Government of Southern Sudan

Ministry of Water Resources and Irrigation

DIRECTORATE OF RURAL WATER SUPPLY AND SANITATION

SUPERVISOR'S MANUAL FOR DRILLING AND TESTPUMPING.

October 2008

For every child
Health, Education, Equality, Protection
ADVANCE HUMANITY
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LIST OF ACRONYMS

CBO	Community Based Organisation
DD	Drawdown
ID	Installation Depth
DWL	Dynamic Water Level
DTH	Down The hole Hammer
GoSS	Government of Southern Sudan
IMK 2	India Mark 2
MWRI	Ministry of Water Resources and Irrigation
NGO	Non Governmental Organisation
PVC	Poly Vinyl Chloride
RWD	Rural Water Department
UNICEF	United Nations International Children Educational Fund
WASH	Water Sanitation and Hygiene
WES	Water Environment and Sanitation

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1.0 INTRODUCTION

This manual has been produced as a practical guide for Supervisors of private sector Contractors involved in construction and test pumping of rural water supply boreholes.

It is envisaged that the manual will be used by staff or Consultants employed by GoSS, States, NGOs and CBO staff who are directly supervising/ managing such contracts. As well as constituting a Supervisors guide, the manual also outlines various general aspects of borehole drilling, development, test pumping, and provides a summary of the broad principles of contract management.

2.0 GROUNDWATER AND THE HYDROLOGICAL CYCLE

Groundwater refers to sub-surface water that occurs beneath the water table in soils and geological formations that are fully saturated. Examples of such geological formations include;

- Gravel;
- Sand;
- Sandstone;
- Weathered rocks (granite, gneiss, schist etc) and
- Fractured rocks (granites, gneisses, schist etc).

2.1 THE HYDROLOGICAL CYCLE

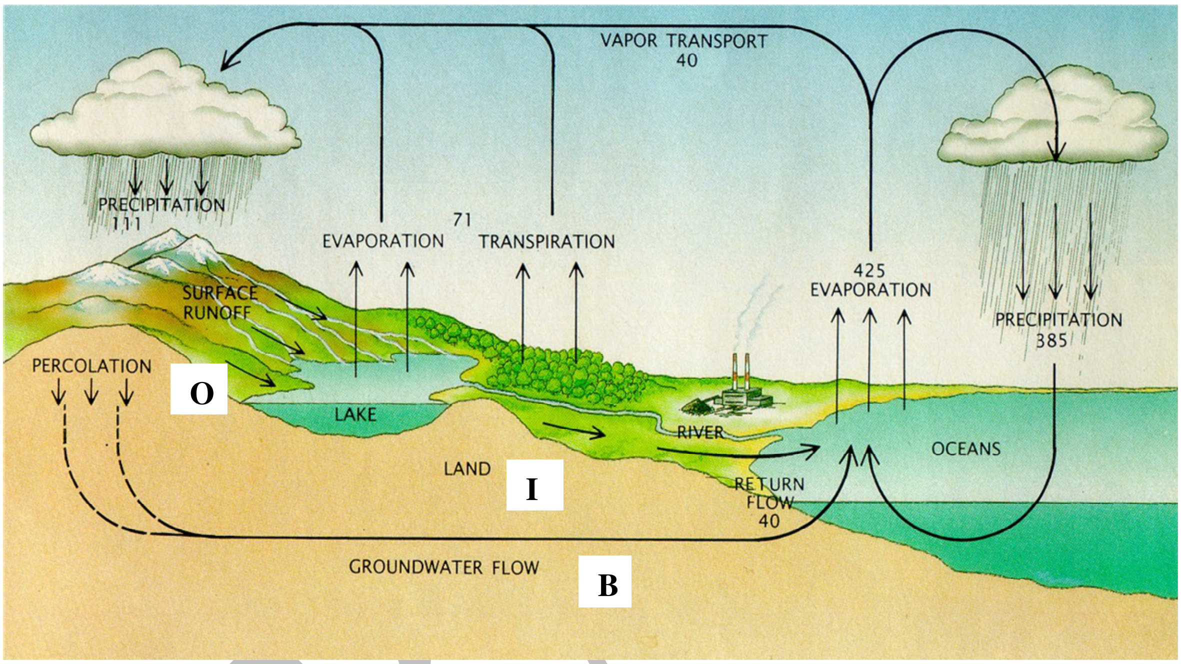
The term 'Hydrological Cycle' refers to the continuous circulation of water between oceans, rivers, lakes, the atmosphere and the land surface. The main components of this cycle are;

- Rainfall;
- Runoff (to the rivers, lakes and oceans);
- Infiltration (to the groundwater body)
- Evaporation and Evapotranspiration and
- Discharge (from groundwater through springs).

These components are illustrated in Figure 1 below.

The surface component of the Hydrological Cycle is called Runoff, in which some of the Rainfall concentrates to form rivers and streams which flow to lakes and oceans.

Some of the Rainfall also percolates into the ground to form shallow aquifers which may be tapped by shallow wells and which may discharge as springs. Some of this shallow groundwater may also infiltrate further down into fractures in the underlying rock, which moves as base flow in the fractures. This deeper groundwater may then provide water to boreholes that draw water from the fractures. At both the shallow and the deeper levels groundwater flows laterally, generally following the topographic slope, towards the surface water bodies which form the groundwater base level and which (often) constitute areas of groundwater Discharge. These surface water bodies, as well as areas where the groundwater is very close to the surface, are where direct Evaporation and/or Evapotranspiration occurs, and from where water is returned to the atmosphere as water vapour.



O => Overflow (Surface streams)
I => Interflow (for springs & S/Wells
B => Base flow (Ground Water for deep boreholes)

Figure 1.: The Hydrological Cycle

2.2 GROUNDWATER OCCURRENCE

Where groundwater occurs in unconsolidated material (soils; overburden) or in consolidated but porous geological formations (sandstone) it exists in spaces between the solid particle matrix. Particles that are large (like those of sand) also have large (pore) spaces between them, and thus will allow water to move through them more easily, whereas formations with fine particles (like clay) will have small pore spaces and will not allow water to move through them easily. In Southern Sudan saturated soils, sand and weathered rocks (collectively termed 'overburden') frequently constitute shallow aquifers, which will yield water to shallow dug or drilled wells.
In the case of massive consolidated rocks such as granite, gneiss, quartzite etc (collectively termed bedrock), there are no pore spaces and water does not

penetrate the rock mass at all. Groundwater can only infiltrate into and exist in such rocks in fractures joints and fissures. Any aquifers in these formations are termed ‘fracture aquifers’. Such fracture aquifers are usually relatively deep (30–100 metres below surface) and are usually of limited dimensions and may or may not be interconnected with other similar aquifers.

Fracture (bedrock) aquifers will most often provide relatively higher yields to deeper drilled boreholes than shallow (overburden) wells, since fractures allow easier and more rapid groundwater flow than pore spaces in overburden materials.

2.2.1 Groundwater Movement

The natural level of groundwater in an aquifer is termed the ‘water table’, except in circumstances where the groundwater is under natural hydrostatic pressure (is ‘confined’) when it is termed the ‘piezometric surface’. The water table is rarely horizontal, with the result that groundwater is always ‘flowing’ towards the lowest point of the water table (usually a groundwater discharge point such as a spring, river or lake). Due to the nature of the aquifers in Southern Sudan, the water table also usually ‘mirrors’ the topographic surface to a very large degree (Figure 2).

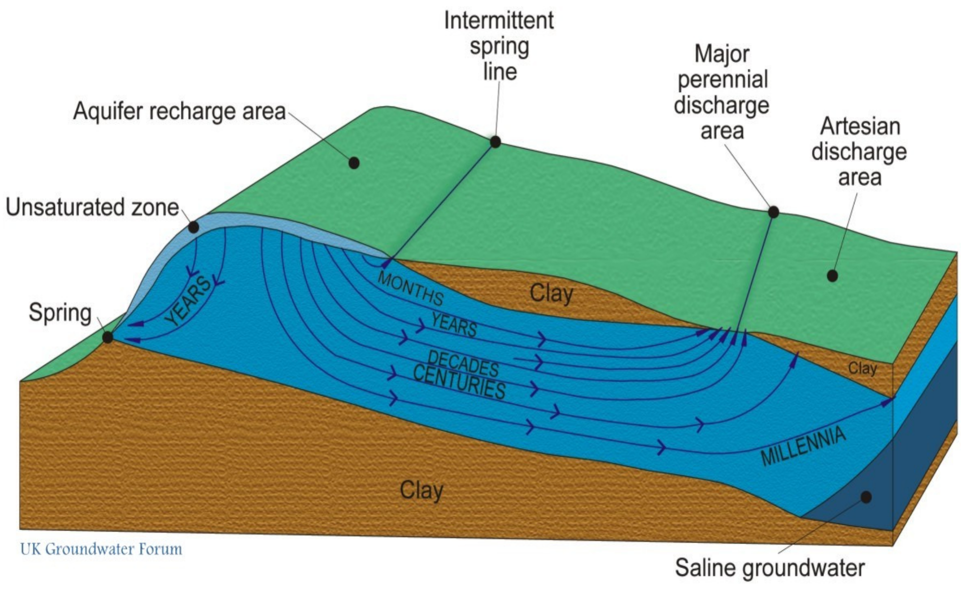


Figure 2: Basic illustration of groundwater Movement in the Earths Crust

2.2.2 Flow towards a Borehole

If water is pumped from a borehole, the natural water table in the vicinity of the borehole drops and groundwater starts flowing towards the borehole. This fall in water level is termed ‘draw down’ (DD), and is the difference between the static water level (SWL) i.e. the natural level before pumping, and dynamic water level

(DWL) i.e. the imposed water level due to pumping (Figure 3). In order to express draw down as a positive number, this is normally stated as:

DRAWDOWN = DYNAMIC WATER LEVEL - STATIC WATER LEVEL
(DD) (DWL) (SWL)

In a homogenous aquifer the inward flow of groundwater is radial, groundwater flow velocity increases as it nears the well where the water table becomes increasingly steep, and the water table assumes the shape of a cone termed the ‘cone of depression’. The distance around a borehole that is affected by the cone of depression is termed the ‘radius of influence’.

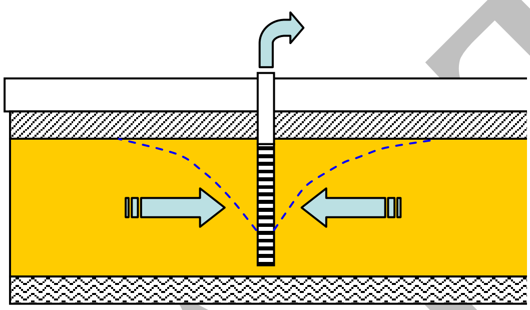


Figure 3: Schematised Flow towards a pumped groundwater well

When pumping is stopped the cone of depression fills by natural flow and the dynamic water level rises back to the static water level. The rate at which this recovery of water level occurs gives an indication of the ‘permeability’ (or water transmitting capacity) of the aquifer. Rapid groundwater recovery indicates an aquifer with a high permeability.

2.3 IDENTIFYING A DRILLING POINT (BOREHOLE SITING)

Identifying a probable drilling point involves a series of steps that include both office/desk work and field work. The office/desk work involves a thorough review of existing borehole data, a study of the aerial photographs and satellite imagery, identifying the prominent fracture and fault zone and the fault directions.

This is concluded by pin-pointing the most feasible location on ground where the field work should start. Field work is started by making observations on ground. Ground observations are aimed at identifying existing tracers/indicators of groundwater occurrence and flow.

2.3.1 Indicators of Groundwater Presence

There are a number of features, both natural and man-made, which may indicate the presence of groundwater and aid in the location of a probable drilling point. These include:

- Valleys, particularly those that are linear, since valleys often occur along bedrock fracture zones.
- Linear distribution of natural vegetation, particularly large trees. This may be indicative of underlying fracture zones, since large trees will have roots into the permanent water table in such fractures.
- Broad areas of permanently green vegetation, since generally healthy vegetation throughout the year indicate the presence of shallow groundwater.
- Existing water sources such as perennial hand dug water holes, perennial springs, indicating the presence of shallow groundwater
- Existing boreholes.

Once pin-pointed, more precise methods are used to locate a point where borehole drilling should be implemented. The precise location methods involve use of sophisticated equipment that makes use of;

- Magnetic polarities/effects
- Electro-Magnetic effects
- Electro-resistivity effects
- Induced polarisation effects

With sound interpretation, weaknesses in the earths, crust (faults, fractures or joints) or very thick weathered zones can be identified to an accuracy of +/- 5m.

All the above methods take into assumption that the anomalies identified are closely associated with the occurrence of groundwater, thus the points/areas are then recommended for drilling.

The various types of groundwater investigations and the office/field investigation activity are summarised in table 1 below;

Table 1. Types of Groundwater Investigations

Type of Investigation	Office/Field Activity
Desk studies of available data and preliminary field reconnaissance	Mainly office
Remote sensing: satellite imagery and aerial photo interpretation	Mainly office
Hydrogeological mapping and well inventories	Field
Surface geophysical investigations	Field
Drilling (Exploration)	Field
Execution of pumping tests	Field
Groundwater monitoring (Quantity and quality)	Field
Collection of groundwater balance data	Office and field
Water demand studies	Office and field

3.0 COMMON DRILLING METHODS

3.1 MUD ROTARY DRILLING

In this method of drilling a borehole is created by a drilling bit attached to the bottom of set of drilling rods which are of a lesser diameter than the bit and which are rotated by means of a hydraulically driven drive unit on the drilling rig. The rotation of the bit together with the weight of the drilling 'string' (i.e. the drill rods, any drilling collars used to provide weight, and the bit itself) cuts and breaks up the rock/soil as it penetrates the formation. In order to remove this broken material a circulating fluid (loosely termed 'drilling mud') pumped via a number of 'mud pits' is used.

In a conventional fluid flush system drilling mud is pumped from a 'suction pit' through the rotating drilling string and out through holes in the drill bit. This mud picks up the soil/rock materials cut by the bit in the bottom of the bore ('cuttings'), then flows upward in the 'annular space' between the drill rods and the wall of the borehole, carrying the cuttings to the ground surface and clearing the hole. The drill string and bit will then continuously move downwards and deepen the borehole. The greater the fluid flow and viscosity, the more efficient the hole cleaning process and, in general, the faster the drilling penetration.

At the surface, the returning drilling fluid (drilling mud + cuttings) flows to a 'settling pit' where the cuttings are allowed to settle out of the fluid to the bottom of the pit. From the settling pit the recovered fluid then overflows back into the suction pit from where it is sucked up by the mud pump and re-circulated again through the drill string.

3.2 AIR ROTARY DRILLING

The essential components of the air rotary method are the same as the mud rotary method, except that compressed air is used as the circulating fluid that is forced down the drill string, through the drill bit and back via the annular space to the surface. The cuttings are forced up through the annular space by the pressure of the ascending velocity of the air, and are carried to the surface. At the surface the cuttings are collected either in a bucket trap or an 'extractor'.

This drilling method requires no mud pits or pump, but the efficiency of the hole cleaning and hence drilling penetration is very much influenced by the volume and pressure of the air (i.e. the capacity of the compressor).

3.3 AIR PERCUSSION DRILLING

This drilling method is the now most commonly used in Southern Sudan, and is essentially the same as the air rotary method, except that air pressure is used to operate a down hole percussion 'hammer'. The hammer relies upon percussive impact and rotation rather than solely rotary action to break up the rock and create the borehole. Cuttings produced by the hammer are similarly returned to the surface by the rising column of air, with the rate of penetration and the efficiency of hole cleaning depending greatly on the pressure and volume of the compressor.

A very significant advantage of this method of drilling is that the percussive action of the hammer bit (which is usually tipped with hardened tungsten carbide 'buttons') allows the rapid penetration of hard formations which may not be easily penetrated by the rotary method.

3.4 'CABLE TOOL' PERCUSSION DRILLING

A cable tool percussion rig operates by repeatedly lifting and dropping a heavy string of drilling tools on a cable into the borehole. The heavy solid steel drill bit on the bottom of this string mechanically breaks or crushes consolidated rock into small fragments. If water is present in the penetrated formation the crushed rock will form'slurry'; otherwise water must be added to the hole to create the slurry.

As drilling proceeds slurry accumulation increases and eventually reduces the percussive impact of the drilling tools. When the penetration rate becomes unacceptable, the slurry is removed at intervals from the hole by a sand pump or bailer. Bailers used to remove the slurry consist of a pipe with a simple check valve at the bottom, which is open as the bailer is dropped into the slurry, but closes as the baler is raised. A sand pump or suction bailer is fitted with a plunger so that an upward pull on the plunger tends to produce a vacuum that opens the valve and sucks sand or slurred cuttings into the tubing.

Although the cable tool percussion drilling method requires relatively unsophisticated equipment and is adaptable to varying geological environments (both soft and hard formations), it has the disadvantages that the penetration rate is generally slow (particularly in hard rocks). It may also be difficult to ensure a truly straight hole (due to the absence of a rigid drill string), particularly in hard fractured formations.

4.0 RESPONSIBILITIES OF THE SUPERVISOR

Drilling supervision may be defined as the continuous monitoring of the day-to-day drilling, test pumping and casting activities on a drilling site including “on-site” guiding of the drilling contractor in the order and implementation of drilling works

The Supervisor is the representative of the Client (or Employer) at the drilling or test-pumping site. In the context of this manual the Supervisor may be either an employee of GoSS, State or NGO, or an employee of a Consultant appointed to provide supervisory services.

The primary role of the Supervisor is to ensure that the works are executed in accordance with Conditions and Technical Specifications of the Contract. At the same time, the Supervisor must act in the best interests of the Client (or Employer) in order to achieve works completion within the budget and time approved. The Supervisor must thus make decisions on site that ensure professional workmanship to the highest standards, that minimise costs to the Client, that maximise efficiency of operation, and that wherever possible ensure a harmonious working relationship between the agreed parties.

4.1 SUPERVISION REQUIREMENTS

With respect to both drilling and test pumping supervision the output of the Supervisor is largely similar and should be adapted from the list below as necessary for each activity. Supervisor’s outputs shall be:

- Introduction of the Contractor to the community and indication of the exact location of the drilling site

- A Supervisors logbook with daily entries

- Completed forms: “Daily Log for Drilling Supervision” or “Borehole Pump Test Supervision”, for each borehole.

- Completed form “Check list for various materials to be provided by the Contractor during drilling, installation of casing and screen, development and test pumping” for each time drilling starts after demobilisation.

- Written site supervision instructions to the Contractor, especially in relation to decision of final drilling depth and installation of casing and screen

- A completed feed-back form comparing the drilling log with the geophysical survey

- A completed performance evaluation form when the drilling work has been completed

- Minutes of site meetings between Contractor, Consultant and Client staff

- Certification of Contractors borehole record

- Certification of Contractors monthly statements and verification of the contractors payment certificates

- A completion report covering a number of boreholes for a particular contract schedule

- A Certificate of Completion of Works

4.2 DUTIES AND RESPONSIBILITIES OF THE SUPERVISOR

The duties and responsibilities of the Supervisor shall also include, but not be restricted to, the following:-

- Issuing necessary instructions using a triplicate book. Copies must be filled in triplicates so that the Consultant keeps a copy of all instructions given, and one copy can be filed in the project file and the third copy is kept by the site supervisor. All instructions shall be clearly written, dated and signed.

- Be responsible for the decision on final drilling depth and borehole construction details including the placement of the lining materials during borehole construction.

- Monitor and supervise all drilling operations, construction supervision (whether temporary or permanent), borehole development and test pumping. Ensure that all operations are performed in a professional manner and to the best standard of workmanship, in accordance with the relevant clauses in the Contractors contract (Technical Specifications).

The supervisor should always have a copy of the Contractor's Contract on the drilling site.

- Fill in all pertinent data sheets showing operations, instructions, events and measurements, number of installed casings/screens, observations on penetration rate and geological conditions, test pump data etc. for documentation. Present the data sheets to the Project Manager at the completion of work at each site.

- Prepare "Daily Log for Drilling Supervision" and "Borehole Pump Test Supervision", for each borehole.

- If any incident takes place which influences the performance of work which is not in accordance with the specifications in the contract or the work plan, the Supervisor shall note this and ensure it is signed by himself and the Contractor. Subsequently, the Supervisor shall inform/consult the Project Manager of the incidence and any decisions made on site.

- Measure and inspect all borehole lining materials before installation to ensure that they meet the contract prescribed specifications, undamaged, with no deformations and are of correct dimensions. Inspect all filter pack before installation.

- At regular intervals inspect the Contractors base camp, the set up and all stored materials and satisfy himself that materials and storage conditions are appropriate and according to the contract. Upon abandonment of camp ensure that Contractors' clean up of the site is satisfactory. A copy of the inspection log (completed in triplicate) should be given to the contract every time this activity is carried out

- Participate in scheduled meetings as required by the either the Consultants' or the Contractors' Contract, normally every month, and prepare minutes of these meeting.

- Approve the Driller's reports. Verify and approve the Contractor's payment certificates and monthly statements for work done.

- Present a report on each group of boreholes drilled during a particular signed contract schedule.

- Complete the feed back form relating the information obtained from drilling to the information derived during the Hydrogeological and geophysical investigations.

- Prepare Certificate of Completion of Works

4.3 SUPERVISORS RECORDS

A series of records have to be kept and maintained by the drilling supervisor for the entire project time. These have been indicated above. However as a guide these are categorised as either;

- Supervisor's daily records;
- Supervisor's borehole technical records;
- Supervisors site records.

4.3.1 Supervisors Daily Records.

The daily records should be recorded on standard forms (see appendix). A copy of the supervisors daily records shall be made available to the client as and when requested and may include other data as may be requested from time to time.

The daily records must include the following;

- Site name;
- Site location (Village, Boma, Payam, County and State);
- GPS coordinates of site (preferably UTM zone, Easting and Northing);
- Date of reporting;
- Name of supervisor's representative;
- Name of contractor;
- Details of contractor's plant and equipment on site (after every 5 boreholes);
- Details of work completed by the contractor, especially time-based activities;
- Gender representation on site (number of women that visit the site);
- Participation of the community, if any;
- A copy of the supervisor's instructions to the contractor;
- Problem encountered/resolved.

4.3.2 Supervisors Technical Records

The technical records should be recorded on standard forms that constitute the drillers log (see appendix). A copy of the supervisors daily records shall be made available to the client as and when requested and may include other data as may be requested from time to time.

The daily records must include the following;

- Site name;
- Site location (Village, Boma, Payam, County and State);
- GPS coordinates of site (preferably UTM zone, Easting and Northing);
- Date of reporting;
- Name of supervisor's representative;
- Name of contractor;
- Depths/diameters (drilling);
- Materials installed such as casings, screens, gravel etc (drilling);
- Equipment installed such as pumps, rising mains etc;
- Lithology log (drilling);
- Penetration rate (drilling);
- Water strike/level/static water level/estimated yield (drilling);
- Discharge rate/drawdown (testing);
- Water quality (Conductivity/pH/colour/taste);
- Problems encountered/resolved.

4.3.3 Supervisors Site Record

The technical records should be recorded on standard forms that constitute the drillers log (see appendix). A copy of the supervisors daily records shall be made available to the client as and when requested and may include other data as may be requested from time to time.

- Site name;
- Site location (Village, Boma, Payam, County and State);

- GPS coordinates of site (preferably UTM zone, Easting and Northing);
- Village location map;
- A copy of the PRA map;
- Geophysical survey information and interpretations in an agreed format;
- Test pumping data in an agreed format;
- Water quality data in an agreed format;
- A water source location map (signed by the chairman of the WUC or member of the WUC. The land owner of the area where the final site is located should also sign;
- A copy of the technical record for the site;
- A copy of the supervisors daily record reports;
- Any other pertinent documentation relating to the site.

5.0 CONTRACT PRE-COMMENCEMENT CHECKS

5.1 ACCESSIBILITY

Before the drilling rig and equipment is taken to the selected drilling sites for the construction of boreholes, the following should be noted:

- The road tracks leading to the selected drilling sites should be repaired or cleared.

- Although trees and/or branches close to the roads should be cut so that there is no obstruction when transporting the equipment, the supervisor should ensure minimal damage to the environment.

- The Contractor and the Supervisor must inspect the roads and the selected sites to make sure that the drilling rig and all the equipment can reach safely.

5.2 SITE INSPECTION

Any site selected for drilling should always conform to the following:

- The ground around the site should be firm and solid for proper jacking up during rigging up.

- Sufficient space around the site should be cleared by the future water source users of any tree stumps and any other obstacles to the drilling rig and equipment.

- For safety precautions, the community around the drilling site should construct a perimeter fence with enough inside working space.

- The community near the drilling site should construct a temporary shelter. The shelter will act as a working place for the Supervisor and the Contractor and as a temporary store for the drill samples.

- Sanitation conveniences should be ensured near but not very close to the drilling site. These should be NOT less than 50m up-slope and 30m down-slope of the source under construction

- The Supervisor and the Contractor in consultation with the local authorities should select suitable areas for the Contractors mobile camp, which should be inspected at intervals to ensure adherence to environmental guidelines.

5.3 EQUIPMENT AND MATERIALS INSPECTION

The Contractor should submit a complete list of machinery and equipment to be used during the drilling program

All machinery and equipment provided by the Contractor must be inspected by the Supervisor and the Clients representative at the Contractor's yard at the start of the contract, and after every 5 boreholes. The purpose of the inspection is to verify the specifications and state of repair of all major items of drilling plant. Particular emphasis should be placed on the following: diameters and state of drilling bits; number, diameter and length of drilling rods and temporary casings, and state of repair of service trucks.

5.3.1 Some of the major items to be inspected should include the following:

i. Drilling rig (top head drive, air rotary percussion)
ii. Compressor (700 cfm or greater, truck or rig mounted)
iii. Support truck (at least one per drilling team)
iv. Water tank (truck or trailer mounted)
v. Light support vehicle (preferably 4WD pickup)
vi. Tricone roller bits (10 5/8")
vii. Drag bits (10 5/8″, 8″.)
viii. DTH button bits (10 5/8″, 8″, 6″, 4 ½″)
ix. Temporary casings (at least 8″ internal diameter)
x. Drilling rods - total length about 120m with max. diameter 4 ½″
xi. Grouting pump and accessories, including tremmie pipes.
xii. Hammers (to accommodate 8", 6" and 41/2" bits)
xiii. Borehole caps (wooden, plastic or metallic)

5.4 STAFF INSPECTION AND FAMILIARISATION

The Contractor should always introduce the drilling crew to the Supervisor. The staff should include the Driller himself, technician, helpers and camp attendants.

The Supervisor should inform the drilling crew about the whole programme and how it will be accomplished.

According to the locations of the selected sites, a drilling programme should be established by the Contractor in co-operation wit the Supervisor. This programme should be maintained for easy communication with the State RWD offices and/or NGO headquarters. Any change in the programme should be communicated immediately to the State RWD office or NGO headquarters via the Supervisor.

In the case of a Consultant supervised contract all formal communication from the Contractor to the Client (or the Employer) should be through the Consultant. Only the Client (or the Employer) is supposed to communicate with the public e.g. the press and Govt officials, about the whole exercise of drilling for that contract period.

All official communications across the parties should be in writing.

6.0 DRILLING SUPERVISION

Borehole construction can be divided into five main operations. These are:

- Drilling the hole,
- Installing plain and screen casings,
- Cement grouting,
- Installing filter pack,
- Installing a clay seal;
- Casting a sanitary seal;
- Developing the borehole to ensure sand and silt free water.

Supervision requirements for each of these operations are noted below.

6.1 BORE HOLE DESIGNS

Conventional drilling in Southern Sudan employs two basic design including;

- Design A
- Design B

6.1.1 Borehole Design – A

This includes boreholes that are drilled with a "telescopic design". In this kind of design, the diameters of the well decrease within increase in depth. In most cases, these boreholes are completed in "open-rock" designs with the final completion diameter is 4½″ for hand pumped boreholes and 6″ for production boreholes (Large diameter, high yield boreholes).

6.1.2 Borehole Design – B

This includes boreholes that are drilled and cased to the bottom. In this kind of design, the well diameters may differ but the final well diameter must allow for installation of 5″ for hand pumped boreholes and 6″ for production boreholes (Large diameter, high yield boreholes) up to the bottom of the well.

Because the borehole is cased to the bottom, this borehole design is most often referred to as "Shallow well design"

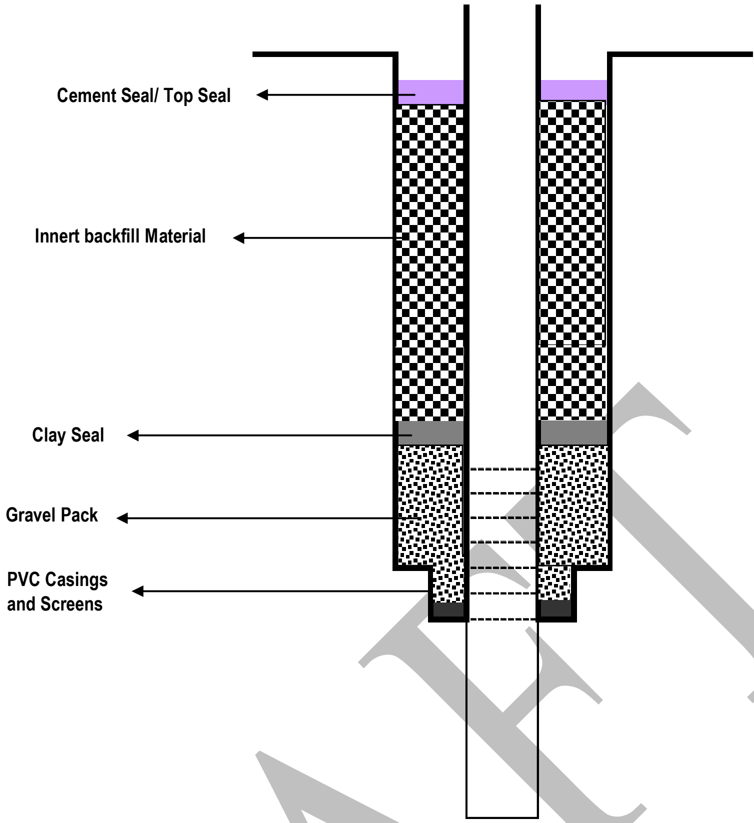


Figure 4: Schematised Borehole Design A

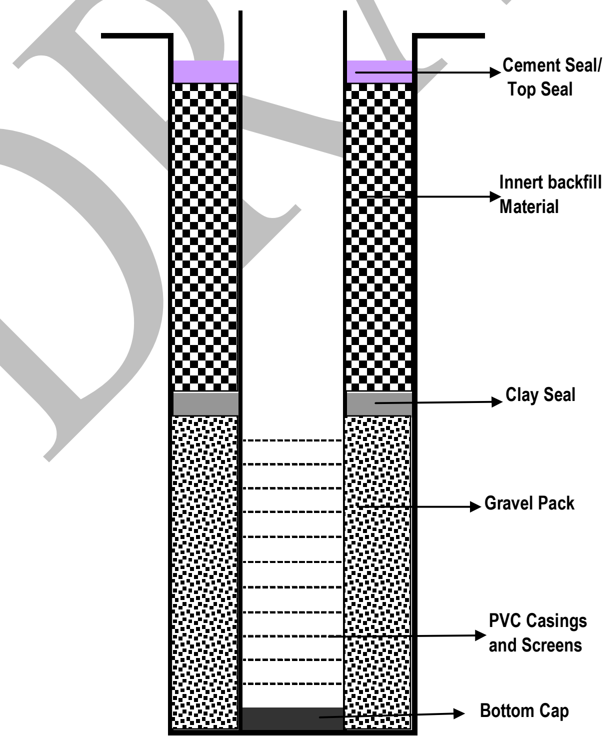


Figure 5: Schematised Borehole design B (Shallow well design)

6.2 INITIAL INSTRUCTIONS AT THE BEGINNING OF A HOLE

The Driller should be given instructions, which must be signed by both the Supervisor and the Driller, on the following:

- To drill the borehole at the exact locations where the peg was placed by the surveying Hydrogeologist.
- To align the machines properly during rigging up in order to drill a plumb borehole.
- To note date/day/time when drilling of the hole commences.
- To record all details on borehole location, and to enter all details of subsequent construction activities as they take place.

6.3 INSTRUCTIONS DURING DRILLING

- To drill through the overburden using either a drag bit or a 10 5/8″ DTH up to the hard weathered rock. If the formation is collapsing, to use foam (biodegradable polymer), or temporary casing, to stabilise the walls of the hole.

- When hard formation (rock) has been reached, to pull out the drill string and the 10 5/8″ bit. To drill 3.0 m into the hard formation using an 8″ diameter DTH bit, and then pulls out the drill string and bit.

- To install the 8″ internal diameter temporary casings to the bottom of the 8″ hole. This temporary casing should remain in place and only be retrieved during gravel packing process.

- In case a substantial amount of water has been struck, to install PVC casings and screens as instructed by the supervisor. This instruction will lead to borehole design B.

- In case little or no water has been struck, to drill 4-6 m into the hard formation using a 4 ½″ diameter DTH bit to prove that the formation is bedrock and not a hard band in the weathered zone.

- To continue drilling with the 4 ½″ diameter DTH bit to final depth. This instruction will lead to borehole design A

- To estimate the yield in m^3/h during drilling process every moment a noticeable increment in flow is observed/realised and during development. The estimation should be done using a calibrated bucket or standard discharge measurement equipment.

- To monitor drilling penetration rates and record any sudden changes in penetration rate and blowouts yield.

- To monitor daily drilling progresses and keep records. This should be done independently from the driller's log.

- To note daily drilled depth, first and main water struck depth at which diameters change, depth and length of screen etc.

- To note reasons for stopping drilling, reasons for shutting down of drilling rig should be adequately recorded with date and time. (e.g. breakdown of equipment, weather conditions or ground conditions etc).

As a guideline, the final depth of the borehole will depend on the following:

- If the Supervisor, based on observations during drilling and especially the airlift tests, feels convinced that the borehole will give a sustainable yield at 1000 l/hr., the drilling may be stopped.
- The drilling may be stopped if the Supervisor concludes that the probability of finding more water-bearing zones at greater depth is very low.
- The drilling should normally be stopped at the depth indicated in the borehole siting report, unless the yield is low and at this depth there is a clear indication that more water bearing zones may be found at greater depth.
- When deciding the final completion depth, the Supervisor should allow for 'sump' of 3 metres at the bottom of the hole.

6.4 OPERATIONAL GUIDELINES DURING DRILLING

The Supervisor should take note of the following operational guidelines during drilling, and should issue appropriate written instructions to the Driller as necessary. All items noted below form part of the Contractors obligations under his contract.

6.4.1 Formation Sampling

- The Driller should collect representative lithological samples of the strata penetrated for each change of colour or texture, or 1m interval, and in a continuous order. The Driller should always take every precaution to guard against sample contamination or mixing during the sampling process.

- The representative samples should not be washed.

- The Supervisor should do the geological logging of the lithological samples.

- The Driller should ensure that samples are put into suitable bags or tubes labelled with the following;
  - Location data;
  - Borehole identification number
  - Depth intervals, and stored such that they will not be contaminated by site conditions or drilling operations.

- Samples of each drill hole should be kept separately in sealed boxes and delivered by the Contractor to the government institution/ministry in charge in mineral development.

6.4.2 PVC Plain Casings (4″, 5″ Diameter or 6″ Diameter for Production Wells)

After drilling through the overburden (collapsible formation), if no substantial amount of water is struck PVC plain casings should be installed into the hard rock and grouting undertaken. Approximately 0.5 m of casing should be left above the ground surface.

6.4.3 PVC Screens (4″, 5″ Diameter or 6″ Diameter for Production Wells)

If enough water is struck in the overburden aquifers, PVC screens should be installed to tap this water. The casing string should have at least one plain casing at the bottom followed by the specified number of screens, with more plain casings placed at the top to prevent collapse of topsoil.

N.B. The Supervisor must always carefully record the number of PVC (plain casings and screens) used on each borehole.

6.4.4 Cement Grouting

With respect to this operation the following should be noted:

- Cement for mixing of slurry must be clean and free of lumps. If any small lumps are found in the dry cement, these must be sieved out.
- The cement slurry should be mixed in a clean and empty oil drum.
- The slurry should be prepared by mixing 24 litres of water per 50 kg of cement.
- Mixing should be done vigorously to obtain uniform slurry.
- The slurry (grout) should be injected into the annulus between the casing and the walls of the hole using a tremmie pipe. It is not acceptable for the Driller to pour the grout down the hole, as it may clog the screens and will probably not reach the bottom of the casing string as intended.

NB. The Supervisor should carefully record the amount of cement used on each borehole (in bags).

6.4.5 Gravel Packing

Gravel should consist of well-rounded particles of uniform grading and dependent on the screen slot sizes specified in the contract. The size of the gravel should be of uniform grading between 2.5 and 4.0 mm and shall comprise 90% siliceous material and must contain no clay, shale, silt, fines and excessive amounts of calcareous material or crushed rock. The following point should be noted:

- After installation of casings and screens and after grouting has been completed, the annular space between the sides of the drilled hole and the screens should be filled with gravel pack.
- Sufficient gravel pack should be placed against the screens i.e. from below the lowermost screen to above the uppermost screen. The gravel pack should extend to approximately 2 - 3 m or more above the uppermost screen to allow for settling during well development.

- The gravel pack should be capped with a clay seal (pure clay) to prevent contamination via the annular space.

NB Amount of gravel (in 100 kg bags) used on each borehole should be carefully recorded by the Supervisor.

6.4.6 Back-filling the Borehole

The annular space above the clay seal should be back-filled with inert drill cuttings. The top 3m of annular space should be left for sealing the borehole with cement slurry.

6.4.7 Well Development

The main objective of well development is to remove finer materials like native silts, clays, sand, drilling fluid residues deposited on the borehole walls during the drilling process from the borehole and immediate surroundings (gravel pack and the aquifer). The pack and the aquifer are cleaned and opened up so that water can flow into the well more easily. The following points should be noted:

- The well should be developed before the borehole is back-filled up to ground level. The reason for this operation is that the gravel pack around the screens will settle and become compact during development, and therefore more gravel has to be added up to the design level, before any other back-fill is put into the borehole.

- Development can be done by either of the following methods:

  - Continuous airlift until water is free from sediment OR

- Intermittent airlift development. The cycles to be determined depending on the rate at which water is clearing. Typical cycles are 10 minutes airlifting followed by 5 minutes recovery. Intermittent airlifting should be carried out until water runs clear to the satisfaction of the Supervisor.

- The Supervisor should always accurately record date and duration in hours for well developing. After well development, the plant can be rigged down.

6.5 INSTRUCTIONS AT THE END OF DRILLING

6.5.1 Sealing the Borehole

The upper 3m of the borehole annulus should be grouted with cement slurry to provide an effective seal against entry of contaminants.

6.5.2 Capping the Borehole

The borehole should always be capped with a wooden cap after well development. A borehole reference number should be marked on the borehole casing above the ground surface.

6.5.3 Clearing the Drilling Site

On completion of the construction of the borehole the site should be left clean and free from all debris, hydrocarbons and all sorts of waste. All dug pits should be filled with soil or murrum free of hydrocarbons. Only then can the drilling plant and equipment be transferred to the next drilling site on the programme. The shifting distance in kilometres between sites should be recorded.

6.5.4 Low Yielding and Dry Boreholes

Design-A boreholes (figure 4), with yields less than 300l/hr or which are completely dry should be back filled with native soil from the bottom to within 3 m from the ground. Two metres are then to be sealed by concrete, cement grout or neat cement, with upper 1 m of the borehole back filled with native soil.

Design-B boreholes (figure 5) are not to be back filled but should be capped whether they are low yielding or are completely dry.

7.0 TEST PUMPING SUPERVISION

For every successfully drilled borehole it is important to carry out test pumping. This will provide data on aquifer performance and the quantity of water that can be drawn out in a given time. The data is also used to determine the optimum depth at which to place the IMK2 (or IMK2-x deep) pump.

During test pumping a sample of water (1–2 litres) is collected and taken to the laboratory for analysis of physico–chemical properties in order to determine portability and acceptability.

It should be stressed that there are agreed water quality as well as quantity limits below which no installation of hand pumps is permitted.

7.1 TEST PUMPING PROCEDURES

7.1.1 Step Tests

Such tests are only considered viable or useful if the borehole indicates an airlift (Driller's) yield of greater than 1500 l/hr. In this case a step test comprising a minimum of 4 sequential steps with each step being of 60 minutes duration should be undertaken in order to determine well characteristics.

The Supervisor should set the range of discharges such that a reasonable spread of yields is obtained, with the first step being undertaken at the minimum acceptable hand pump yield of 1200 l/hr. for step tests, discharge rates are usually pre determined as multiples of the airlift yield,Q, (i.e, 1/3Q, 2/3Q, 3/3Q, 4/3Q, .. etc).

In situations where the above can not be attained, then the increment in discharge between the minimum and maximum yield should be at least 300% .The final draw down for the first step can be used in determining the optimum depth at which the hand pump (IMK2) should be set. Data from other steps at higher yields with greater draw down can subsequently be used to determine other borehole (and aquifer) characteristics.

The Supervisor must ensure that the Contractor records the initial test information and collects data during the test at the frequency required. The specifications for step testing should form part of the Contractors contract; if not, then data collection should be as per the form attached in the Annex to this manual.

The Contractor should also record water quality parameters (pH, Total Dissolved Solids and/or Electrical Conductivity) at least twice during each step, at 30-minute intervals.

7.1.2 Constant Discharge Rate

If the borehole indicates an airlift (Drillers) yield of less than 1500 l/hr, a constant rate test should be undertaken at a discharge close to this airlift yield, or at 1200 l/hr, whichever is the lesser. The length of the test should be as provided for in the Contractors contract, or for a minimum period of 3 hours. However, if draw down is minimal (implying that the Driller may have grossly under estimated the airlift yield), the Supervisor may consider repeating the test at a higher yield.

The Supervisor must ensure that the Contractor records the initial test information and collects data during the test at the frequency required. The specifications for constant rate testing should form part of the Contractors contract; if not, then data collection should be as per the form attached in the Annex to this manual.

Water quality parameters (pH, Total Dissolved Solids and/or Electrical Conductivity) should also be recorded by the Contractor at least twice during the first 60 minutes, at 30 minute intervals, and thereafter every 2 hours.

7.1.3 Recovery Monitoring Test

At the end of both the tests discussed above, the Supervisor should ensure that recovery monitoring is undertaken. This test also provides information on the production capabilities of the aquifer and acts as a back up where error may have occurred during the draw down tests.

The Supervisor should ensure that recovery measurements are taken for a minimum period of not less than 25% of the total pumping period, at the same frequency as during the draw down test.

7.2 PRE-TESTING CHECKS

The Supervisor must ensure that all the required equipment and tools are on site and in good working order before starting the test pumping. In addition, it should be confirmed that the Contractors technicians on site are the ones specified in the contract documents. Any staff alterations can only be made with the consent of the Client (or Employer).

A list of standard equipment that should be expected at a test-pumping site is presented below:

- Submersible pumps
- Riser mains (Pipes or horse pipe)
- Discharge pipe/horse (at least 100m)
- Adjustable valve
- Generator
- Fuel

- Tent (for long duration tests)
- Stop watch
- Calibrated discharge measurement container
- Water level meter (Dipper)

7.2.1 Pumping System

On the basis of earlier testing results, most of the aquifers to be tested have a yield in the range 0.5 m^3 /hr to 4 m^3 /hr. It is therefore important that the Contractor has on site suitable submersible pumps to accommodate these yields. A non-leaking valve system for adjusting discharge rate must also be available.

The riser pipes (or hose) for suspending the pump in the borehole should be long enough to install the pump at depth specified by the Supervisor.

The discharge (delivery) pipe should also be at least 100 m in length to ensure water is discharged at an adequate distance from the borehole.

A diesel/petrol generator able to reliably power the pump during tests without failure during the required pumping time. The generator should be filled with enough fuel to complete the test, preferably a full tank

7.2.2 Discharge Measurement

Calibrated containers should be available for measuring the rate of discharge of the water. For low discharges these should preferably be 10 or 20 litre buckets, with a drum of 100 or 200 litres for higher discharges.

An accurate and reliable stopwatch should be available for measuring the rate of discharge (time taken to fill a calibrated container), and to record time intervals for measuring water levels during draw down and recovery monitoring.

7.2.3 Water Level Measurement

An electric contact gauge incorporating an accurately calibrated measuring tape (accurate to 5mm) must be available for measuring the static water level, and for monitoring the dynamic water level during the draw down test and recovery monitoring.

7.2.4 Water Quality Monitoring

For regular measuring of the electric conductivity and pH of the discharge water (as per the test specifications), suitable portable digital meters should be provided by the Contractor. These meters should be reliable (good batteries) and should be calibrated prior to the start of testing.

To enable the collection of water samples for submission to the laboratory the Contractor must provide a suitable number of clean 1liter plastic sample bottles with tight fitting caps. The number of bottles will depend on the testing schedule, and any requirements for 'acidified' bottles will be as per set out in the Contractors contract document.

7.3 INSTRUCTION AT THE BEGINNING OF TEST PUMPING

On the basis of information obtained from the drilling reports and in accordance with the relevant clauses in the Contractors contract, the Supervisor should issue written instructions to the Contractor on site before commencement of the test pumping. Such instructions may be subject to modification during the course of the test, but any modification made by the Contractor must be with the approval of the Supervisor. Key instructions to be issued by the Supervisor at the beginning of a test should include the following:

- On arrival at site, the location details of the site should be entered on an approved test pumping data sheet.
- After removing the borehole cap, the static water level should be measured and recorded.
- The entire riser pipe and pump assembly should be examined to ensure all are securely connected, and then installed to a depth specified by the Supervisor.
- Immediately after switching on the pump, the gate valve should be adjusted to the specified discharge rate in less than 3 minutes. The initial discharge rates must be confirmed using the calibrated container.
- The step test should last at least 60 minutes each step, while the constant rate test should last at least 3 hours or until the Supervisor feels the dynamic water level has attained equilibrium.

7.4 INSTRUCTIONS DURING TESTING OPERATIONS

Additional instructions to be given to the Contractor during the course of the testing operations may include the following:

- The discharged water should be disposed of beyond the radius of influence of the test on the aquifer. The distance should be at least 100m from the borehole, but may be reduced or increased where deemed necessary by the Supervisor.

- Readings of the dynamic water levels should be taken in accordance with the time intervals specified on the test pumping test sheet. Each step during a step test should be recorded on a separate sheet.

- Electrical Conductivity and pH measurements should be taken periodically and whenever required by the Supervisor.

- Water samples should be collected as specified in the Contractors contract, or as required by the Supervisor.

- The Contractor should note any changes in watercolour, discharge rates and technical failures during the entire operations.

- The final step of the step test should not lower the final dynamic water level to less than 3m above the level of the pump.

- The pump should be switched off at the end of the final step, and monitoring of aquifer recovery should commence immediately. If feasible within the time allowed (i.e. 25% of the total testing time) the water level should recover to 95 % of the draw down before recovery monitoring is terminated.

7.5 INSTRUCTIONS ON COMPLETION OF TESTING OPERATIONS

After completion of the testing schedule at any particular site, instructions from the Supervisor to the Contractor may include the following:

- After recovery monitoring, the equipment should be taken out of the borehole with care to avoid the pump or pipes falling back into the borehole.

- The borehole capping should then be replaced and protective branches put around the borehole.

- The site should be cleared of any foreign materials introduced during the testing.

- Any water samples collected by the Contractor should be passed on to the Supervisor before the Contractor leaves the site. The Supervisor should then ensure that samples are delivered to the laboratory within 7 days of being collected.

8.0 INSTRUCTION DURING THE PLATFORM CASTING AND BOREHOLE INSTALLATION

Successful borehole development is concluded with platform casting and hand pump installation. This usually includes the above the ground concrete work activities as detailed below;

8.1 INSTRUCTION BEFORE THE PLATFORM CASTING OPERATION

- While on site, determine the best direction with a slope to allow free-flow (by gravity) of the water off the concrete works.
- Clear the area surrounding the borehole casing pipe that stands above the ground
- Excavate around the borehole casing pipe a pit of dimensions 0.5 X 0.5 X 0.5 meters.
- Place and setup the casting mould around the borehole as indicated in the appendix drawings.

8.2 INSTRUCTIONS DURING PLATFORM CASTING OPERATIONS

- Cut/trim the casing pipe such that not more than 0.5m of the pipe is above the ground surface level
- Place the pedestal in over the casing pipe in the excavated pit such that;
  - Parts of the pedestal including the three legs are in the excavated pit
  - The third leg of the pedestal is in line with the spout and are all facing the chosen spill way direction.
- Prepare a concrete mix with a ratio of 1:2:4 (Cement: Sand: Aggregate)
- Apply the concrete first to the pedestal stands/legs then latter all over the area covered by the mould down to the spill way
- Allow the concrete to set for at least 24 hours before removing the mould. Apply the fine cement slurry to give a final finish
- Allow the concrete to cure for at least 2 weeks while keeping the concrete works wet all day

NB: unless otherwise specified, no brickworks should be allowed/accepted during casting

8.3 INSTRUCTIONS ON COMPLETION OF PLATFORM CASTING AND HAND PUMP INSTALLATION

- Measure and record the SWL after 2 weeks
- Refer to the test-pumping data and determine the installation by using the relationship below;

Installation Depth, ID (m) = DWL (m) + 6

This relationship gives an ideal installation depth however; the actual installation depth should be in multiples of 6 because of the pipe lengths)

9.0 A PRACTICAL GUIDE TO CONTRACT MANAGEMENT

9.1 INTRODUCTION

In the context of overall contract management the role of the site Supervisor is extremely important. As noted earlier, the Supervisor acts as the representative of the Client (or Employer) at the site of works, either directly on the Clients' behalf or on behalf of a Consultant who has been engaged to undertake work and act for the Client. In this role the Supervisor is required to make decisions on behalf of the Client. These decisions should be in the best interests of the Client, but must also consider the interests of the Contractor and ensure a smooth and efficient completion of the works for which the Contractor has been engaged. It is essential, therefore, that the Supervisor establishes a good professional working relationship with the Contractor. The Contractor's advise and technical experience (which is often greater than that of the Supervisor) should be considered in the decision making process, and both Supervisor and Contractor should apply their skills together in order to successfully complete the work.

The essence of good contract management is to ensure that the terms of the contract signed between the Contractor and the Client (or Employer) are followed by the Contractor as well as the Client (or Employer) in relation to all matters. The quantity and quality of works and services, time tables and payments are all important. If the Contractor does not follow the contract, certain 'remedies' are available in the contract document that can be used to rectify the situation, or eventually to terminate the contract if necessary. Similarly, the contract also includes clauses that protect the Contractor if the Client (or Employer) does not follow the terms of the contract, or if circumstances that could not reasonably have been foreseen make it impossible for the Contractor to adhere to the intentions of the contract.

Virtually all contracts include a standard set of General Conditions of Contract, along with certain special conditions that are related to a particular contract. The Supervisor should become as familiar as possible with these conditions, as well as the actual technical specifications that the Contractor is required to follow. In the following sections, some of the key points in relation to the most common contract documents are outlined.

However, it is important to note that these guidelines do **NOT** constitute a contract document, and that the actual contract should be well known to and used by both the Contractor and Supervisor alike.

9.2 THE ROLE OF CONTRACTOR, SUPERVISOR/CONSULTANT AND EMPLOYER OR CLIENT

The **Contractor's** role is relatively clear: he is responsible for and has to carry out the works that he has contracted to undertake (siting, drilling, test pumping, installation etc). He shall follow the contract and instructions issued by the

Supervisor on behalf of the Client or the Consultant. He must not take instructions from any others, including from any other Client staff. The Contractor shall also only accept instructions from the Consultant which result in additional work if such instructions have been approved by the Client.

The **Supervisor/Consultant** is employed by the Client to manage the Contractors contract on behalf of the Client, whilst at the same time acing as much as possible as an impartial arbitrator to the Contract, between the Client (or Employer) and the Contractor. The Consultant is also expected to guide the implementation of the contract in relation to quality of work and financial issues in a professional manner, and to advise the Client when the need arises.

The Consultant normally delegates most of the daily supervision to a Supervisor. As previously discussed, the role of the Supervisor is to ensure that the Contractor follows the contract and to issue the necessary instructions and approvals to enable this to take place. If such instructions may result in expenses on the Contractors side which the Contractor did not and had reason not to anticipate, then the Consultant shall get approval in advance from the Client (or Employer). The Consultant shall then certify and the Employer pays such reasonable expenses. The Consultant also has the power to suspend the Contractors progress, but this is a serious issue and must be referred to the Client (or Employer) as in some cases the Employer may have to pay for the suspension. The Consultant shall also verify the Contractors progress reports and certify on behalf of the Client the payments to the Contractor.

The **Employer** or Client is the body that employs the Contractor to execute the required work under the terms and conditions of the contract. The person signing the Contract with the Contractor represents the Employer, but this role is most often delegated to other persons or bodies.

9.3 COMMENTS ON IMPORTANT CONTRACT CLAUSES

- **Approval in writing**

"Approved" means approved in writing. It is therefore crucial that all approvals are given in writing - as well as instructions and other communication in general.

- **Supervisor**

The Supervisor shall generally check that the construction work is carried out in accordance with the contract, in particular the Technical Specifications. The Supervisor must therefore have a copy of the contract on site in connection with the supervision and be familiar with all details of the contract. The Contractor is obliged to follow instructions from the Supervisor. All instructions shall be given in writing.

- ❖ **Use of Sub-Contractors**

The Contractor needs a written approval from the Employer (sought via the Consultant, if appropriate) before he can assign a Sub-Contractor. If the Contractor has assigned a Sub-Contractor without obtaining such approval, he should be instructed in writing to stop the Sub-Contractors work until he has obtained such approval. Approval of sub-contractors should only be given if assignment of the Sub-Contractor is considered advantageous to the programme.

- ❖ **Clause A: Contractor's Superintendence and employees**

The representative undertaking the Contractors superintendence must be identified. The Contractors superintendent must be capable of ensuring the necessary quality of the works as well as the necessary progress. Should this not be the case, the Supervisor should make a report to the Client, or the Consultant as the case may be, who may request that the employee be removed with reference to Clause …..

- ❖ **Clearance of Site on Completion**

The Contractor has to leave the site clean when the works have been completed and shall be instructed to do so if cleaning has been unsatisfactory.

- ❖ **Clause B: Work Materials and Plant - Basis for Supervision**

This gives detailed specification of the basis for the supervision. Important details are:

- The work shall be in accordance with the contract and the Supervisors instructions.

- The Supervisor is allowed to perform tests on the works, and the Contractor shall assist and under certain conditions pay for tests to be performed.

- The Supervisor shall have access to all areas where work is performed, and can request that parts of the works are uncovered for inspection.

- The Supervisor can instruct the Contractor to remove and/or replace materials and or personnel which are not in accordance with the contract, as well as to remove and re-execute work which "in respect of materials or workmanship is not in accordance with the contract". If the Contractor fails to do so, then the Employer can employ and pay other persons to do this, and deduct the corresponding amount in the payment to the Contractor.

- The Supervisor may suspend all or parts of the works, but under certain conditions the Employer will have to pay the Contractor for the costs in connection with the suspension.

- **Clause C: No Night or Sunday Works**

The Contractor can only work at night or on Sundays if the Supervisor who shall supervise the work has approved this.

- **Clause D: Plant and materials only to be used for the Works**

According to this clause, the Contractor is not allowed to use any type of equipment or materials used on the contract on other works unless the Client has approved this. For example, he may not drill a private borehole, even on a Sunday, with a drilling rig that is being used on the programme.

- **Clause E: Measurement and Payment**

The Supervisor should have carefully checked the quantity as well as the quality of the works in connection with his supervision, before payment is certified. Payment shall not be made for works not carried out, or work not made in accordance with the contract. Parts of the works, e.g. drilling boreholes, are generally required to be completed totally and satisfactory before they can be paid.

Retention money shall be deducted from each certificate with the percentage indicated in the Form of Tender, until the Limit of Retention Money indicated in the Form of Tender has been reached. This Retention money shall be paid when the Period of Maintenance, including all repair works, has been completed and the Maintenance Certificate has been issued.

It is crucial that the Contractor is paid timely. The result of a late payment can be that the Contractor can claim interest, as indicated in clause ….. It is advisable that the Client (or Employer) should therefore give timely payment a very high priority.