MINISTRY OF AGRICULTURE, IRRIGATION AND WATER DEVELOPMENT

Standard Operating Procedure for Drilling and Construction of National Monitoring Boreholes

Document No 06GW01/2012

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Contents

1.0 GENERAL INFORMATION

1.1 Purpose

The purpose of this document is to describe procedures, methods and considerations to be used and observed when drilling and constructing groundwater monitoring boreholes to be used for measuring groundwater levels and collecting groundwater samples.

This procedure aims to obtain representative groundwater data (including water strike depths, blow out yields and static water levels) and representative groundwater samples from targeted zones of interest in the subsurface. The siting of the boreholes and ultimate borehole construction requires a comprehensive study and understanding of the hydrogeology of the area.

1.2 Application

The procedures contained in this document are to be used by field personnel when drilling and constructing groundwater monitoring boreholes. In the event that the field personnel determine that any of the procedures described in this section are either inappropriate, inadequate or impractical and that another procedure must be used for any aspect of the drilling and construction of a groundwater monitoring borehole, the variant procedure will be documented in the field log book, along with a description of the circumstances requiring use of alternative procedure.

1.3 Scope

This procedure describes procedures and applicable techniques for drilling and constructing standard groundwater monitoring wells suitable for various aquifers in Malawi.

This procedure will be used during drilling and construction of all monitoring boreholes for the purpose of ground water level, quantity and quality monitoring by the Groundwater Department. All field personnel conducting drilling activities are required to be familiar with the procedures provided herein.

This procedure will facilitate the acquisition of accurate groundwater levels and accurate groundwater samples from screened aquifers.

1.4 Groundwater division SOPs

The following documents form part of the series of Standard Operating Procedures for best management practices in groundwater management:

Document No.	Title
GW01/2012	**Standard Operating Procedure: Drilling and Construction of National Boreholes**
GW02/2012	Standard Operating Procedure for Aquifer Pumping Tests
GW03/2012	Standard Operating Procedure for groundwater level monitoring
GW04/2012	Standard Operating Procedure for groundwater sampling
GW05/2012	Standard Operating Procedure for operation and management of the national groundwater database
GW06/2012	Standard Operating Procedures: Water Use Permitting
GW07/2012	Standard Operating Procedure: Drilling and Construction of Production Boreholes

All official copies of the division's documents are kept, in electronic format and hard copies, by the office of the Deputy Director – Groundwater Resources.

1.5 Responsibilities

The responsibilities of the Groundwater Division staff for the effective implementation of the National Groundwater monitoring systems, and this procedure in particular is indicated in Table 1.

Table 1 Responsibilities of Groundwater Division staff

Position	Responsibilities
Director - Groundwater	Planning national drilling and construction programme for

Position	Responsibilities
Resources (Project Manager)	monitoring boreholes. Implementation of the procedure. Organising and allocating resource (human and financial) for successful implementation of the procedure. Project leadership and control. Reviewing, updating and re-issuing the procedure. Keeping records of all the monitoring boreholes i.e. drilling, construction, location and monitoring records, and maps.
Regional Hydrogeologists	Directly oversee the drilling and construction of the monitoring boreholes by the driller. Keep all construction and completion records for all monitoring boreholes in their respective regions and maps of borehole locations. Coordinate and supervise implementation of the procedure in their respective regions. Ensure all pertinent data are recorded on appropriate forms and in the field notebook. Ensure all appropriate project records are maintained.
Field/Site Hydrogeologist or Engineer	Supervise the drilling and construction of monitoring boreholes. Determine the final drilling depth and final borehole construction, based on hydrogeologic data obtained during drilling. Collect all the daily logs/records from the driller.
Site Safety Officer	Typically the Field Hydrogeologist is responsible for overseeing the health and safety of employees and for stopping work if necessary to fix unsafe conditions observed in the field. In the event of use of external drilling contractor, the contractor

Position	Responsibilities
	will assign their own site safety officer.

1.6 Definitions of terms

Airlift	To lift water or drilling fluid to the surface using compressed air, associated with airlifting water, such as airlift development or an airlift test.
Annulus	The space between the drill string or casing and the wall of the borehole or outer casing.
Aquifer	A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield economical quantities of water to wells and springs.
Bentonite	Colloidal clay largely comprised of the mineral sodium montmorillonite (a hydrated aluminium silicate).
Bit	The cutting tool attached to the base or bottom end of the drill string that breaks the formation into smaller pieces (cuttings) during drilling.
Development	The act of repairing damage to a formation that was caused by drilling procedures.
Drilling fluid	A water- or air-based fluid used in a drilling operation to remove cuttings from the hole, clean and cool the bit, reduce friction between the drill string and the sides of the hole, and seal the borehole.
Grout	A fluid mixture of cement and water (neat cement) of a consistency that can be forced through a pipe and placed as required. Various additives, such as sand, bentonite, and hydrated lime, can be included in the mixture to meet certain requirements. Bentonite and water sometimes are used for grout.
Grouting	The operation by which grout is placed between the casing and the sides of the wellbore to a predetermined height above the bottom of the well. This process secures the casing in place and excludes water and other fluids from the wellbore.

Hydrogeologic	Those factors that deal with subsurface waters and related geologic aspects of surface waters.
Jetting	To develop a well by applying high-velocity horizontal streams ("jets") of water or compressed air to the well screen.
Observation well	A well drilled in a selected location for the purpose of observing parameters such as water levels and for the collection of water samples.
Reverse circulation	The circulation of the drilling fluid down the annulus and back up to the surface through the drill stem; the opposite of direct circulation.
Well screen	A filtering device used to keep sediment from entering a well.

1.7 Health and safety

Proper safety precautions must be observed during drilling and construction of groundwater monitoring boreholes. A health and safety plan must be prepared prior to field work and must be followed during drilling and construction of monitoring boreholes. The plan should address all potential and known and hazards.

When using this procedure, minimise exposure to potential health hazards through the use of personal protective clothing (PPE). The following PPE is recommended, as a minimum requirement, at all drilling sites for health and safety reasons:

- Hard hat.
- Leather boots
- Gum boots
- First aid kit
- Fire extinguisher
- Eye protection.
- Hearing protection.
- Dust protection.
- Gloves.

Workers stationed and working greater than 3m above ground level will also be provided with and made to wear fall protection harnesses.

The Drill Site shall be fully marked with a barrier tape that clearly denotes and encompasses the work site and have warning signs in English and local language(s) stating the recommended PPE to be worn within the work area.

All non-designated personnel are to be kept away from and out of the work site for safety reasons.

2.0 DRILLING METHODS

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

2.1 Cable tool drilling (non-circulation)

The cable tool method, a non-circulation technique of drilling wells, is also referred to as "percussion," "solid tool" and "standard" drilling. It is used for wells of all sizes and almost any depth.

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. 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 can be 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 also affected by resistance of the formation, weight of the drill tools, length of the stroke, strokes per minute, diameter of the bit and 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. The casing is thus 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 down 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.

2.2 Rotary drilling (Direct circulation technique)

Rotary drilling is used almost universally in drilling and has in most cases replaced the percussion cable tool rig to drill water boreholes. Several variations of rotary drilling exist and these depend on the size and design of the drilling rig. The most common types are: Air Cave, Diamond, Rotary Air Blast (Blade and hammer), Reverse circulation (Blade and hammer), Mud drilling including reverse circulation mud, Bucket (Calwell type) and Casing drive (Cavey type).

Whereas the cable method relies on the up and down motion of drilling tools to crush or loosen formation material, the rotary 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.

As the bit turns, drilling fluid is pumped down the drill pipe to lubricate and cool the bit. The materials from the bottom of the hole are removed by carrying the cuttings upward to the surface by way of the annular space between the borehole wall and the drill pipe. Once at the surface, the fluid is channelled into a settling pit, where cuttings settle out, and then into a storage pit where it is picked up for re-circulation. This drilling fluid forms a thin layer of mud on the wall of the hole which reduces seepage losses and, together with the hydrostatic head exerted by the mud, holds the hole open.

Though plain water is often used as drilling fluid, several other drilling fluids can be used. These include mud, foam and/or air. In general, the functions of a drilling fluid are to (Johnson Screens, 2007):

- Carry the cuttings from the bottom of the hole to the surface;
- Support and stabilise the borehole wall to prevent caving;
- Seal the borehole wall to reduce fluid loss;
- Cool and clean the drill bit;
- Allow cuttings to separate from the fluid at the surface; and
- Lubricate the bit, bearings, mud pump, and drill pipe.

Mud is used as a drilling fluid for the following reasons:

- 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
- Act as media for wall chemical reaction prevention.

Foaming agents are usually injected with water and/or air. Their principal use is to improve the removal of chips in situations where up-hole velocities are inadequate.

Air as drilling fluid is used effectively only in semi-consolidated or consolidated materials to carry cuttings to the surface. During air rotary drilling, cuttings are deposited on the ground or in a collection system and the circulating air goes back into the atmosphere.

Water can be used as a total drilling media or as an intermittent flushing agent by pressure injection in air rigs. Other uses include removing cuttings, cool the bit and 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.

The volume rate of drilling media (mud, water, air) should increase to maintain up-hole velocity to clear cuttings and maintain an adequate circulation return. For instance, a 150mm diameter hole to 100m may be air drilled with 500cfm air supply but a 200mm diameter hole to 100m could require more than 1000cfm air supply.

2.3 Rotary air blast drilling (Direct circulation technique)

Air rotary drilling is a variation of conventional rotary drilling. The rig is essentially the same as for 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 down hole 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.

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.

2.4 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 (500gpm or more) pump is attached to the drill pipe and keeps the fluid moving at a high velocity. 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.

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 volumes 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.

2.5 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; usually, it needs to be forced down. An open hole can be drilled by jetting to limited depths in unconsolidated materials. Temporary casing must, however, eventually be installed and must follow the bit closely when the hole tends to cave.

The drilling diameter for all boreholes shall not be less than 160mm.

3.0 GEOLOGIC 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 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 and exploratory drilling.

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

3.1 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.

3.2 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 or 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.

3.3 Cavernous formation

Cavernous formations as in limestone, volcanic flows and highly fractured zones such as fault 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 as circulation of drilling media. Cuttings are intermittently bailed from the hole. When casing is progressively run in the hole, an undercut bit is used to enlarge the hole below the casing “shoe”.

The Casing Rotary Drill Method involves rotating the casing which has a cutting foot so that it follows closely behind a rock but in some machines the rock bit has an acentric motion which undercuts the casing.

3.4 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 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 the boulders can be cracked or chipped by hard blows of the bit.

4.0 PROCEDURES

4.1 Field Preparation

Prior to leaving for the borehole location site, the Field Team Leader ensures that the following activities have been completed:

a) Locate and mark planned borehole locations and ensure clearance of appropriate drilling pad prior to drill rig mobilisation to site.
b) Ensure access to site by preparing access road. In case of inaccessible location, provide recommendations for any relocation required thereof based on field observations and accessibility aspects.
c) Establish a decontamination area away from (and preferably up wind of) potentially contaminated areas where possible. Decontaminate non-disposable sampling equipment and down-the-hole tools that may come in contact with the sample matrix prior to use.

4.2 Drilling equipment cleaning and decontamination

Prior to mobilisation, the drill rig and all associated equipment should be thoroughly steam cleaned or cleaned using high-pressure hot water, and rinsed with pressurised potable water to remove all oil, grease and mud. Any equipment that is not required at the site should be removed from the rig prior to entering the site. To the greatest extent possible, drilling should proceed from the least to most contaminated sections of the work site.

Special attention should be given to the thread section of the casings and to the drill rods during cleaning. Additional cleaning may be necessary during the drilling of individual holes to minimise the carrying of contaminated materials from shallow to deeper strata by contaminated equipment.

Equipment with porous surfaces, such as rope, cloth hoses, and wooden blocks or tool handles cannot be thoroughly decontaminated. These should be disposed of properly at appropriate intervals. These intervals may be the duration of drilling at the site, between individual bores, or between stages of drilling a single bore, depending upon characteristics of the tools, site contamination, and other considerations.

Cleaned equipment should not be handled with soiled gloves. Surgical gloves, new clean cotton work gloves, or other appropriate gloves should be used and disposed of when even slightly soiled. The use of new painted drill bits and tools should be avoided since paint chips will likely be introduced to the monitoring system.

All drilling equipment should be steam cleaned or cleaned using high-pressure hot water, if appropriate, at completion of the project to ensure that no contamination is transported from the sampling site.

4.3 Field recording and logging

At a minimum, the following should be recorded in the field log book for the drilling records at each borehole site:

- Borehole Identification.
- Location coordinates (GPS or preferably surveyed) of the borehole.
- Starting and completion dates.
- Lithological logs and any geophysical logs collected.
- Borehole depth.
- Water strike positions.
- Depth to static-water level.
- Size of the drill hole and method of drilling.
- Length, depth, and size of the casing; changes in size of the casing and type of casing.
- The amount, type, slurry weight, and location of grout used in the hole; a narrative description of the grouting procedure.
- The location and type of packers used in the hole.
- The length of the screen or casing perforations.
- The location of the top and bottom of the screen, the top and bottom of the aquifer, and the location of multiple screens.
- The screen slot or perforation size.

- The gravel pack and its volume, type, or size.
- Borehole-test data, if available.
- The type and method of disinfection.
- The date and signature.

In addition, the borehole records should identify the datum from which borehole measurements are made, the depth of the drilled hole, and the height of riser pipe above the ground. The datum should be a bench mark whenever possible or a permanent structure.

4.4 Lithological chip sampling and measuring yield and penetration rate

Collection of samples shall be done by the Driller. A representative continuous sample of the strata intercepted shall be sampled at each meter drilled or any other interval as instructed by the Field Hydrogeologist. The Driller shall also ensure that the samples are not contaminated due to poor circulation, hole erosion, caving or due to inconsistent collection of samples at the end of drilling of every meter. The samples will be laid out close to the drill rig in a protected area.

Blow out yield measurements should be done at 1m or 5m intervals and at every water strike. Water quality measurements should also be made at every 1m or 5m intervals and at every water strike.

Lithology penetration rates should be monitored and recorded throughout the drilling process.

4.5 Construction procedure

Monitoring boreholes will be constructed according to the specified designs for the target aquifers at each site, using a minimum of the following materials:

- Casing and screen.
- Filter pack/gravel pack.
- Backfill.
- Sealing materials (such as bentonite pellets, cement and powdered bentonite).
- Surface seals and materials for well surface completion (e.g., concrete, protective steel casing, steel posts, surface boxes).

4.5.1 Casing and screen

Plain casings are installed above the main aquifer and against non-water bearing formations or against water bearing sections of the borehole to be sealed off. They support the walls of the borehole, prevent caving and contaminated subsurface water (in shallow water tables) to enter the borehole. Of the different types of casings in Malawi, UPVC pipes of 3m lengths (class 10 pressure rating), are the preferred permanent casings for monitoring boreholes.

Screens are mostly used in water bearing sections of the borehole, usually in unconsolidated or poorly consolidated formations with a granular fabric and water bearing structures. They also support the walls of the borehole, prevent formation from caving and permits water to enter the borehole through closely spaced openings. The diameter of the screen corresponds with the diameter of the plain casings.

The diameter of the screen shall be chosen in a way to allow collection of water samples from the borehole, according to the specified borehole design.

The size of the screen openings is chosen based upon the grain sizes of the water bearing formation. The well screen shall have a minimum slot size of 0.79mm and shall give an open area of at least 10%.

The screen will be installed against water bearing formations except for the last 6m from the bottom. 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.

4.5.2 Filter pack (gravel pack)

All monitoring boreholes shall be gravel packed. The gravel pack to be used must be approved by the Groundwater Division. 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.

The 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. The filter pack material may be placed in the well using a tremie pipe. Filter pack material should be added carefully with continuous measurements by the field Hydrogeologist to prevent bridging of the filter pack material. 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 casing. Once initial placement of the filter pack material has reached a height of 0.6m above the base of the 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.

4.5.3 Grouting and backfilling

Grouting shall be done with a tremie pipe or similar means within the annular space extending from the top of the filter pack to the surface. The annular sealing material above the filter pack will prevent the migration of fluids from the surface and between aquifers. Sealing material will be chemically compatible with anticipated contaminants. Bentonite and cement grout are the usual sealants placed between the borehole annular space above the gravel pack, in accordance with the specified borehole design.

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. The borehole cuttings will then 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.

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. Backfilling shall only be done with material which will not pose a pollution threat to the aquifer. A grout seal shall be placed above the back fill.

4.5.4 Surface Completions

After backfilling the borehole shall be capped with a sanitary seal and a head block constructed for borehole completion. The seal will prevent the ingress of potentially contaminated surface water into the borehole through the annular space between the borehole side wall and the outside of the casing. This seal must be made from cement mixed to slurry with water which is free from oil and organic matter. The borehole cap shall be of a suitable material and lockable.

The locking cap will be placed at the top of the casing and the cap will be watertight. The section of PVC casing that sticks up above ground will be protected by a steel protective pipe, set at least 0.5m deep into a concrete surface seal. A concrete pad should be constructed around the protective steel pipe. The pad should be square; approximately 1m x 1m x 0.5m, and the top of the pad should be approximately 0.2m off the ground. The concrete mixture used to construct the pad shall consist of water, Portland cement, stone aggregate (10mm) and river sand. The required strength of the concrete will be 30 Mpa after 28 days.

4.5.5 Borehole straightness and vertically

All boreholes in Malawi shall be lined.

Borehole straightness and verticality are highly important for construction of monitoring boreholes to allow the running of casing. To maintain a straight and vertical borehole 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.

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 and failure to correct such a fault will normally lead to the rejection of the borehole by the Manager.

4.5.6 Well Development

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

1) to maximise the yield of the well,
2) to prevent clogging,
3) to stabilize the formation, and
4) to wash out fine cuttings, silt and clay that had worked into fissures, crevices or pores of rock during drilling operations.

Monitoring borehole development ultimately ensures that complete hydraulic connection is made and maintained between the well and the aquifer material surrounding the well screen and filter pack.

Borehole development 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 move the fine material towards the screen and into the well where it can be removed through 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/l.

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

4.5.7 Monitoring borehole location and surveying

Each well will be surveyed by a licensed surveyor where the well has been installed and tied to an established country benchmark, site conditions permitting.

4.5.8 Marking of boreholes, trimming and finishing

Upon completion of the above, the borehole number allocated by the Water Resources Directorate will be affixed to a marker plate and pole or to the bore head block, as directed by the Field/Site Hydrogeologist. The following information must be punched (i.e. 10 mm letter size) or script-welded onto the concrete block:

1) Borehole number,
2) Borehole depth,
3) Date drilled,
4) Water strike depths and blow out yields, and
5) Casing sizes installed and depth of each casing.

All completed work shall be trimmed and all the debris of construction, such as unsuitable or rejected materials, spillage and cuttings shall be removed. The site of the work shall be cleaned of all rubbish, excess materials, false works, temporary structural installations and abandoned equipment. All sumps or other excavations shall be back to a pre-drilling state. All contaminated soil shall be removed and placed in a suitable and approved waste disposal site. Any subsequent subsidence of the back filled sumps will be re-filled and graded to the original condition of the site.

Unsuccessful boreholes shall be backfilled (grouted) or plugged with a rock.

5.0 QUALITY ASSURANCE AND QUALITY CONTROL

A qualified Field Hydrogeologist shall supervise the drilling and construction of each monitoring borehole. The drilling contractor (or Driller) will prepare and hand over the following reports to the Field Hydrogeologist, at the specified frequency:

Table 2 Report information

Name	Description	Supplied
Strata log	An accurate record of strata passed through and the depths at which the strata were intercepted.	Daily
Penetration rate log	An accurate record of the penetration rates achieved, in minutes for each meter drilled, together with type, size and grade of bit.	Daily
Drilling media log	An accurate record of the components and quantities used in or injected into the drilled medium, including for drilling muds; viscosity, weight, sand content, water loss, filter cake, pH and temperature. The Driller/Contractor will carry out the above tests each hour and as directed at random by the Field/Site Hydrogeologist.	Daily
Construction log	An accurate record of all casing and screens run into the boreholes, and quantities of all other materials used, such as cement.	On completion of construction
Time log	An accurate record of time spent on all phases of drilling.	Daily and summary on completion submitted to Site Hydrogeologist for signature

In addition, the Field Hydrogeologist shall keep borehole drilling and well construction details well documented in detail in the field using field documentation forms. Any deviations from drilling and construction design shall be documented and explained in daily field notes and discussed with the Program Manager.

Field quality control shall be maintained through:

1) making sure employees are properly trained to conduct the work being implemented
2) performing routine field audits to evaluate how well employees are following procedures

6.0 COMMISSIONING

Once the bore is complete and approved by the Groundwater Division, the bore shall be included in the national ground water monitoring network.

7.0 REFERENCES

The following documents were consulted in the preparation of this SOP:

California Environmental Protection Agency, 1995. Monitoring Well Design and Construction for Hydrogeologic Characterisation; Guidance Manual for Ground Water Investigations, California Environmental Protection Agency, USA

Ohio EPA, 2007. Technical Guidance Manual for Ground Water Investigations Chapter 5 Monitoring Well Placement, Ohio Environmental Protection Agency: Division of Drinking and Ground Waters, Ohio.

U.S. EPA., 2008. Design and installation of monitoring wells, Region 4, U.S. Environmental Protection Agency (EPA), Science and Ecosystems Support Division, Athens, Georgia

U.S. EPA., 1991. Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells EPA160014-891034, U.S. Environmental Protection Agency (EPA), Las Vegas, Nevada

Sterrett, R. J., 2007. Groundwater and Wells, Third Edition, LilhoTech, Bloomington, MN, United States of America