extraction of temporary casing is done after the installation of permanent casing and during the installation of gravel pack.

As the casing is driven, vibration causes the sides of the hole to collapse against the casing. When frictional forces prohibit driving the casing any further, a smaller diameter casing is telescoped into the established casing and drilling continues with a smaller-diameter bit until the required depth is attained.

Table 5 shows the advantages and disadvantages of cable tool drilling (HWE, 2012 and Driscoll, 1986).

Table 5 The advantages and disadvantages of cable tool drilling technique

Advantages	**Disadvantages**
Good samples can be obtained if the driller does not drill too far ahead of the casing	The technique is slow and may be costly for some subsurface conditions, especially in clays and clayey formations
Good well development is achieved if surge blocks are used	Frequent equipment failures especially in older cable tool rigs
Versatile depth and diameter can be achieved	Temporary casing may get stuck
Water bearing formations are noted easily	Casing for deep holes may be difficult
Method applicable in crystalline rocks and hard rock formations,	Drilling usually begins with a larger diameter and casing size than specified to enable installation of

boulders and gravels	temporary surface casing to prevent caving
Rigs are relatively inexpensive	Cutting samples are usually reduced to a slurry because of the repeated crushing action of the bit.
Wells can be drilled in areas where little make-up water exists	It may be difficult to pull back long strings of casing in some geologic conditions, unless special equipment is available.
Wells can be drilled in formations where lost circulation is a problem	Casing costs are usually higher because heavier wall or larger diameter casing may be required

6.1.2 AIR AND MUD ROTARY DRILLING (DIRECT CIRCULATION)

The direct rotary drilling method entails the rapid rotation of a bit on the bottom of a string of drill pipe. The rotation speed can be varied according to the type, form and size of the bit, the formation being drilled, and the strength of the drill pipe.

Drill cuttings from the bottom of the hole are removed by continuous flow of air (air rotary drilling method) or other drilling fluid e.g. mud (mud rotary drilling method) in the annular space between the borehole wall and the drill pipe. Once at the surface, the fluid is channelled into a settling pits or mechanical equipment extracts the cuttings to allow clean drilling fluid to be re-circulated into the borehole.

If air is used as the primary drilling medium (air rotary drilling), cuttings are deposited on the ground or in a collection system while the circulating air goes into the atmosphere (Sterrett, 2007). There are two drilling techniques that use air as the principal drilling fluid - direct air rotary and downhole air hammer.

The rig for air rotary drilling is essentially the same as for mud or direct circulation rotary drilling, except that fluid channels in the bit are of uniform diameter rather than jets, and the mud pump is replaced by an air compressor. The drill bit can be tungsten blade, rock roller or downhole hammer (DTH) depending on the hardness of the rock. Compressed air is circulated down the drill pipe, out through holes in the drill bit, and upward through the annular space between the drill pipe and the side of the hole. Moving at high velocity, this air carries cutting to the surface.

Drilling with air as the circulating fluid can be done effectively only in consolidated materials. The method has a disadvantage in unconsolidated formations through contamination of the sample by hole wall erosion and through water flows after groundwater has been encountered. Air rotary drilling machines for this type of work are usually equipped with a conventional mud pump in addition to a high capacity air compressor. Drilling mud can then be used in drilling through caving materials above bedrock. Drilling with air can follow later. It may be necessary to install temporary casing through the overburden materials to prevent caving after changing to air circulation.

The function of various drilling fluids used in air and mud rotary drilling are shown in Table 6.

Table 6 The role of various fluids in air and mud rotary drilling

Drilling fluid	Function
Mud – as drilling fluid	• Circulation to remove cuttings. • Cool the bit. • Provide a wall cake for wall stabilisation and loss of fluid. • Inhibits mixing of formation fluids. • Thixotrophy – will jell when drilling eases and return to fluid conditions or re-establishment of rotation • Provide pressure control Media for wall chemical reaction prevention
Foam	Foaming agents are usually injected with water and/or air to improve the removal of chips in situations where up-hole velocities are inadequate.
Air – as drilling fluid	Used effectively only in consolidated materials to carry cuttings to the surface.
Water	• Can be used as a total drilling media or as an intermittent flushing agent by pressure injection in air rigs. • Removing cuttings • Cooling the bit • Provide pressure control

Considerable technology is associated with drilling media. Variations are used with different formation conditions with regard to chemical compatibility with the formation and its fluids, viscosity, density and scaling ability. Numerous additives are used and these often vary as drilling progresses.

Biopolymer muds are mostly used in the construction of water wells because they are degradable or biodegradable and do not permanently clog the formation.

Two different methods are employed to rotate the drill string in air and mud rotary drilling. These are table-drive or tophead drive. Rotation is provided by a hydraulically driven gearbox which travels up and down the rig mast for tophead rigs while on table-drive rigs power is supplied to the drillpipe through a kelly bushing located on the table (Figure 11).

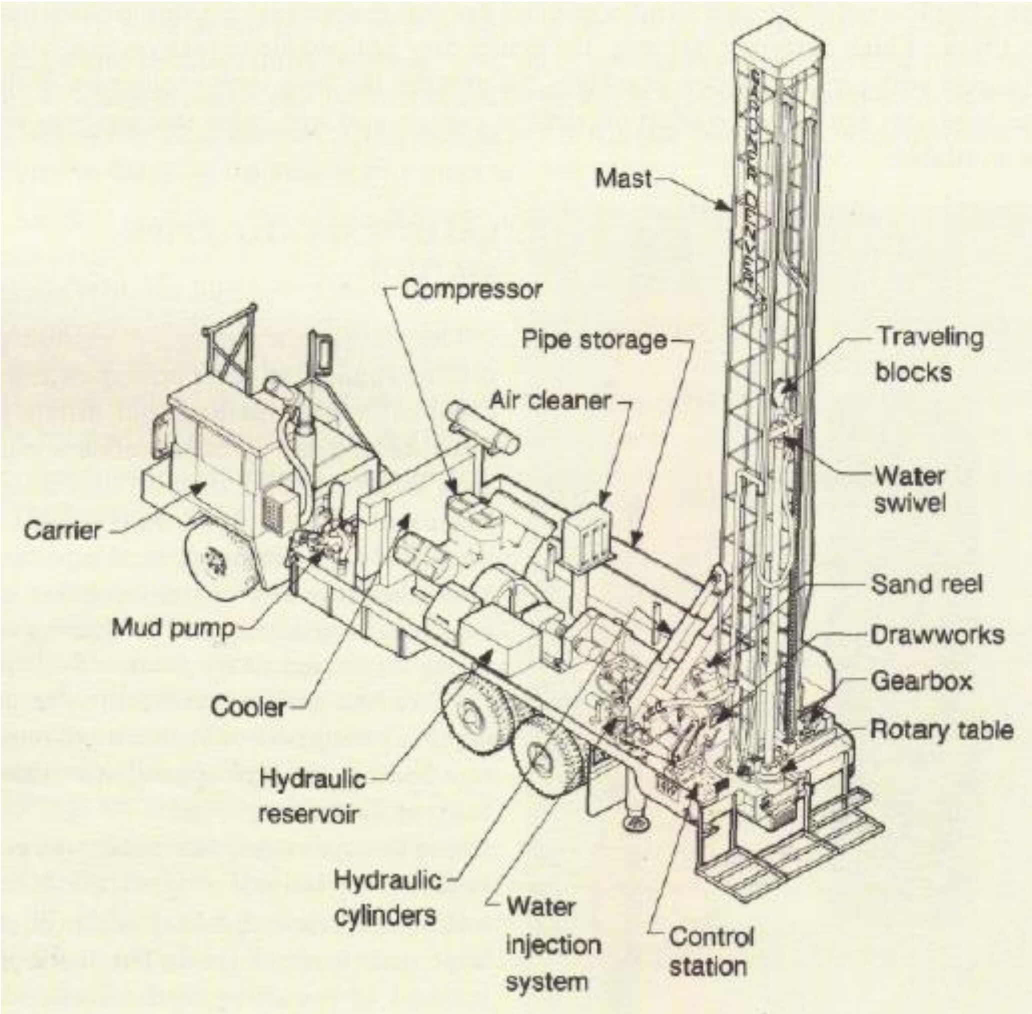

Figure 11 Schematic diagram of a truck mounted direct rotary drill rig (Driscoll, 1986)

Table 7 summarises the advantages and disadvantages of mud and air rotary drilling techniques.

Table 7 The advantages and disadvantages of direct circulation drilling techniques (Sterrett, 2007)

Advantages	Disadvantages
Mud rotary drilling	
Penetration rates are relatively high in all types of materials	Drilling rigs require a high level of maintenance
Minimal casing is required during the drilling operation	Mobility of the rigs can be limited
Rig mobilisation and demobilisation are rapid	Most rigs must be handled by a crew of at least two people
Well screens can be set easily as part of the casing installation	Collection of accurate samples requires special procedures
	Use of drilling fluids can cause plugging of certain formations
	The drilling method is difficult and less economical in extremely cold temperatures
	Drilling fluid management requires additional knowledge and experience
Air rotary drilling	
Cuttings removal is extremely rapid	Restricted to use in semi-consolidated and well-consolidated materials
Aquifer is not plugged with drilling fluids	High initial cost and maintenance costs of large air compressors
Mud pumps are not used during air drilling, eliminating that maintenance cost	
Bit life is extended	
Drilling operations are not hampered by	

extremely cold weather	
Penetration rates are high (especially when using downhole hammers) in highly resistant rocks such as dolomite or basalt	
An estimate of the yield of a particular formation can be made during drilling	

6.1.3 REVERSE CIRCULATION ROTARY DRILLING

In reverse circulation rotary drilling, the drilling fluid circulates in the direction opposite that of the conventional rotary method. The fluid (usually water with no mud additives) flows down the borehole and rises in the drill pipe, carrying cuttings to the surface. A high capacity pump is attached to the drill pipe and keeps the fluid moving at a high velocity. Air is pumped into a special double-walled drill stem to increase the cuttings removal efficiency as shown in Figures 12 and 13 (Sterrett, 2007). Water may be discharged to waste if a large, fresh supply is available, or cuttings may be allowed to settle out and the fluid re-circulated.

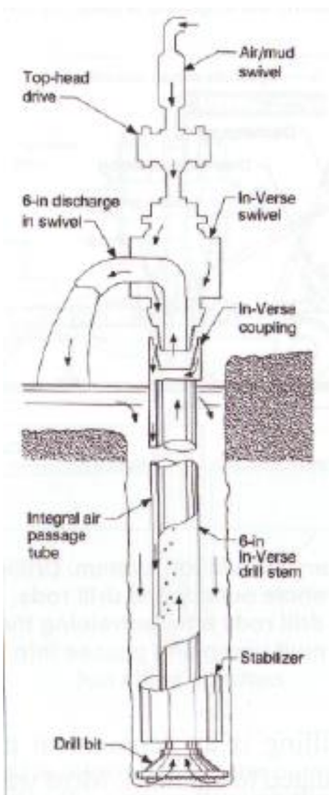

Figure 12 Air circulation during reverse circulation drilling (Sterrett, 2007)

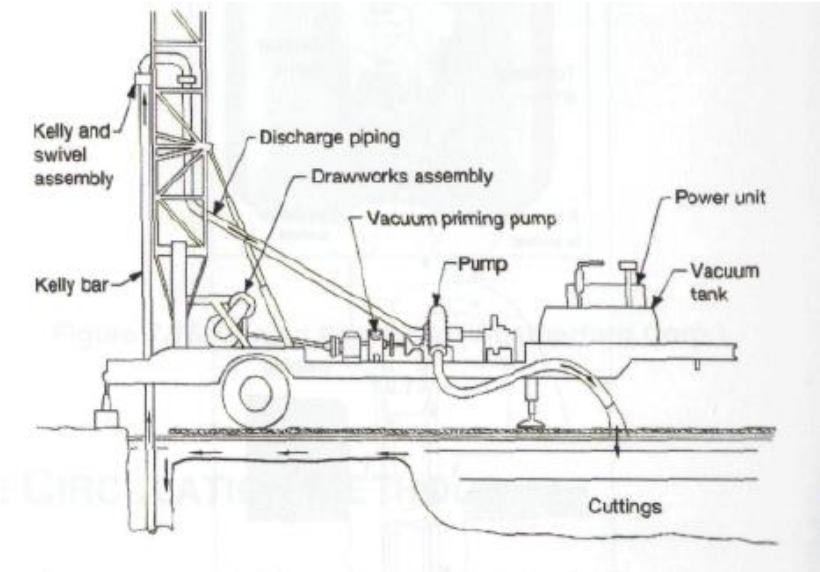

Figure 13 Reverse rotary circulation system (Sterrett, 2007)

Keeping the borehole open in reverse circulation drilling may be a problem. Fluid must be kept at ground level at all times to prevent caving. This requires a large volume of water. When permeable formations are penetrated, great amounts of water can be lost. This is offset somewhat when some of the suspended particles in the fluid adhere to the hole wall, creating a thin deposit that partially clogs pores and reduces water loss. If large quantities of water are not available when drilling a highly permeable formation, it may be necessary to artificially "mud the hole". Caving may result from the wash action of the fluid moving down the hole.

The advantages and disadvantages of reverse circulation drilling are shown in Table 8.

Table 8 Advantages and disadvantages of reverse circulation techniques (Sterrett, 2007)

Advantages	Disadvantages
Porosity and permeability of the formation near the borehole are relatively undisturbed (as compared to other methods)	Large water supply generally is needed during drilling
Large-diameter holes can be drilled quickly and economically	Reverse rotary rigs and compound, usually are larger and more expensive
Casing is not required during the drilling operation	Large mud pits are required

Well screens can be set easily as part of the casing installation	Some drill sites are inaccessible because of the rig size
Most geologic formations can be drilled (except igneous and metamorphic rocks)	For efficient operation, a larger crew generally is required as compared to that needed for other drilling methods
Little opportunity exists for washouts in the borehole because of the low velocity of the drilling fluid	Extra costs for drillpipe, special swivel, and air compressor (if the rig is not equipped with one)
Large-diameter boreholes can be drilled	Drillpipe handling time can increase for deep holes
Penetration rates are high in unconsolidated sediments	
Less drilling-fluid additive is required to lift the cuttings	
Reduced development time	

6.1.4 JETTED WELLS

In jetting a well, a hole is drilled by the force of a high velocity stream of water that loosens the material it strikes and washes particles upward out of the hole. Jetting can be used to penetrate some sandstone and schist formations that are not very hard. It is particularly successful in construction of small-diameter wells in water-bearing sand.

Also referred to as the jet percussion method, jet drilling employs a chisel-shaped bit attached to the lower end of a string of pipe. Holes on each side of the blade of the bit serve as nozzles for water jets that keep the bit clean and help soften the material being drilled.

In the jetting operation, water is pumped under pressure through the drill pipe and jetted from the drill bit. The water then travels upward in the annular space around the drill pipe, carrying cuttings in suspension, and then overflows at ground surface. Cuttings settle out in drainage pits and the water is picked up by the suction of the pump and re-circulated through the drill pipe. The fluid circulation system is comparable to that of conventional rotary drilling.

With water circulation maintained, the drill rods and bit are lifted and dropped in a manner similar to cable tool drilling, but with shorter strokes. The chopping action of the bit coupled with the washing action of the jetted water opens up the borehole.

Temporary casing is usually sunk as the drilling proceeds. Sometimes it sinks substantially under its own weight, ordinary, it needs to be forced down. Open hole can be drilled by jetting to limited depths in unconsolidated materials. Temporary casing must eventually be installed, however, and must follow the bit closely when the hole tends to cave.

The advantages and disadvantages of jetting are summarised in Table 9.

Table 9 The advantages and disadvantages of rotary drilling techniques

Advantages	Disadvantages
The equipment is simple to use	Water is required for pumping
Possible above and below the water-table	Suitable for unconsolidated rocks only (e.g. sand, silt, clay)
	Boulders can prevent further drilling

6.2 GEOLOGICAL FORMATIONS AND SELECTION OF DRILLING METHODS

Since the geologic formations to be drilled dictate the drilling method best suited to the operation, drilling methods used in production and monitoring hole drilling depends on available information on the geologic section and its hydraulic properties. This can be gained by examination of data from:

- Regional Geology
- Geophysical Survey
- Nearby wells
- Exploratory Drilling

By far the most reliable information is gained from a test borehole on or close to the site of the proposed production borehole. Often this is the only reliable and worthwhile procedure when the high expenditure and performance of a production borehole is considered.

In fractured formations, the test borehole and production borehole locations need to be the same site or close enough for confidence of predicting production conditions.

The following drilling methods are usually applicable to the formations listed below.

6.2.1 UNCONSOLIDATED, SLUMPING OR PRESSURE FORMATIONS

These conditions are drilled with the normal circulation rotary mud of casing drive methods:

(a) Reactive clays (swelling clays) are a problem, the mud may require chemical additives (conditioning)

(b) Pressure conditions such as artesian gas pressure or formation pressure (squeezing clay) may require mud weight increase such as adding barite.

(c) Running of unconsolidated sands require good wall conditioning or mud cake formation to reduce fluid loss and to stop wall erosion by circulation return.

6.2.2 CEMENTED SEDIMENTS OF WEATHERING PROFILE

Formations of cemented or bonded particles such as in sandstones, shale, siltstone or the laterite weathering profile can be drilled open-hole using air, combinations of air, water and foam. Water and form is used where circulation return is inhibited by wet clay. Drill bits to be used depend on the hardness of the formation. With increasing hardness drag, rock roller or air hammer should be used.

6.2.3 CAVEROUS FORMATION

Caverous formations as in limestone, volcanic flows and highly fractured zones require special methods usually involving the running of casing progressively as the borehole is drilled. Two principle rigs are used and these are the cable tool and the casing rotary drill.

The cable tool method does not depend on circulation of drilling media. Cuttings are bailed from the hole intermittently. When casing is progressively run in the hole, an undercut bit is used to enlarge the hole below the casing “shoe”.

The casing rotary drilling method involves rotating the casing which has a cutting foot so that it follows closely behind a rock bit but in some machines the rock bit has an acentric motion which undercuts the casing.

6.2.4 HARD (CRYSTALLINE) ROCKS

The down-hole hammer on a rotary rig is almost universally used for hard rock formations such as stray cemented sediments, igneous and metamorphic rocks. Down hole hammers are usually operated by air pressure. Foam and water injection is used where cutting return (circulation) is inhibited by dampness on the walls of the hole.

The size of the hole and depth (particularly below a head of groundwater) is limited back by air velocity to remove cuttings (up-hole velocity) and the pressure to maintain efficient hammer operation.

In granular formations, such as in alluvial plains, the rotary method is usually preferred to cable tool because penetration is more rapid, a better well seal is obtained and maintaining a straight hole is easier.

Boulder beds in alluvial fans are extremely difficult to drill by any method. Cable tool is preferred, though since the boulders can be cracked or chipped by hard blows of the bit.

6.3 WELL COMPLETION

Well completion and development must follow the actual drilling to prepare a well for use. Elements of this process include:

- Installation of casing and screen
- Installation of gravel pack
- Development
- Test pumping

- Water sampling
- Cementing and grouting
- Sterilisation

6.3.1 INSTALLATION OF PLAIN AD SLOTTED CASING

There are basically two uses of casings and these are: -

(a) For drilling progress (temporary casings). These are used as surface collar to start drilling in the soil zone, and as upper casing to seal off running formations.

(b) For hole completion (permanent casings). These are used as production casing and they include screen, slots and accommodate the pump and riser pipes, electric cable, pump suspension cable, monitoring controls and facilities.

Permanent casings are used for wells in water bearing sand and gravel and in some consolidated rock formations. The casings support the formation and prevent caving. Different types of casings are used nationwide although in Malawi the permanent casings used are UPVC pipes of 3m length each.

Table 10 shows a list of the different types of casing used nationwide.

Table 10 Types of casings used in Malawi

TYPE	USE	ADVANTAGES	DISADVANTAGES
Mild steel	Deep wells, pressure conditions, miming	High strength availability, low cost	Difficult to handle, high cost, threaded or requires on-site welding
Stainless steel	Deep wells, highly corrosive conditions	High strength, corrosion resistant	Very high cost, difficult to handle, specialist welding not readily available
PVC	Shallow boreholes (less than 100m)	Availability, low cost, corrosion resistant, easy to handle	Brittle and low strength solar deterioration
Polyurethane and fibreglass	Mining, quarrying, construction sites,	Impact resistant, easy to handle, non-brittle	High cost, limited strength

	corrosive conditions		

The strength of casing relates to composition and wall thickness. The strength is mostly pressure rated and is designated as “class” i.e. Class 6, 9, 10, 12, 16, 18 etc. Class 9 has a pressure rating of 90m pressure head, Class 12, 120m pressure head and so on. In Malawi the recommended class is Class 10.

Production boreholes with yields less than 1 litre per second (l/s) will be lined with 110mm diameter of casing. Those with yields greater than 1l/s will be lined using 152mm diameter casings. The diameter of the permanent casing usually corresponds to the drilling diameter.

6.3.1.1. PLAIN CASING

Plain casings are installed above the main aquifer and against non-water bearing formations. These support the walls of the borehole, prevents curving and contaminated subsurface water (in shallow water tables) to enter the well.

6.3.1.2. SCREENS (SLOTTED CASING)

Screens are mostly used in unconsolidated or poorly consolidated formations with a granular fabric.

The screen also supports the walls of the borehole, prevents formation from caving and permits water to enter the well through closely spaced openings. The diameter of the screen corresponds with the diameter of the plain casings.

When installing screens, several factors need to be taken into consideration and these are:

a) *Length* -Selection of the length of the screen should take into consideration the yield versus the aquifer thickness. Casing off part of the aquifer will reduce the yield of the borehole. Length depends primarily on the desired well yield and the thickness of the aquifer, and is influenced by the open, intake, area of the well screen.

b) *Diameter* -The diameter of the screen will determine the size of yield pump to be installed.

c) Slot size -The size of the screen openings is chosen based upon the gradation. Or grain sizes of the water bearing formation. The well screen shall have slot size of 0.75mm.

The screen will be installed against water bearing formation save for the last 6m from the bottom that must be cased, unless otherwise instructed. A bail plug consisting of a 6m length of plain casing complete with end plug shall be fixed at the bottom of the slotted casing.

At no circumstance, however will screens be placed against clays or silty formation.

6.3.1.3 JOINTS

The joints for the casings shall be spigot and socket joints. The joint ends shall be cleaned first and cemented together using solvent cement.

6.3.1.4 CENTRALISERS

Centralisers shall be fixed to plain casings and screens at intervals not exceeding 6m to ensure that the casing is central and that there is enough annular space to facilitate the installation of gravel pack.

6.3.2 GRAVEL PACK (FILTER PACK)

All boreholes shall be gravel packed. The gravel pack to be used must be approved by the MoWDI. Gravel pack must be sieved and then stored in such a way so as to avoid contamination or heavy rain washing (recommended size of not less than 0.75mm). Ironstone or calcareous fragments in gravel packs are not acceptable.

Gravel pack should be evenly installed around the annulus of the hole. Installation shall be carried out as a continuous feed operation (to prevent segregation) using water above to flush as necessary. Where temporary casing has been installed, initial packing shall continue inside the temporary casing prior to casing pull back, to a height of at least 1.5m above the base of the temporary casing.

Once initial placement of filter pack material has reached a height of 0.6m above the top of screen gentle well development work shall commence.

Placement of gravel, temporary casing pull back and gentle well development shall proceed until gravel is settled to a height of 0.5m above the top of the screen. Temporary casing shall be retained in the hole at this stage until well development is complete. Gravel shall be topped up as necessary during development to maintain this level.

6.3.3 GROUTING AND BACK FILLING

There are two types of grouting, design type A and design type B.

For design type A, a 5m thick grout seal shall be placed above the gravel pack then the borehole cuttings will be back filled to 3m below ground level where another grout seal will be placed. For design B, the grout above the gravel pack shall be 2m thick and the one near ground surface shall be 4m thick. When grouting, there is need to put something between the filter pack and the grout. The recommended material is plastic paper. Grouting will be done after the pumping tests have been completed.

All dry boreholes shall be back filled to 1m below ground level with the drill cuttings or any other suitable materials approved by the Project Manager. A grout seal shall be placed above the back fill.

6.3.4 HOLE STRAIGHTNESS AND VERTICALLY

Hole straightness and verticality are highly important for construction of water boreholes both to allow the running of casing as well as for the installation and operation of pumps. To maintain a straight and vertical hole becomes a problem in certain formations such as steeply dipping rock structures. The problem also increases as the magnitude of the diameter of the bit exceeds drill rod diameter. This results in the rods becoming subject to bending or whipping from the increased tongue of the large bit.

Boreholes shall be constructed and all linings installed plumb and true to line as defined below. Results of verticality tests in the form of plots against drift from centre line shall be prepared and furnished to the responsible Hydrogeologist or manager.

After the installation of casing, a cylindrical “dummy” equivalent to at least two casing lengths and of an external diameter 20mm less than the internal diameter of the casing tubes should be free to travel the full depth of the borehole.

Deviation of greater than 1:300 shall require correction by the Contractor. Failure to correct such a fault will normally lead to the rejection of the borehole by the Manager.

6.3.5 GENERALISED BOREHOLE DESIGNS

Figures 14 - 16 show generalised borehole construction designs for groundwater monitoring boreholes completed in various geological formations. For their construction procedures refer to SOPs for drilling and construction on National monitoring Borehole.

The design for production boreholes is shown in Figure 17. The final drilling depth for production boreholes will be determined by the depth to the principal aquifer unit and the type of pump to be installed.

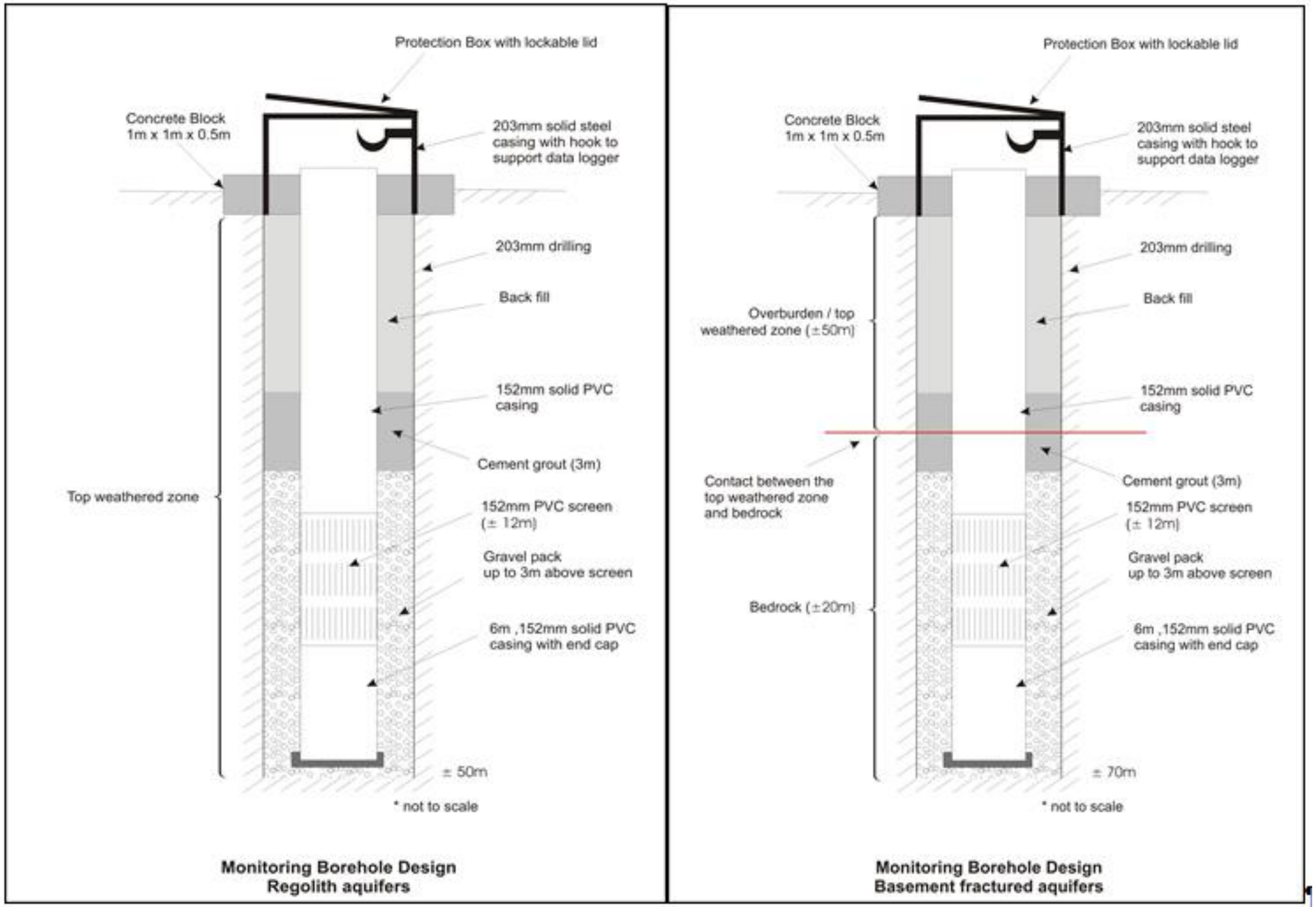

Figure 14 Monitoring borehole design for regolith and fractured basement aquifers

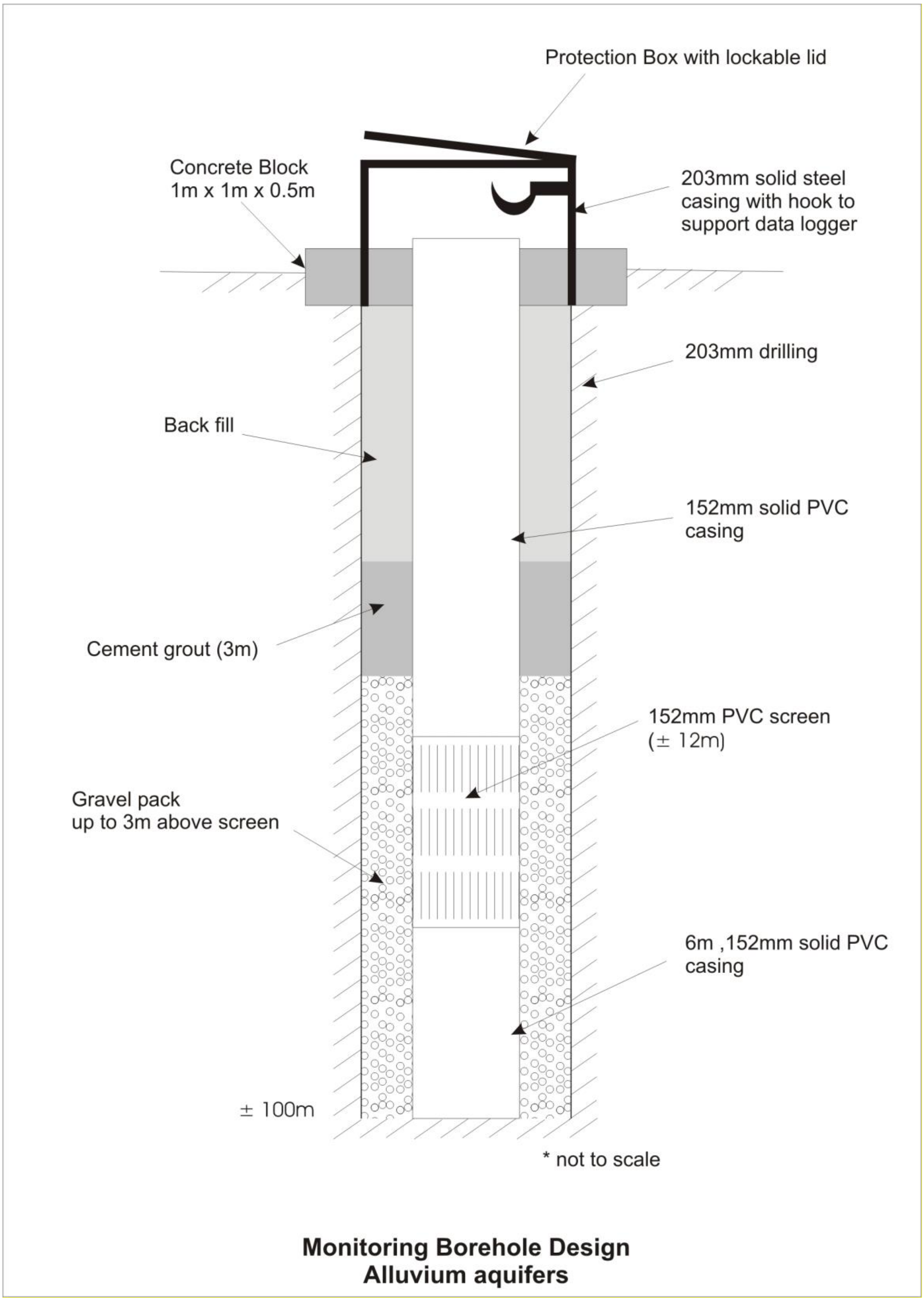

Figure 15 Monitoring borehole design for alluvium aquifers

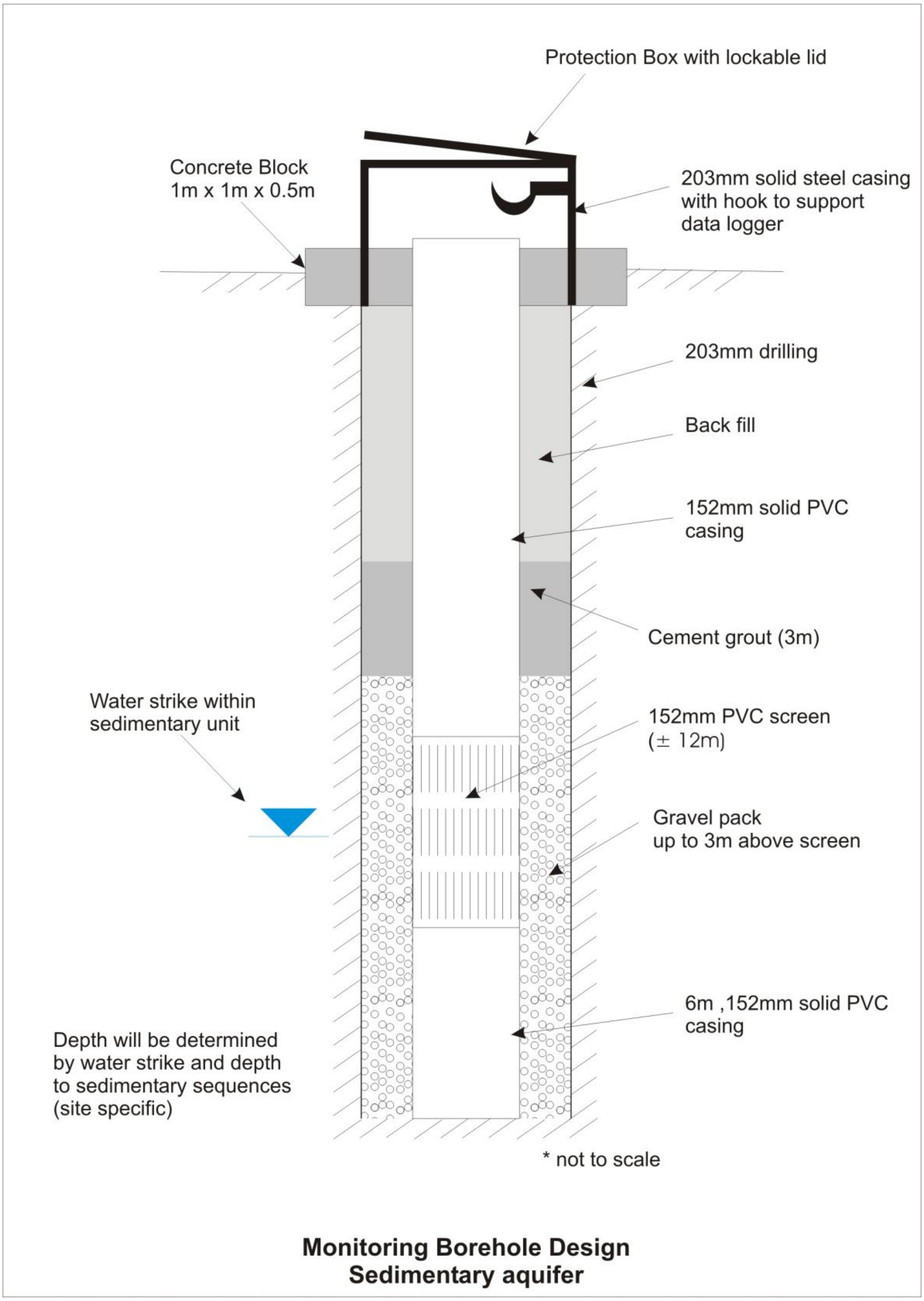

Figure 16 Monitoring borehole design for sedimentary aquifers

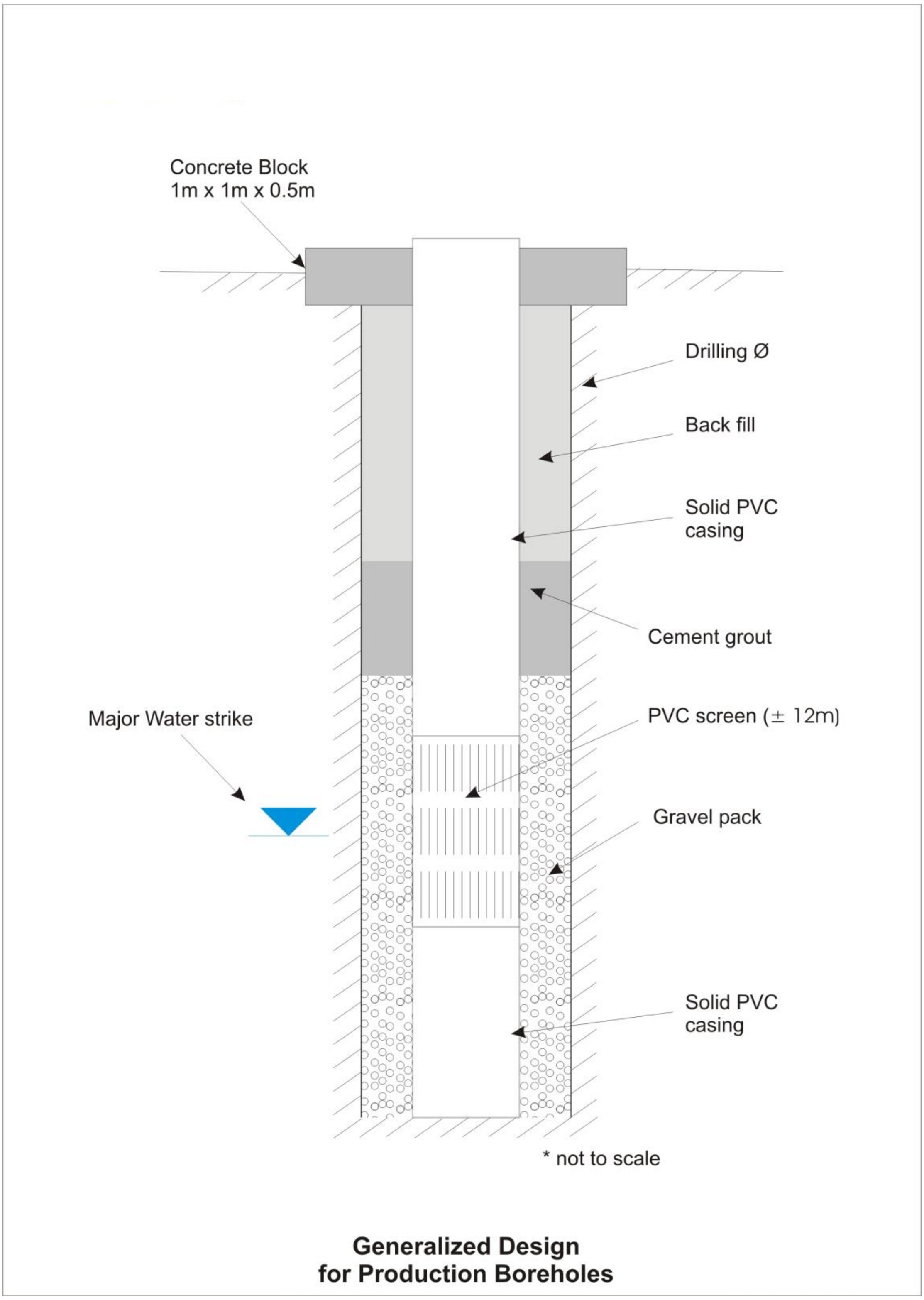

Figure 17 Generalised design for production boreholes

The following drilling and casing diameters are used for production boreholes:

Table 11 Nominal drilling diameters and casing diameters for production boreholes

Type of pump to be installed	Nominal drilling diameter (mm)	Casing diameter (mm)
Hand pumps (Afridev, Climax, etc.)	177	110
	191	125
Motorised pumps	229	160
	254	200

6.3.6 WELL DEVELOPMENT

There are many different methods of well development and they all share the same fundamental purposes, which are: -

- to maximise the yield of the well
- to prevent clogging
- to stabilise the formation
- to wash out fine cuttings, silt and clay that have worked into fissures, crevices or pores of rock during drilling operations

This is accomplished by inducing alternate reversals of flow through the well screen openings to rearrange the formation particles and break down bridging groups of particles. The outflow portion of the surge cycle breaks down bridging and the inflow portion then moves the fine material toward the screen and into the well where it can be removed by pumping.

Well development may be carried out using one of these methods:-

(i) Water jetting
(ii) Air lifting
(iii) Surge block

(iv) Rawhiding

If either (i) or (ii) is used jetting must take place using a tool of approved design. Air lifting whilst jetting is preferred. If (iv) is used, pumping must be accompanied by surging.

Development shall continue for a minimum of 4 hours until a visually sand and silt free water sample of at least 1 litre collected over a 1 minute period from the total discharge should be obtained. Actual sand tolerance will be 5mg/1.

Should such a sample not be obtained after a maximum of 10 hours, the borehole shall be declared poorly designed by the project manager.

6.3.7 BOREHOLE NUMBERING

The main historical styles used for numbering water points are the use of:

a) Initials of the person siting the borehole followed by a sequential number e.g. FD101, SM210
b) Traditional Authority (TA) abbreviation followed by borehole number e.g. T.A Chowe: CH207
c) Variety of abbreviations, e.g. project/donor/driller/lot number/date followed by number, e.g. CDC/MASAF/18, EU/MPP4/LOT1/SFL024, CDC/CHAM/03/08
d) Borehole category / catchment / sub-catchment / borehole number e.g. 01-04-04-008

The advantages and disadvantages of these four systems are listed in Table 12. Only one numbering system will be selected and adopted from this list.

Table 12 Borehole numbering schemes

Item	Scheme	Example	Advantages	Disadvantages
A	Persons initials	FD201	Concise Easily inscribed on site	Does not conveys locational information Does not promote ownership
B	T.A	CH207	Concise	The T.A may straddle catchment

	abbreviation		Easily inscribed on site Conveys locational information Promotes ownership	areas.
C	Long string Donor	CDC/CHAM/03/08	Project or Driller reference	Not easily inscribed on site Does not conveys locational information Does not promote ownership
D	Long string Catchment	01-04-04-008	Conveys locational information in terms of catchment. Unique for database	Not easily inscribed on site Not easily replicated by stakeholders

6.3.8 PUMPING TESTS

A pumping test is a test that is conducted to determine aquifer or well characteristics. It is the most reliable method for estimating aquifer hydraulic conductivity (K) of wells. Based on observations of water levels near pumping wells, an integrated K value over a sizeable aquifer section can be obtained.

Whereas laboratory tests provide point values of the hydrogeological parameters, and piezometric tests provide in-situ values representative of a small volume of porous media in the immediate vicinity of a piezometer tip, pumping tests provide in-situ measurements that are averaged over a large aquifer volume.

Aquifers are tested by several hydraulic methods. The test pumping will comprise three types of test:

1) Calibration Test
2) Step Test
3) Constant Rate Test and Recovery

6.3.8.1 Calibration Test

A calibration test comprising up to four (4) fifteen (15) minute steps will be under taken to determine engine RPM required to establish borehole yields and drawdowns for different pumping rates. The borehole water level will be allowed to recover before the next test.

6.3.8.2 Step Test

Step drawdown tests comprise a minimum of four continuous ninety (90) minute well tests conducted to determine borehole hydraulic parameters and a suitable yield for the constant rate tests. Step test results are used for the following:

- Predicting well yields
- Evaluating well performance
- Predicting groundwater inflow zones
- Estimating a suitable well yield for constant rate test

For mechanised boreholes, a step drawdown test shall be carried out before the long drawdown test. The step pumping shall be carried out using continuous discharge equipment and shall take the form of a step test of 400 minutes duration using 100 minutes each step. It is the contractor" responsibility to fix the discharge rates on the basis of the interim yield tests. The rates should be close to 50%, 70%, 100% and 150% of the expected long term yield.

In cases where a yield higher than the minimum 1.0 litre/second is not suitable for the period of the step test, constant pumping at this yield for a period of 420 minutes shall be regarded as an alternative constant yield test. The water should be discharged at least 100m from the hole down slope, to prevent the water from returning to the aquifer.

An eight hour continuous discharge test shall be carried out using a suitable submersible pump approved by the Project Manager. The discharge rate will be determined by the results of the interim yield tests and as specified by the Project Manager. This will be followed by a recovery test until 90 % of the static water level is attained.

6.3.8.3 Constant-rate pumping test

This test is used widely to obtain the specific capacity of a well and the transmissivity and storage valves of the aquifer. One or more observation wells are installed and appropriate distances from the pumping well to record data during the test, because accurate drawdown data from the pumped well are normally difficult to obtain.

During the pumping test, the well is pumped at a constant rate for either 24 or 72 hours, depending on the type of aquifer. During this time, periodic drawdown measurements are taken in the observation wells and pumped well.

In most cases, the recovery of the water level should be recorded after the pump has been shut off at the conclusion of the test. These recovery data can be used to check the results from the actual pumping test.

Drawdown data are plotted versus the time they were taken or the distance from the pumped well to obtain the transmissivity and storage coefficients. Once these factors are known, the well or aquifer performance under different pumping conditions can be predicted with good accuracy.

Drawdown readings for both the pumping well and observation boreholes will be taken at the time intervals in Table 13 using an electric or alternative water dipper graduated at 0.01 m intervals. The datum point for measurements shall be recorded plus the height of the datum above ground level.

Table 13 Range of intervals between water-level measurements in well (Kruseman and de Ridder, 2000)

Time since start of pumping	Time intervals
O- 5minutes	0.5 minutes
5- 60minutes	5 minutes
60- 120 minutes	20 minutes
120-shutdown of the pump	60 minutes

6.3.8.4 Recovery

Recovery will be recorded, at the same time intervals as above, until either 90% recovery has been attained or a period of time equivalent to the pumping period has passed. For conducting pumping test, refer to SOP for aquifer pumping tests

6.3.8.5 Water Quality Samples

Water quality samples shall be collected at the end of the constant rate test for both the chemical and bacteriological analysis. The Chemical analysis should determine primarily the TDS, pH, sulphates, fluoride, nitrates, chloride, electric conductivity and iron. The bacteriological test should determine the total coliform and the E. coli.

6.4 DRILLING RECORDS AND REPORTS

The Contractor shall submit daily log sheets and a construction report for each completed borehole. The logs shall be completed on the Government or Equivalent forms which shall be available for the Contractors use. Data shall include: -

1) Date, borehole number, locality (village and Chief's names) and GPS coordinates
2) Depth of borehole at the end of each day.
3) Strata encountered.
4) Hole diameter
5) Amount of temporary casing installed.
6) Depth at which water was encountered.
7) Water level in the borehole at the start of each day.
8) Statement of each operation conducted and time taken, including breakdowns.
9) Signature of driller

6.5 PROBLEMS DURING THE DRILLING OPERATION

All drilling methods impair the ability of an aquifer to deliver water to a drilled hole. Impairment may be due to physical rearrangement of the matrix of the aquifer material. Formation damage can result from the invasion of foreign fluids and/or solids into the aquifer, causing reduced permeability around the hole.

Rotary drilling relies on hydrostatic head to maintain an open hole. The pressure differential forces both drilling fluid and cuttings against the wall of the hole, and if the aquifer pores are large enough, particles will be absorbed. Drilling mud presents a special dilemma. Composed of fine clay and/or polymer material, it can be forced a considerable distance into the aquifer despite its caking properties. Cable tool drilling poses a similar problem: The drilling churns cuttings into thick slurry and the surging action of the tools can force the slurry into the aquifer, clogging the formation and decreasing well yield.

This problem is compounded if the drilling fluid or cement filtrate used in drilling is contaminated. The introduction of biological agents into an aquifer via drilling muds or other materials can lead to the growth of corrosion/incrustation-causing bacteria or iron bacteria. Both are capable of reducing the permeability of a formation, either through deposition of their by-products or through their presence in extremely large numbers. Sulphate-reducing bacteria contamination of a single well in an area can conceivably lead to the contamination of an entire reservoir.

Contamination by oils and lubricants introduced during the drilling process can cause long term problems.

Unsatisfactory well yields that prompt maintenance operations may result from the nature of the formation in which the well was constructed. Shallow limestone/dolomite wells, deep sandstone wells, and sand and gravel wells, in particular, suffer from low well yields due to clogging of the well bore, well loses, and leaking casings. Caving or bridging of deep sandstone well is troublesome and diminishes yields from deeper strata. Well yields in igneous and metamorphic formations (as well as in limestone/dolomite aquifer) are influenced by natural forces. Experience shows that the yield per meter of well penetration in these aquifers generally decreases as depth increases.

6.6 SUMMARY OF WHAT TO LOOK OUT FOR AT A BOREHOLE CONSTRUCTION SITE

Supervision during construction is critical. Even experienced drillers require some supervision at the critical stages of well completion. Below is a summary of what to look out for: -

6.6.1 DURING SITE SELECTION

The community's preference should be taken into consideration. Flood prone areas should be avoided. Similarly areas likely to lead to contamination of the well should be avoided. A compromise may have to be reached between the community preference and well siting technician recommendation in deciding the location of the well. However, the critical factor is to locate the well at the most feasible site for finding water. It is costly to drill unfavourable sites that will not yield water.

6.6.2 DURING DRILLING

a) It is important that a drilling crew includes an experienced drilling master. The drilling master will organise the drilling operation. An organised drilling crew will lay their tools and equipment orderly and will appear (diagram of crew) organised in their operations.

b) Number of rods used will give an approximation of the depth drilled. Six 3 metre long rods imply that at least 18m have been drilled.

c) Cuttings or samples will be collected at regular intervals usually every metre and at every change of formation and laid out on the ground or packed in sample containers. These are used in designing the completion of the well.

d) The driller will keep records such as the following: -

- Drilling log: a record of depth and type of formation drilled.
- Drilling rate: speed at which the formation is drilled into. Usually, the time taken to drill a 1m.
- Interim yield test: how much water (number of litres of water) per unit time (second or minute) the well is able to yield at a given point (depth) during the drilling.
- Time log or day works: the work the drilling crew have done that day and for how long.

The samples, drilling log and yield test are important elements for designing how the well should be installed.

e) PVC well casing (plain and slotted) should be stored in the shade

f) Filter pack (gravel pack) should be kept clean.

6.6.3 DURING WELL COMPLETION

The well is completed according to a design made by the drilling master or supervising Hydrogeologist. Well casing (usually PVC pipes: plain and slotted) are installed to the full depth of the well. Partial casing or open hole designs are generally not recommended. Expert advice should be sought on site if this general practice is not followed.

The installation will consist of the following:

a) A sump pipe with an end cap will be installed at the bottom of the well. The sump usually consists of a 2 or 3 metre plain PVC pipe. A slotted PVC pipe can be used for sump pipe if the Hydrogeologist specifically recommends so.

b) More pipes are installed. The pipes are joined using solvent cement (not fire). The joints should be cleaned before pipes are joined. Slotted casing will be placed in the productive zones (depths that are yielding water).

c) The last top 3-6 metres should be installed with plain PVC pipes.

d) Clean and well sorted filter (gravel) pack should be placed around the slotted pipes (well screens). The gravel pack should be allowed to settle before the remaining annulus is back-filled.

e) The well should be developed until the water is clean.

f) The last top 3 metres should be grouted with cement or bentonite/clay.

g) The well should be tested: pumping continuously for 2 to 4 hours or until the water level stops lowering further with continued pumping. The yield and water level should be recorded regularly until the pumping water level stops lowering. This operation is called a pumping test. A quick way to estimate the yield is to measure the time (seconds) taken to fill a 20 litre bucket. A suitable well for a hand pump will be able to fill a 20 litre bucket in less than 60 seconds.

h) After the pumping stops, the water level in the well should be measured until the original (rest) water level is recovered by the well. This is called a recovery test. The results of the pumping and recovery test are used to establish safe well yield as well as a safe pump set for the well. A well designed well will usually recover within minutes.

7.0 BOREHOLE REHABILITATION

7.1 AIMS

From the description of groundwater development in Malawi it is clear that there has been a very considerable investment in boreholes already. The aim of the rehabilitation component is to ensure that previous investment is not written off but effectively utilised by maximising the well performance and incorporating the existing boreholes into the community-based maintenance system.

7.2 PROBLEMS

There are many variables that contribute to reduction in well performance. These include pump damage or wear, well screen and casing corrosion or incrustation, incrustation of the aquifer and structural failure of the well. These problems are often traced to factors such as poor well design or construction or improper selection of pump materials. Hydrogeological conditions such as reduced aquifer recharge, over pumping of aquifer or interference from nearby wells may also contribute to reduced well performance. Change in groundwater quality is also a significant factor in well performance decline.

7.3 SOLUTIONS

If the existing boreholes are to be incorporated into the community maintenance structure, then the pumps must be replaced. Some of the existing hand pumps cannot be maintained at the village level. They should therefore be replaced by the

Afridev hand pump supplier/manufacturer so that maintenance requirements of new and existing boreholes are unified.

Simply replacing the hand pump is not, however, sufficient to ensure that the existing borehole does play a full part in providing an adequate and reliable supply that is of an equal standard to that of a new water point. The design and construction defects of the existing boreholes are variable. These include poor screening; inadequate wrong or poor quality gravel packing and mismatching of formation. This may lead to boreholes continuing to pump sand throughout their lives.

Unless this problem is rectified, the new pump may require frequent maintenance. A procedure for cleaning out the existing boreholes and, where appropriate, installing an inner lining and gravel pack is, therefore, an important component of the rehabilitation work.

There may be occasions when it is cheaper to drill a new borehole rather than go to great expense of cleaning out and relining a particular difficult existing borehole. Each rehabilitation attempt is, therefore, an individual exercise requiring the judgment of a Hydrogeologist.

To bring the existing boreholes fully into operation also requires the involvement of the Community. The people living around the existing borehole may have had poor service in the past from a pump which breaks down frequently and is out of action for long periods. The rehabilitation will have to be explained to them clearly emphasising that rehabilitation will not leave them with an inferior water point.

It is important to ensure that the community is happy with the location of the old borehole, whose site they will not have chosen. A new pump and apron may not necessarily be sufficient to change people’s attitude. If they are unhappy with the location, for example if a graveyard is close by, an alternative site must be chosen and a new water point constructed.

7.4. REHABILITATION PROCEDURE

7.4.1. PLANNING

The number of existing boreholes in an area of intervention is obtained in the planning phase. At this stage all that is required is the number of boreholes so that sufficient, provision for rehabilitation is made.

In the preparation phase more detailed information can be obtained from the construction details and maintenance records of each borehole. The important information required from the construction and maintenance records (borehole history) is:

- Original depth and depths of borehole measured periodically on maintenance visits
- Original yield
- Original water level
- Water levels measured on maintenance visits
- Frequency and nature of pump repairs
- Original first water struck
- Original casing details

The boreholes are visited in the course of the initial survey to collect additional information on:

- The current state of the borehole and its surrounding.
- The site location in relation to pollution hazards.
- The attitude of the community to the borehole.
- The chemical and biological quality of water from the borehole.
- Population using the borehole.
- Pump type.

7.4.2 THE GENERAL CRITERIA FOR REHABILITATION OF BOREHOLES

All the information necessary to decide whether or not to rehabilitate a borehole and the nature of rehabilitation required is compiled by the Hydrogeologist. The information required is described below.

7.4.2.1 Water Quality

If the electrical conductivity of the water is above 3,000µs/cm the borehole should not be rehabilitated, unless there is little chance of finding a nearby site to drill a borehole or construct an alternative facility to provide water of more acceptable quality. If there is no alternative site, and the community has been using the borehole and wish to continue using it, a full chemical analysis should be taken. If no constituents are unacceptably high then rehabilitation should be considered.

7.4.2.2 Yield

If the original tested yield of the borehole was very low (less than 0.25 l/sec) then rehabilitation is unlikely to be successful. An alternative site for a new water point should be selected. If the original tested yield was over 0.25 l/sec but the yield has substantially decreased, the borehole should be included in the rehabilitation program, where a decision to proceed with rehabilitation is made on the basis of the initial test pumping of the borehole.

7.4.2.3 In-fill/siltation

Many boreholes have in-filled/silted to some extent because of the poorly designed screens. It is commonly thought that a very large number of the existing boreholes require immediate cleaning because of the amount of in-fill/silt. It is, however, the rate of infill in relation to the borehole depth and casing configuration that is important.

If a 45m deep borehole with 25m of slotted casing at the bottom has in-filled by 10m in 35 years, then the sand pumping problem is not too severe. In contrast, a 45m deep borehole with 20m of slotted casing at the bottom has in-filled by 20m or more in two years, then water inflow must be greatly restricted and rehabilitation is certainly required.

7.4.2.4 Frequency of Repairs

If a borehole has been pumping sand it is likely that the downhole components will require frequent replacement. This will present a continuing problem to the new pump, unless it can be resolved by installing an inner liner and new gravel pack. If a borehole has required much less frequent replacement of downhole components and there is little evidence of in-fill, then the full rehabilitation procedure may not be necessary.

7.4.2.5 Lithology

Most existing boreholes were poorly designed whatever the lithology of the aquifer. In an area where an alluvial aquifer occurs, sand pumping is likely to be a very significant problem and most of the boreholes will need cleaning and relining. In a weathered basement area, many of the existing boreholes will have been completed in the fresh bedrock and the infill and repair frequency will be much lower.

The criteria for selecting boreholes for rehabilitation and the operational procedures for carrying out the work are complex. The complex relationship between the in-fill, the original borehole construction depth, and the need to relate the technical aspects and cost of the rehabilitation to the alternative of providing a new water point nearby, need a professional Hydrogeological input.

7.5 STEPS IN OPERATIONAL PROCEDURE

- Once the Community has agreed and displayed the need for borehole rehabilitation, the Village Health and Water Committee is requested to organise the contributions towards the rehabilitation exercise. This includes cash, labour and supply of local materials.
- Remove the existing pump and, if necessary, break the apron so that the drilling rig can move over the borehole.
- Measure the depth of the borehole and the water level.
- Start cleaning the in-filled borehole using a compressor. This is the quickest method of removing the in-fill if it is fined grained (silt or sand) and not too compacted. Cleaning with the compressor using a flexible air hose may clean out many metres of soft sand infill in a few minutes. Once the borehole is cleaned to a maximum depth, the procedure for installing PVC and placing gravel is as outlined below.
    - When original depth is reached or the borehole is blocked, perform test pumping for one or two hours to determine the yield of the borehole in order to confirm an adequate yield for rehabilitation.
    - If the sustained yield is 0.5 l/sec or more, the borehole should be relined.

- If the sustained yield is less than 0.25 l/sec and the borehole is blocked at shallow depth, the borehole should be abandoned.
- If the sustained yield is between 0.5 and 0.25 l/sec and the borehole has been cleaned to its original depth, development should be attempted to increase the yield (see Section 3). In many existing boreholes the pump intakes are set unnecessarily deep and merely raising the cylinder may greatly ease the sand-pumping problem. If development does not result in clear water after 10 hours, the borehole should be retested. If the yield is 0.5 l/sec or more the borehole can be relined, if not the borehole must be abandoned and an alternative site chosen.
- If the borehole has been cleaned to its original depth and the sustained yield is less than 0.25 l/sec then the borehole should be abandoned and an alternative site chosen.
- After testing, measure the depth of the borehole and bail out any infill.
- Install 110mm Class 10 PVC casing and screen. Select screen length and position according to depth at which water was struck, water level and location of existing slotted casing (from construction records). This should be a maximum of five or six 3m lengths of PVC screen. The PVC for use in rehabilitation has much smaller centralisers to allow gravel to pass in the very small annular space between the PVC and the steel casing.
- Install gravel pack material very slowly to allow adequate settling. It is not possible to measure the gravel level in the annulus. Water poured into the annulus may assist in settling the gravel.
- Measure depth of borehole inside casing.
- Install test pumping equipment to 1m or 2m above the bottom of the PVC lining. Develop the borehole by interrupted over-pumping ("rawhiding"). This should continue for at least three hours or until the water is clear.
- Carry out test pumping for five hours at a constant rate determined from development results. If the sustained discharge after installation of the PVC and gravel has dropped below 0.25 l/sec an alternative site should be selected and the borehole abandoned.

- Remove testing equipment. Measure depth of borehole and water level.
- Use testing results to determine hand pump cylinder setting
- Install new hand pump
- construct new apron and washing slab
-

If there is an obstruction in the borehole caused by a dropped cylinder, rising main or rods:-

- If standing above the infill, it may be easy to "fish" out.
- If buried by infill material it cannot be economically retrieved.

7.6 OTHER METHODS OF CLEANING BOREHOLES

The conventional drilling rigs (percussion rig) can be effectively used to rehabilitate boreholes. The procedure is outlined below.

- Begin bailing with a 100mm diameter bailer, measuring the increased depth.
- Continue bailing to original depth or until bailer is producing water only, in which case infill material is very compacted to be removed by bailer.
- Run in drill bit to disturb infill material.
- Continue alternate drilling and bailing until original depth is reached.
- Proceed to complete borehole as outlined above.

8.0 GROUNDWATER MONITORING, DATABASE MANAGEMENT AND WATER PERMITS

8.1 GROUNDWATER MONITORING SYSTEM

8.1.1 OBJECTIVES

The specific objectives of the groundwater monitoring are:

- To assess long term groundwater level trends due to changes in natural and/or anthropogenic factors
- To monitor and manage the utilisation of groundwater e.g. for irrigation or urban water supplies in light of increased demand as surface water resources come under increasing pressure.
- To study and effectively document whether availability of groundwater is steadily declining in light of reported steady declines in river flows during dry seasons in some areas of Malawi.
- To determine and document water quality status and trends of all aquifer formations across the country or aquifers determined to be at risk of pollution to enable effective groundwater development, management, protection and distribution.
- To improve current knowledge on spatial variations in aquifer hydraulic characteristics.
- The define variation in groundwater recharge across the country for effective management of groundwater resources.
- To provide a reliable estimate of the quantitative status (how much) of groundwater and improve demarcation of aquifers for increased abstraction in areas where groundwater availability is sufficient to encourage increasing demands (e.g. in the alluvial deposits of the Rift Valley) or where significant abstraction from localised aquifers may take place.
- To estimate flow rate and flow direction of groundwater at a national level
- To supplement and validate environmental impact assessment (EIA) studies through data and information
- For Groundwater monitoring refer to SOP for Groundwater sampling

8.1.2 GROUNDWATER LEVEL MONITORING

The groundwater level monitoring network will consist of rehabilitated existing monitoring boreholes and drilling of a total of 100 additional/new monitoring boreholes. The additional boreholes will be drilled in 5 years, with 20 boreholes drilled in each year.

8.1.2.1 EQUIPMENT AND MATERIALS

The following equipment and materials will be required:

- Field log book or electronic field log book
- Dip meter and data loggers
- Laptop computer
- Desktop computer
- Software (HYDSTRA and WISH)
- Microsoft Office software products (Word, Access, Excel)
- Level logger software

8.1.2.2 MANUAL WATER LEVEL MEASUREMENT

Manual water level measurements using an electronic sounding dip meter will be carried out once every week at monitoring boreholes nationally by WMAs staff in each of the three regions. The following measurements should be recorded at each site:

1) GPS or surveyed X, Y, Z coordinates of the monitoring borehole
2) Date and time of water level measurement
3) Borehole number
4) The height of the measuring point above the ground from which the personnel will take the reading
5) any nearby activities that could be affecting groundwater elevations such as irrigation, production boreholes, and test pumping
6) Depth to water level from the top of measuring point (i.e. water level depth below measuring point)

8.1.2 AUTOMATIC WATER LEVEL MEASUREMENT

Automatic water level measurements will be recorded using data loggers at specified time intervals e.g. every 6 hours. The data loggers used should be pressure compensated. Site visits will be performed once every month to download data and ensure the integrity of the monitoring site and its data.

A laptop will be connected to the data logger and the data downloaded and stored in the laptop at each site and backed up to an office computer. The name of the data logger being downloaded is recorded and a manual groundwater level measurement is taken according to the procedure above for manual data measurements to be used for integrity checking and groundwater level trend analysis. Any readings that appear to be incorrect in the downloaded data are noted in the field log book for further analysis in the office.

8.1.3 GROUNDWATER QUALITY MONITORING

Water samples will be collected from the groundwater monitoring boreholes and selected surface water points as well as rain water samples from selected rain gauges. Only a description of the sampling procedure at groundwater sampling points is presented in this document.

Purging, using an appropriate borehole pump, is recommended at each borehole prior to sampling to remove the standing water in the borehole that may not be representative of the water within the borehole aquifer. As a general guideline, purging should remove at least 3 times the volume of water in the borehole.

A checklist of equipment and prior preparation for sampling is:

1) Letter of introduction and visiting cards for site access
2) Key to get into site and oil to lubricate padlocks
3) GPS
4) Dip meter, distilled water to clean dip meter, spare batteries
5) Tape measure (as long as possible)
6) Pump or purging device, power, compressor
7) Clear plastic bailer

8) Containers for purged water
9) Container to measure pumping rate, 25 litre or 10 litre
10) Sample record sheets to identify sample and/or sample sets and to record field measurements
11) Shovel
12) Torch
13) Indelible ink fibre tip pen/s, pencils, ballpoint, field note book, micro-cassette recorder (especially useful for recording field notes in the rain)
14) Protective clothing - rain gear, cold weather gear, warm clothing, sun glasses and sun hat.
15) Camera, plus film or memory chip
16) First aid kit (commercially available kits)
17) Drop sheet (some type of sheeting to protect instruments from contamination in the event of their falling to the ground)
18) Folding table or other work surface
19) Calculator
20) Personal equipment: money, driver's license, identity card, credit card, food and drink etc.
21) Decontamination kit, sprays, detergent, buckets, soap, rinse water and PVC pipe.
22) Conductivity meter and calibration solutions
23) pH meter and calibration solutions (+ capacity to measure temperature)
24) Spare batteries for all the meters
25) Wash bottle (distilled water)
26) Extra distilled water
27) Chain of Custody forms
28) Sample bottles and caps plus foil and teflon inserts when necessary
29) Ensure bottles are cleaned and/or sterilised by the laboratory as needed
30) Bottles or ampoules containing preservatives (clearly labelled)
31) Material to spike samples for quality control
32) Trip blanks for VOC samples
33) Filter apparatus for field filtered samples, including extra filters
34) Preservation equipment e.g. ice box/cool box with cooling medium such as frozen ice-bricks, ice.
35) Paper towels, rags, plus plastic garbage bags for discards

36) Before packing the equipment, calibrate all the field measuring equipment to ensure that it is in working order.

Groundwater sampling SOP collected immediately after purging. The following guidelines apply for sample handling (GeoSyntec Consultants, 2006):

- Gloves worn during purging will be discarded and replaced with clean gloves for sampling
- Sample containers will not be opened until immediately prior to filling
- The insides of sample containers will not be touched, including with clean gloves
- Chain-of-custody forms will be maintained throughout the sample collection
- Sampling containers will be filled completely, but not overfilled, as this will result in the loss of preservative
- Filled sample containers will be labelled, prepared for transport, and stored in an ice chest or cooler

Samples collected for dissolved metals will be filtered using a 0.45-μm filter or equivalent and acidified with nitric acid before storage.

Waterproof, indelible ink should be used to label the water samples. The following information will be included on each sample label:

- Sample identification e.g. borehole number and region
- Location
- Date and time

Duplicate samples will be collected and analysed, 1 for every 10 regular samples, for quality control. In addition the following field parameters should be recorded for comparison with the final laboratory analysis results: pH, temperature and electrical conductivity or TDS.

A chain-of custody form will be completed for all the samples collected and submitted for laboratory analysis. Details of all the people handling the samples and their signatures will be entered on the form to track movement of the samples from the sampler to the laboratory custodian. Preservation details and the analyses required for each sample will be indicated on the chain of custody form. Table 14 lists the chemical and physical parameters to be analysed for from the water samples. Water sampling will be carried out once every month.

Table 14 List of recommended parameters for laboratory analysis

Chemical Parameter	**Physical Parameter**
Anions	
Chlorides as Cl	Total Dissolved Solids
Fluoride as F	Suspended Solids
Sulphate as SO_4	Total Alkalinity as $CaCO_3$
Bicarbonate HCO_3	Total Hardness as $CaCO_3$
Nitrate NO_3 as N	Calcium Hardness as $CaCO_3$
Nitrite NO_2 as N	Magnesium Hardness as $CaCO_3$
Phosphates (tot.& ortho)	Conductivity at 25° C in mS/m
Free & Saline Ammonia NH_3 as N	pH-Value at 25 ° C
Ammonium as NH_4	
Cations:	
Calcium as Ca	
Magnesium as Mg	
Sodium as Na	
Potassium as K	
Silver	
Silicon	
Iron as Fe	
Manganese as Mn	
Aluminium as Al	
Cadmium as Cd	
Total Chromium as Cr	
Copper as Cu	
Nickel as Ni	
Lead as Pb	
Selenium as Se	
Boron as B	
Zinc as Zn	
Barium as Ba	
Cobalt as Co	
Arsenic as As	
Strontium as Sr	

Chemical Parameter	Physical Parameter
Molybdenum as Mo	
Antimony as Sb	
Titanium	
Mercury	
Tin	
Hexavalent Chromium as Cr^{6+}	
Vanadium	
Antimony	
Phosphorus	

8.2 DATABASE MANAGEMENT

All the data collected from the boreholes is input into the national groundwater database comprising HYDSTRA and WISH. Data is initially stored in HYDSTRA and exported into MS EXCEL spread sheets for the WISH database.

Field groundwater level data will be reduced to groundwater elevation above mean sea level (msl) by using surveyed elevation of the borehole site and the height of the measuring point above ground level. Measurements from data loggers will be converted to msl using data from manual measurements at the same site.

Groundwater level data will be plotted on a time series graphs using WISH software for management purposes. Any errors noted from the graphs will be analysed and if it is established that the data logger may be malfunctioning, the data logger will be sent for repair.

Hydrochemistry data for groundwater, surface water and rain samples will also be stored in the database and various graphs plotted using WISH. The graphs include time series for rainfall, groundwater levels and all the chemical and physical parameters, Piper, Stiff and Durov plots, test pumping curves and borehole logs. Other data sets that will be stored in the database are: borehole drilling and construction details, surveyed coordinates for production and groundwater monitoring wells and other monitoring stations (e.g. surface water monitoring stations, rain gauge stations) from other national departments, daily rainfall (mm) from Meteorological stations, test pumping data, abstraction volumes from production boreholes etc. Aquifer hydraulic parameters will be estimated from the test pumping curves generated from the database using WISH, using various analyses techniques e.g. Hantush, Cooper and Jacob.

The mapping function of the database management system, using mapping software such as ArcGIS, will be an integral component of the database. It will be used to generate the following spatial data plots:

- Topographic maps
- Drainage maps
- Map showing aquifer distribution
- Map showing borehole location and distribution
- Map showing variation in monitored chemical parameters

The various plots generated from the data management system will be used to generate various hydrogeological reports used for groundwater management.
The groundwater database will be backed up monthly on hard discs to be used to restore the database in case of any malfunctioning to the main database or any system failure or corruption to the database.

8.3 WATER USE REGISTRATION AND LICENCE APPLICATIONS

This is critical to management of water resources as this will enable the monitoring of sector use and demands, ensuring compliance of water users to authorisation requirements, and where appropriate, recovery of water use charges. A registration system is essential and will be developed and implemented in Malawi, commencing in those areas of water stress and where limited availability of water resources is leading to conflict among user groups.

The goal of such a programme would be to eventually register all significant water users throughout Malawi into a regionally-distributed and accessible database system. This allows authorities at local, provincial, and national level to access water use information timeously and to assist in rapid decision making regarding water use activities which may be unsustainable and pose a threat to the aquatic environment, to human health and safety. In the case of water pollution, the polluter is responsible for remediation. The National Water Resources Authority (NWRA) may rehabilitate the polluted wetland and recoup the costs from the polluter using appropriate Regulations in the Water Resources Act, 2013.

The purpose of the water registration and licencing is to:

- Provide a framework for the use, protection, development, conservation, control and management of the country's water resources
- Provide a framework within which water will be managed at regional or local level
- Identify water development opportunities and constraints
- Provide information about sustainable, equal and effective integrated water resource management

The following are Water Uses that will be applied in the water permitting system:

a) taking water from a water resource;
b) storing water;
c) Impeding or diverting the flow of water in a watercourse;
d) Engaging in a stream flow reduction activity;
e) Discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit;
f) Disposing of waste in a manner which may detrimentally impact on a water resource;
g) Disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process;
h) Altering the bed, banks, course or characteristics of a watercourse;
i) removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people; and
j) Using water for recreational purposes.

The following steps will be followed for permit evaluation:

- Stakeholder is given Form NWRA 1, which details the procedure and required supporting documentation
- A Hydrogeologist checks that the hydrogeological conditions are favourable for an additional abstraction point

- Stakeholder is advised whether or not project can proceed to the drilling stage
- NWRA registers the water point once stakeholder submits forms NWRA 1, 2, and 3 and the application proceeds to adjudication with the Water Apportionment Board
- NWRA grants abstraction right
- Water point is added to the database and key information of GPS coordinates, water levels, abstraction rates and quality are cross checked to ensure elimination of errors.

8.3.1 PROPOSED FEATURES OF THE WATER USE REGISTRATION SYSTEM

The system will house and manage the following broad categories of data and information:

1) An **Application Tracking System** to manage requests for water permits and evaluation and approval of the applications.
2) A **Water Permit Register**, organised according to the water user categories defined in the Water Regulations:
    - Domestic purposes
    - Public purposes
    - Industrial purposes
    - Power purposes
    - Irrigation purposes

The Water Permit Register will house the information provided on approved permit applications, including:

- Owner details
- Location
- Purpose and quantity of abstraction
- Method of diversion/abstraction
- Dam construction details
- Water use charges
- Other water user category specific information

The MacDonald 2003 report outlined the main features of the permitting system. These have been reviewed for the current project, and where necessary adapted (*italics*) to reflect requirements expressed by the WRB.

The main features of the permitting system are:

- The database should be a multi-user program for use on a network. (The 2003 report recommended MS Access or SQL. As MS Access is essentially a personal or single use database, we recommend that SQL Server be used in conjunction with a Windows client application).
- The package should allow users to generate standard format reminder letters, and the permit certificate with its attached conditions. The generation of such documents would be associated with respective stages in the permit process.
- The software should provide an audit trail of all activities by users. Each user should have a unique password/user ID to allow the audit trail to record user actions and dates when tasks are initiated and completed.
- The level of authority that is assigned to a specific user will determine which functions of the application are available for use. For example, each main stage of the permitting process will have to be signed-off by a user with supervisory rights.
- Standard check lists will be developed for each type of permit application to record non-computerised actions that form part of the permitting process and to support decisions on the granting or rejection of permits
- For Groundwater registration and licence application refer to SOP procedure for groundwater use permitting

8.3.2 FUNCTIONS REQUIRED OF THE DATABASE

The main functions are listed in Table 15. These correspond with the computerised steps in the permitting process flow that is described in MacDonald, 2003.

Table 15 Main functions required of the database

Activity	Tasks

Activity	Tasks
Administration of permit database	• Add new user and set level of authority • Routine backup
Administration of permit applications and renewals	• Audit trail by date/stage tracking
Accounts (Not for implementation during this phase)	• Tracking payment of permit fees, rent, and fines • Calculate rents (using Regulation factors) • Issue of invoices • Issue of reminders • Advise all payment irregularities
Data entry from application forms	• Entry forms to match originals in appearance i.e. one for each form in the Regulations • Basic checking for invalid entries • Print back replica form for checking
Geographical type search	• Find existing permits within specified radius (GW) • Find existing permits within same water resource unit (SW) • Find existing permits within a District • Show maps with the locations of existing permits, water resource management area boundaries, rivers, and other relevant layers.
Standard reports to management	• Monthly reports of permit progress (how many received, how many approved, how many in progress, maximum and average time to process from receipt to issue) • No. of trips/spot checks for policing compliance
Communications with WRB members	• Report permits for consideration at meeting • Standard letters, sending agenda, minutes and others

8.3.3 TABLES

Based on the functionality outlined above, Table 16 shows a provisional list of tables (or groups of tables) that will be required:

Table 16: Provisional list of tables

Table	Expected content/fields
Date tracker	Record of stages/dates and name of the database user
Stages	Codes for identifying steps in the permit processing used in the date tracker e.g. sent renewal reminder, renewal fee received
Permit applicants/holders	Name, postal address, permit numbers, application number
WRB members	Name, postal address, phone contact details etc.
WRB1	All data from Form WRB.1 SW application + unique number
WRB2	All data from Form WRB.2 GW application
WRB4	All data from Form WRB.4 application
WRB7	All data from Form WRB.7 discharge application
Permit – Surface water	Permit number, grid reference, source, quantity, purpose, fee calculation factors applicable
Permit – Groundwater	Permit number, grid reference, source, quantity, purpose, fee calculation factors applicable
Permit – Discharge	Permit number, grid reference, receiving water body, quantity, purpose, fee calculation factors applicable
External accounts (Not for implementation during this phase)	Amount, Invoice date, Date paid for initial fee, rents, fines etc.
Internal accounts (Not for implementation during this phase)	Section of Ministry doing work on behalf of the WRB, type of expense (transport, allowances, laboratory analysis charges etc.), date(s) expenditure incurred
Water quality standards	Limit values for parameters (e.g. N, P, K, BOD)
Effluent sampling	Permit number, water quality parameter values, date sample, conditions met/not met
Quantity policing	Permit number, quantity spot check, date sample, conditions met/not met
Conditions	Permit number, attached conditions as text for use on Certificate
Fee calculation factors (Not for implementation during this phase)	Various factors from the current Regulations used to calculate rent for each permit
Users	Login name, level of authority

8.3.4 WRB FORMS

8.3.4.1 FORM WRB 1A

NOTIFICATION PRIOR TO AN APPLICATION FOR A GRANT OF WATER RIGHT (GROUND WATER)

This form is to be submitted to the Chairman of the National Water Resources Authority. Private Bag 390, Capital City, Lilongwe 3

(1) Full name of applicant

…………………………………………………………………….

Postal address

………………………………………………………………………......

Occupation

………………………………………………………………………………

(2) Location of land on which borehole is to be sunk, 1:50,000 sheet No

…………………………………………………………………………………………….

NGR ………………………………………………………………………………….

Traditional Authority …………………………………..

District ……………………………………………………………………………

……………………………………………

(3) Briefly describe purpose for which water will be used

…………………………………………………………………………………

…………………………………………………………………………………………

……...……………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

………………………………………

Date ……………………… ....

Signature of applicant or his duly Authorised Agent

NOTE: This form is intended to notify the Authority of the applicant's intention to drill or sink a borehole. Full details as to the purpose for which water is required will be shown in paragraph (7) of form WRB 2. Having evaluated the yield of his well or borehole, the applicant will be in a position to decide whether water will be abstracted by hand or pump: and if by pump, the applicant may then fill paragraph (6) of the said Form WRB 2 with the necessary details.

8.3.4.2 FORM WRB 2

APPLICATION FOR A GRANT OF WATER RIGHT/ CERTIFICATE OF EXISTING RIGHTS*(GROUND WATER)

This form is to be submitted in triplicate

To: The Chairman of the National Water Resources Authority
Private Bag 390
Lilongwe 3

(1) Full name of applicant

…………………………………………………………………………

Postal address

……………………………………………………………………………......

Occupation

……………………………………………………………………………………

(2) Details of land on which borehole*will be/has been sunk

……………………………………………………………………………………………………

……………………………………………………………………………

Give Registered No

………………………………………………………………………………

(3) Give details of land where water will be used if different from (2) above

………………………………………………………………………………………………

………………………………………………………………………………………………

………………………………………………………………………………………………

(4) Acreage

……………………………………………………………………………………..

(5) Description of borehole/well

………………………………………………………………..

(6) Diameter, Depth, etc.

…………………………………………………………………………

Details of Pump (where hand –operated

(a) Type of Pump

…………………………………..…………………………….

(b) Type of driving machine and fuel used

……………………………………………..

……………………………………………..

……………………………………………..

(c) Brake horse power of (b)…B.H.P.

(d) Approximate elevation of pump above sea-level

………………………………..meters

(e) How pump is connected to driving machine

……………………………………………………………………………………………

……………………………………………

(f) Internal diameter of suction main …………..

…………………………………………...cm

(g) Height of suction …………………….meters (maximum)

(h) Height to which water is to be lifted above pump

…………………………………meters

(i) Internal diameter of delivery pipe…………..

(j) Length of delivery pipe …………………….

……………………………………….meters

(k) Pumping hours per day ………………hours

(l) Quantity of water to be pumped when plant is working ………………….litres per hours

6 Details of pump (continued)

7 Purposes for which water is required: Litres per day

Domestic	..	..	..	..	…………………………………….
Public	..	..	..	..	…………………………………….

Industrial	..	..	..	..	…………………………………….
Irrigation	..	..	..	..	…………………………………….
Any other purpose (to be stated)					……………………………………..

Total quantity of water per day

8 Alternative source of water available to the applicant (if any)

……………………………………………………………………………………

……………………………………………………………………………………

9 The following are the existing boreholes within one- half kilometre of which this applicant cation refers:

Borehole no. (If known)	Name of Farm (Reg. No)	Distance from site
………………………	………………………….	…………………………
………………………	………………………….	……………………………
………………………	…………………………..	……………………………
………………………	…………………………..	…………………………….

NOTE: This paragraph is note (10)*

Applicable to applications to Record an existing right under the act, I enclose herewith crossed Cheque/Postal Order/Money Order No ……………………………

For K3000.00 to cover the prescribed fee for this application and undertake to pay the Malawi Government on demand the cost of insertion in the Government Gazette and in at least one newspaper circulating in Malawi of a Notice requiring any person objecting to the issue of a Grant of Rights to lodge such a complaint with the Chairman of the National Water Resources Authority.

Date ………………………   ....

Signature of applicant or his duly Authorised Agent

NOTE: this form is to be accompanied by a sketch map, in duplicate on a scale of not less than one cm to one kilometre, on which must be shown the farm or holding boundaries, the approximate position of the proposed borehole and existing boreholes within one –half kilometre radius and the position of any body of surface water.

9.0 GLOSSARY OF TERMS

Aesthetic	Aspects of drinking water quality that are perceivable by the senses, namely taste, odour, colour and clarity.
Anchor bolts	Screws welded into a frame or plate or are grouted directly into the cement pad. They are used to attach the pump to the pad.
Annular space/annulus	The space between the well casing and the borehole wall.
Apron	A slightly sloped concrete pad which surrounds the well and helps prevent contaminated surface water from finding its way back into the well.
Aquifer	A saturated geological unit (e.g. sands, gravels, fractured rock) which can yield water to wells at a sufficient rate to support a well.
Aquitard/aquiclude	Geological formation or strata that have the ability to store water but can only transmit water in very small quantities (e.g. silt or siltstone).
Artesian aquifer/well	A well that reaches water which, from internal pressure, flows up like a fountain.
Bearings/fulcrum	Pivot points used in all lever action hand pumps to connect handles to the pump head.
Bit	The piece which operates at the bottom end of the tool string to loosen the soil or rock to deepen the hole.
Borehole	A hole drilled, bored or dug into the ground into which a well casing is placed.
Bottom plug	A concrete slab across the bottom of a well which can act to prevent anything from entering the well or allow only water to enter.
Bottom section	That part of the well that extends beneath the water table.
Capture zone	The area of water table/piezometric surface drawdown created by pumping a well.
Cement	A grey powder used as an ingredient in mortar and concrete.
Centralisers	Devices used to ensure that the pump rod moves straight up and down within the rising main. Can also be installed to ensure the well casing is installed within the centre of the

	borehole
Chemical precipitation	Contaminant removal from solution through the chemical combining of anion and cations to form solids.
Concrete	A hard strong building material made by mixing cement, sand and gravel with sufficient water to cause the cement to set and bind the entire mass.
Cone of depression	The draw-down of the water table or potentiometric surface that happens when a well is pumped. The drawdown cones of two wells close together may overlap so that if the wells are pumped simultaneously they will compete with each other for available groundwater (well interference).
Confined aquifer	A fully saturated aquifer whose upper and lower boundaries are impervious geologic units. Water is held under pressure and the water level in wells stands above the top of the aquifer. Completely impervious layers rarely exist in nature and hence truly confined aquifers are relatively rare.
Contamination	The introduction of materials which makes otherwise potable water unfit or less acceptable for use.
Cup leathers	Seals used to create suction and pull water up the rising main when the plunger is moved up. Most pumps used curved "cup" leather seals, but some rely on leather or nitrile rubber rings.
Curb	A part of the well lining that extends out from the dining into the surrounding soil, helps to hold it in place and prevents it from sliding down.
Discharge area	The zone in which groundwater leaves the ground either as a spring or into a water body.
Drawdown	Drawdown is a measure of the amount of lowering of the water level in a well when pumping is in progress.
Filter pack	A filter pack is coarse sand or fine gravel (2-6 mm diameter) that is placed between the borehole wall and screen. Filter packs are used to settle-out fine grained particles that may otherwise enter the well.
Fishing	The act of trying to retrieve a tool or pump part dropped down into a well. It also is the name for the tool used to

	extract foot valves from open top cylinders.
Flowing well	A well in which the static water level is above ground level.
Foot valve	A valve at the bottom of the suction pipe which prevents the water pulled up into it by the cylinder from flowing back into the well.
Form	The structure or material around or in which concrete will exactly conform to.
Fracture	A general term for any break in a rock attributable to tectonic forces, magma movement, thermal processes; glacial or erosional loading or unloading, and earth tides. (Exact causes of fractures are not always known). They occur in all types of rocks. Incomplete fractures are cracks; a fault is a fracture zone along which movement occurs. Fractured-rock aquifers often have a fast, turbulent flow; are less isotropic and less homogeneous than porous media, and Darcy's law may not apply to them. Hydrogeologic investigations in fractured rock are usually either discrete studies (based on the careful measurement of each fracture) or continuum studies (which investigate the properties of large regions of the fractured material).
Ground water	Water deep enough in the ground so that it cannot be drawn off by plants or evaporated out through the ground surface; accumulates in quantity in aquifers from which it can be drawn out of the ground through wells.
Grout	A sealing material of cement or bentonite (swelling clay) used to create a sanitary seal in the annular space above the filter pack to prevent surficial contaminants from entering the well.
Handle/lever	Lever that connects the pump rod to the pump head. Often includes some mechanism to add counterweights to balance the weight of the water being lifted up the rising main.
Hand pump	A water pump powered by the movement of people's arms or legs.
Head wall	A short wall which extends above the ground level around a well.

Hydraulic conductivity	The ability of subsurface materials (sand, rock etc.) to allow a fluid (i.e. water) to flow through it.
Hydraulic gradient	The change in hydraulic head (pressure) per unit distance in a given direction (dimensionless). It is the driving force of fluid flow in a porous medium.
Hydrogeology	The subject dealing with the occurrence, characterisation and movement of water below the earth's surface.
Hydrologic cycle	Continual natural cycle through which water moves from oceans to clouds to ground and ultimately back to oceans.
Impermeable	A substance through which water cannot penetrate.
Intake section	That part of the bottom section through which water enters the well.
Lining	Masonry wall built to reinforce dug well hole walls.
Lining ring	A hollow circular column, usually made of concrete, which is used to reinforce a dug well.
Maintenance	Work proactively done to prevent unexpected pump breakdown.
Milligrams per litre (mg/l)	A unit of measure expressing the concentration of a substance in a solution. Is equivalent to parts per million (ppm).
Observation well	A well drilled solely for the purpose of monitoring a potential or an existing source of contamination.
Outlet	The term used to describe the spout assembly of some pumps.
Overburden	Unconsolidated (loose) soil overlying rock.
Permeability	The ability of an aquifer or water-bearing formation to allow water to pass through it. Permeability is also known as effective porosity because it is a function of interconnected saturated pore spaces.
Permeable	Permitting the flow of water or other liquids.
Phreatic zone	See saturated zone.
Piezometer	A device for measuring pore water pressure (i.e. measuring the location of the water table). Some types of piezometers can also be used for collecting water samples. As a result, wells designed specifically for collecting water samples are

often referred to, incorrectly, as piezometers.

Piezometric surface	The water level surface that can be defined from the mapping of water level elevations in wells tapping into a confined aquifer.
Porosity	The ratio of the volume of voids to the total volume of a rock or unconsolidated material. It is a measure of the amount of empty 'space' in a material. See permeability.
Positive displacement	Downhole cylinders pushing (displacing) water up the rising main.
Potable water	Water fit for human consumption.
Pump head	Pump assembly attached to the stand. Contains the following parts: Surge chamber, Handle, Bearings, Outlet Assembly.
Pumping level	The level at which water stands in a well when pumping is in progress.
Pumping lift	The maximum height of the water column that can be pushed up the rising main.
Rings	Some pump cylinders rely on leather or nitrile rubber rings instead of cup leathers to create suction within the cylinder when the plunger is moved up.
Rising main/drop pipe/draw pipe/pump column	The pipe connecting the pump cylinder to the pump body. Water moves up this pipe and out the pump spout during pumping when the plunger is moved up and down within the cylinder.
Saturated zone	The zone below and including the water table in which all pore spaces or fissures are totally filled with water. Also referred to as the phreatic zone.
Semi-confined aquifer	A semi-confined (leaky) aquifer is a completely saturated aquifer overlain by a semi-impervious layer and underlain by an impervious layer. Lowering of the potentiometric head in a leaky aquifer by pumping will generate a vertical flow of water from the semi-pervious layer into the pumped aquifer.
Specific capacity	A measure of pumping rate per unit drawdown.
Static water level	Static water level is the level at which water stands in a well when the water level is at equilibrium with atmospheric

pressures). It is a measure of the depth from the ground surface or from a known measuring point to the water level.

Storage coefficient	See storativity.
Storativity	The volume of water released from storage per unit surface area of aquifer per unit decline in hydraulic head (dimensionless).
Strata	Layers of deposited rock, soil etc. which are distinguishable from each other.
Suction	Pumps without down-hole cylinders rely on suction generated by above-ground cylinders to lift water up the rising main.
Surface recharge	The amount of water that soaks down through the ground to reach an aquifer in a certain length of time.
Swivel connection	A device used to connect two pipes or hoses and which permits one or both to turn freely.
Transmissivity	The rate at which groundwater can flow through an aquifer section of unit width under a unit hydraulic gradient. It is the average permeability of a section of the entire aquifer at a given location multiplied by the thickness of the formation.
Unconfined aquifer	An aquifer whose upper boundary is defined by the water table (water is at atmospheric pressure). Water usually saturates only part of the geologic unit and there is no upper confining layer. Also called a "water table aquifer".
Unsaturated zone	The zone above the water table in which soil pores or fissures are less than totally saturated. It is also called the vadose zone or the zone or aeration.
Vadose zone	See unsaturated zone.
Valve	A device that allows water to move in only one direction.
Water table	The top of the zone in which all pore spaces or fissures are totally filled with water.
Water table aquifer	See Unconfined Aquifer.
Watertight seal	An impermeable material used to prevent water from moving from one area to another.
Well	A hole drilled or dug into the ground to extract liquid. Drinking water wells must be deep enough to reach far

	below the water table or they may have no water during the dry season when the large of recharge causes the water table to fall.
Well development	The act of pumping and surging water in a well to remove mud and dirt from within the filter pack, borehole wall and local aquifer. When done completely, pumped water will be free of suspended material. Wells must be developed after drilling to ensure that the cylinder is not prematurely worn-out by the abrasive action of suspended material moving between the plunger and cylinder walls.
Wellhead protection	The pro-active management of land to assess and mitigate potential risks posed to well water quality.
Yield	The amount of water that is produced when a pump is operated for a fixed number of full strokes.

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