Rural Water Supply Network

Field Note No 2012-2

Dotun Adekile

2012

Supervising Water Well Drilling

A Guide for Supervisors

Summary

Good supervision of water well drilling is essential for the provision of long-lasting water wells. This guidance note assists geologists and engineers in charge of the supervision of borehole construction as well as project managers. It can be used to prepare for training, and as a manual.

This guide details the responsibilities of the drilling supervisor at the different stages of borehole construction. It explains the actions to be carried out at each stage that will ensure that the driller delivers the borehole as specified in the contract.

The supervisor is expected to display great professionalism in carrying out his or her duties. A good knowledge of geology, hydrogeology and borehole construction is essential. Although the supervisor represents the client, he or she is expected to act with honesty, impartiality and fairness in any dispute over the contract. Young drilling supervisors need to be supported by more experienced personnel.

The publication part of a series by RWSN on Cost Effective Boreholes alongside:

- Code of Practice for Cost Effective Boreholes (Danert et al, 2010)
- Sustainable Groundwater Development: use, protect and enhance (Furey, 2012)
- Siting of Drilled Water Wells: A Guide for Project Managers (Carter et al, 2011)
- Costing and Pricing: A Guide for Water Well Drilling Enterprises (Danert et al, 2010)
- Procurement and Contract Management of Drilled Well Construction: A Guide for Supervisors and Project Managers (Adekile, 2012)

It is assumed that readers will have access to the other documents, all of which are available on the RWSN website http://www-rural-water-supply.net.

Contents

Introduction

There is currently a big push to meet the Millennium Development Goals target for drinking water. Soon the world may be talking about universal access. Whilst this is positive, it is important that quality is not compromised in the drive to serve more people. A poorly constructed borehole can fail after one year, resulting in wasted investment and disappointed users. If drilling and construction are not adequately supervised by trained professionals, corners may be cut, quality will be compromised and services will fail. Governments, NGOs and agencies have a responsibility to ensure that quality is not compromised by a lack of drilling supervision.

Groundwater sources, namely wells and boreholes, are often the first choice of water source for supplying rural areas. It is estimated that 1.25 billion people directly use boreholes for their drinking water (WHO/UNICEF 2012). If one assumes that 40% of the sources for drinking water through piped supplies are from boreholes, then 2.9 billion people (42% of the world's population) depend on drilled water wells. Groundwater sources are found in most places and are relatively easy and cheap to install. They are also not as prone to pollution as other sources of water.

It is crucial that boreholes are delivered in a cost effective manner. Cost effectiveness means getting the long-term best value for money invested, i.e. boreholes continue to function through the lifespan of 20 to 50 years. In some African countries, as many as 60% of groundwater sources are not working. Poor borehole construction contributes to this alarming figure. One of the best ways to tackle this problem is to improve the quality and professionalism of water well drilling including supervision.

Box 1: Why is good supervision important?

Abuja, Nigeria: The expected drilling depth was 35m. The Supervisor was late to site. When he arrived the driller was already at 60m depth, claiming little water was encountered at 35m and he had to continue. It was obvious he was only doing it to earn more metres, but it could not be proven. The clause in the contract that drilling should not commence without the Supervisor on site could be invoked but as a one-off case, the Driller's claim was accepted. Conclusion: the Supervisor should not keep the driller waiting.

Lagos, Nigeria: A telescopic design was specified. A large-diameter hole was drilled, cased and grouted in, and then drilling through the grout was performed with a smaller diameter *bit*. The grouting failed, and an eruption of sand and water occurred. Two truck-loads of sand were carted away from the site. The Driller said he was not used to the method specified and he would have used another method to achieve the design. A senior hydrogeologist in the Ministry of Water Resources was asked to arbitrate. He blamed the Supervisor for not using a pre-contract meeting to establish the ability of the Driller to execute the design. He blamed the Driller for not proposing a method within his competence. Conclusion: establish a common understanding with the Driller, in writing, before drilling starts.

In 2010, the Rural Water Supply Network (RWSN) published the Code of Practice for Cost Effective Boreholes based on international best practices. The Code of Practice focuses on nine principles (Box 2). These enable international organisations, private enterprises and NGOs to evaluate their approach to borehole delivery in accordance with good international practices. To strengthen the *Code of Practice* and support practitioners in the practical application of the principles, RWSN is publishing detailed guidance documents to cover all the principles.

This guidance note is part of the series and focuses on Supervision, which falls within Principle 6, which recommends that "*Supervision should be undertaken by government personnel or by the private sector; additional expertise can be brought in to cover capacity gaps with a view to build up long-term expertise*". RWSN identified that there is a capacity gap in water well drilling supervision. Hence this guide is aimed at inexperienced drilling Supervisors e.g. fresh geology and engineering graduates, general technicians and project managers. By applying this guidance, the reader should be able to reduce overall drilling costs, improve the quality of the finished borehole, and create a useful set of written records that will help rural water supply service managers operate and maintain that water source for many years.

To get the most from this guide, the reader should have a good knowledge of groundwater occurrence and drilling practices, and use the guide in conjunction with the other *Code of Practice* publications (listed in the summary on page 2). Note also the glossary of technical terms (page 17), *italicised* in the text.

Box 2: Nine principles of Cost Effective Boreholes

1	**Professional Drilling Enterprises and Consultants** - Construction of drilled water wells and supervision is undertaken by professional and competent organisations which adhere to national standards and are regulated by the public sector.
2	**Siting** - Appropriate siting practices are utilised and competently and scientifically carried out.
3	**Construction Method** - The construction method chosen for the borehole is the most economical, considering the design and available techniques in-country. Drilling technology needs to match the borehole design.
4	**Procurement** - Procurement procedures ensure that contracts are awarded to experienced and qualified consultants and drilling contractors.
5	**Design and Construction** - The borehole design is cost effective, designed to last for a lifespan of 20 to 50 years, and based on the minimum specification to provide a borehole which is fit for its intended purpose.
6	**Contract Management, Supervision and Payment** - Adequate arrangements are in place to ensure proper contract management, supervision and timely payment of the drilling contractor.
7	**Data and Information** – High-quality hydrogeological and borehole construction data for each well are collected in a standard format and submitted to the relevant government authority.
8	**Database and Record Keeping** - Storage of hydrogeological data is undertaken by a central Government institution with records updated and information made freely available and used in preparing subsequent drilling *specifications*.
9	**Monitoring** - Regular visits to water users with completed boreholes are made to monitor functionality in the medium as well as long-term, with the findings published.

Principles of Drilling Supervision

Aims, Roles and Responsibilities

The aim of supervising borehole drilling is to ensure that boreholes are produced as designed and all the data collected during the drilling are accurately recorded and reported to the relevant agencies. Good supervision is essential for a high quality borehole, even if a competent drilling contractor (henceforth referred to as the 'Driller') is employed. Without good supervision, the quality of the work may be compromised. An experienced Driller can easily hoodwink an inexperienced Supervisor. Supervisors thus need to be trained and given the chance to acquire the knowledge that will enable them carry out their duties.

Box 3: Drilling Roles and Responsibilities

The **Community** members are the end users of the water supply. They must be included in the process of siting and design so that the finished water point can meet their needs. There are cases where the Community is involved in supervision, but they should not be responsible for technical or contractual details unless their capacity has been built extensively.
The **Client** is the organisation or community that is contracting out the borehole construction. Their responsibility is to fulfil regulatory requirements and ensure that they have well trained Supervisors present on site for the full duration of drilling operations.
Note that even if **district local government** is not the client, it is still important for them to be involved in the process. District local government should attend the pre-mobilisation meeting as well as the end of construction supervision.
The **Funding Organisation** pays for the borehole. It may be the Client, or another organisation such as an international development partner or NGO. The funding organisation should not impose conditions that create perverse incentives or undermine the long-term sustainability of the finished borehole (e.g. by insisting that the cheapest bid is accepted regardless of quality). It should work within national or local government systems.
The **Regulator** issues permits or licences for drilling or abstraction. Legal requirements should be established by the Client early on to avoid delays.
The **Project Manager** is usually responsible for a wider project. The drilling will be just one component within a project plan comprising community training/mobilisation, pump technology choice, water point design and construction, and establishing or strengthening a rural water supply service.
The **Supervisor** is sometimes called the 'Rig Inspector'. Supervision is usually done either by the Client's staff or by a consultant. The Supervisor may be a hydrogeologist, an engineer, or a technician. Although the Driller and the Supervisor work together to deliver the product, their roles are different. The Supervisor's responsibility is to ensure that the Driller adheres to the *technical specification*, makes all the required measurements, keeps all records accurately and ensures that health and safety procedures are adhered to.
The **Driller, or Contractor**, is the organisation that physically does the drilling. Sometimes, this will be an independent private sector company. In other cases, it will be an in-house team working for a government agency or NGO. The Driller's responsibility is to drill the borehole as specified. Each Driller should have a designated 'Record Taker' who should remain on site at all times, with the duty to collate all the measurements and complete all the forms.

Levels of Supervision

There are three levels of drilling supervision:

1. **Full-time supervision:** a Supervisor stays with the drilling team throughout the drilling process, from the inspection to *demobilisation*. On large drilling programmes with multiple rigs, several Supervisors are deployed, and they stay in the Drillers' camp and go out with them each morning. While this supervision level is ideal, the resources needed are not always available.

2. **Part-time milestone supervision:** one Supervisor is in charge of several drilling rigs and may only witness crucial stages (milestones) of the drilling. The stages that must be carried out in the presence of the Supervisor need to be specified in the contract document and the consequences of not abiding by them stated. However, the Supervisor is expected to be promptly on site and should not cause undue delays. The milestones are:

   - *mobilisation*
   - check siting/site selection
   - termination of drilling
   - lining of the borehole
   - borehole development
   - pumping test
   - *demobilisation*
   - platform construction and pump installation (may be delegated, depending on contract).

The 'Record Keeper', one of the Driller team (Box 3) plays a very important role. He/she is designated to collating the measurements and preparing the forms at all stages of the process set out in the milestones above. This role should be specified in the contract documents.

Figure 1: Some kit – depth meter, electronic dipper, tape, EC and PH meters, Global Positioning System (GPS)

3. **End of contract supervision** is not actually supervision but a site inspection when the Supervisor goes through the records and inspects the functionality of the borehole on completion. Where this is the planned level, the supervising role of the community members is particularly important (Section 2.3). As in the case of part-time supervision, the role of the 'Record Taker' is also very important.

In all cases, the Supervisor requires a minimum level of equipment (Box 4) and needs to issue site instructions (Box 5).

Box 4: Supervisor Equipment

Vehicle: Ideally, the Supervisor should be independent. However, this may not be possible, in which case the Driller provides transport to and from the site.

Down-the-hole camera: useful for preventing arguments about casing lengths. In one example, a Supervisor carried out a camera survey of several boreholes on a project. The Driller had hurriedly drilled the boreholes not allowing any supervision. Several of the holes were found to be open holes whilst it was specified that they be lined. He had to re-drill them. Cameras are getting cheaper. Every project should have one.

Other: Boots; hard-hat; clipboard; notebook; duplicate book; digital camera; *global positioning system (GPS)* device; mobile phone; caliper; spirit level (for checking verticality of drill mast and pedestal as well as slope of run-off drains); dip meter; measuring tape; simple calibrated V-plate for measuring borehole yield, magnifying glass; stop watch; pH stick meters and calibrants; iron-checker disc and reagents; bottle of hydrochloric acid if limestone is predicted and a first aid kit.

Box 5: Site Instructions

The technical specification for the borehole should include the procedure for site instructions and the consequences for not abiding by them. Site instructions issued to the Driller by the Supervisor should be in writing in duplicate using carbon paper. The Driller should sign on the original and the duplicate instructions. The original is handed over to the Driller, and the Supervisor keeps the duplicate.

Community Involvement

Whichever level of supervision is adopted it is essential that community members are involved in the entire drilling process. This should foster the spirit of ownership and understanding of post-construction operation and maintenance. The need for this is even greater when either part-time supervision or end-of-project inspection is used.

Prior to the Driller's mobilisation or at the initial stages of the borehole construction, selected community members (school teachers, health workers, water users' association members) are taken through the drilling process and are taught how to:

- take the required measurements and record observations;
- keep daily records such as start and end times of drilling and any breaks, and the reasons for them;

- determine depth of drilling by counting the number of drill pipes lowered down;
- record depth and time of the first *water strike* and other strikes when drilling with air;
- count and record the length and number of casings and screens installed;
- count the number of bags of cement used;
- observe the installation of gravel and the sanitary seal, test pumping and whether borehole chlorination is undertaken.

From the information provided by the community supervision, the Supervisor can build an accurate account of the drilling progress which he/she can cross-check with the driller's daily log.

What can realistically be expected of the community will depend on their level of literacy and numeracy, too. It should also be clear that community involvement can never replace an experienced supervisor.

Borehole Construction Workflow and Steps

Figure 2 shows the borehole construction workflow and the responsibilities of the Driller and Supervisor at each step. This document is structured according to these steps. For each stage, a checklist for the Supervisor has been prepared (Annex B).

Figure 2: Borehole Construction Workflow

Steps in borehole construction	Driller's responsibilities	Supervisor's responsibilities
1. Inspection	Assemble equipment & personnel for inspection.	Inspect equipment and interview personnel.
2. Siting	Hydrogeological survey; geophysical survey; submit report.	Check equipment; provide guidance on siting borehole; approve siting report.
3. Pre-Mobilisation Meeting	Raise specific questions regarding the contract requirements.	Together with the client, thoroughly discuss the design, materials and procedures for each step of the contract.
4. Mobilisation	Submit program of work; submit samples of materials; move equipment to site.	Liaise with the community; approve drilling equipment & material; guide driller to site.
5. Drilling	Position and operate the rig; collect samples; report.	Monitor drilling; advise depth to stop drilling; log the borehole.
6. On-site Design Modifications	Install casing and screen; gravel pack; sanitary seal; report.	Instruct screening and casing depths; ensure gravel pack and sanitary seal properly placed.
7. Borehole development and site completion	Develop the hole; undertake test pumping; collect water sample; disinfect the hole.	Ensure water is clean; proper disinfection; supervise pumping test; ensure samples are taken and platform installed.
8. Demobilisation	Remove all equipment and rubbish from site; report.	Ensure the site is restored to its former state.
9. Complete documentation and handover	Submit all records. Hand over.	Hand over borehole to community. Report.

Step 1: Inspection

Aim: To verify the capabilities of the Driller BEFORE a contract is signed.

A pre-qualification inspection of equipment and personnel may be carried out as a pre-requisite for eligibility to tender, or as part of the tender process. This may be undertaken by the client, or a Supervisor may be engaged for this. It is essential to agree a date with the prospective Drillers. Minimum requirements vary from country to country, but Table 1 provides a list of essential equipment and personnel the Driller should have for a contract package of 10 boreholes from Nigeria. Supervision Checklist 1 (Annex B) shows the main aspects for inspection.

Where the Driller is required to carry out the geophysical survey for the siting of the boreholes, his capability for such surveys has to be determined. If the Driller proposes to employ a consultant to carry out the siting, the availability of the consultant should be confirmed and the equipment inspected and tested. The Driller's personnel or consultant should be a qualified hydrogeologist or geophysicist. Depending on the specification for the siting, the Driller should have a resistivity and electromagnetic meter, a *global positioning system (GPS)* and appropriate software for data interpretation. The sources of remote sensing tools, maps and existing borehole data should be confirmed.

When the Driller has been selected and the contract awarded, prior to mobilisation, the Driller should be asked to confirm the availability of the approved items of equipment

Table 1: Example of basic equipment and personnel required for a project of 10 boreholes

Type of Equipment	Personnel
1 drilling rig	1 drilling manager
1 *compressor*	1 hydrogeologist
1 mud pump	1 rig operator
1 water tanker	1 driver
1 support truck	1 mechanic
Adequate lengths of drill pipes to drill the deepest hole	3 rig assistants
Drill bits of the right diameter	
Casing, gravel and filter pack, drilling mud	

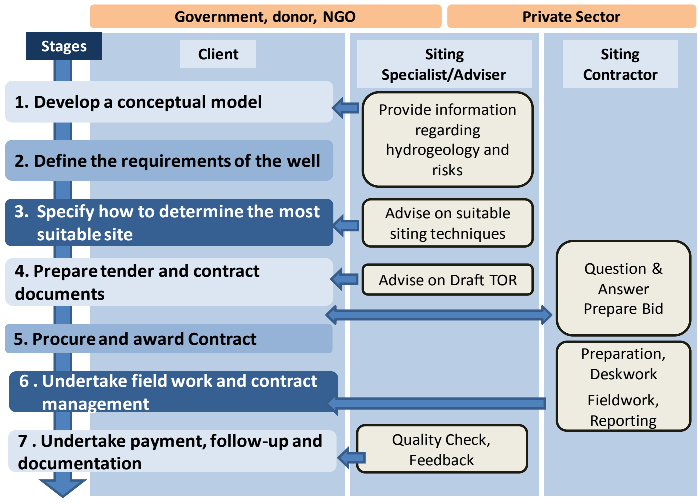
Step 2: Borehole siting

Aim: To ensure that the borehole is drilled in the right place so that it has water that is accessible to users and protected from pollution.

The Supervisor should refer to RWSN Publication 2010-5 *Siting of Drilled Water Wells: A Guide for Project Managers*, which provides details of the procedure for borehole siting. Checklist 2 (Annex B) highlights the areas that will require particular attention from the Supervisor.

Site Survey: A survey of the community or project area should have been carried out before the commencement of the project and the estimated drilling depth in the *Bill of Quantities* based on the depth indicated by the siting survey. The potential borehole sites should be marked and shown to the Community. Some communities have areas of cultural and religious values or sacred ground which should be avoided. The Drillers are responsible for siting the borehole if the contract does not pay for dry wells, the so-called "no water no pay" approach, in which case they should follow steps 1 to 3 in *Siting of Drilled Water Wells* (Figure 3).

Figure 3: Work Flow for Water Well Siting



Water Source Protection: When the Supervisor, Community representatives and landowners walk over the project area identifying suitable borehole sites, the areas of potential pollutants such as pit latrines, burial grounds, refuse dumps, fuel and lubricant depots should be identified. Main roads, animal kraals, power-lines also need to be considered, as well as the vulnerability of existing water sources such as private wells (see Carter et al, 2010). Table 2 gives some guidelines on the minimum distance of a borehole from existing structures. Such guidelines should exist for each country, and perhaps even for specific ground conditions. However, it should be remembered that where *aquifer* risk is low, i.e. the surface is impermeable and the *aquifer* confined, distances from potential pollution sources to the borehole can be less. If the best site identified is near a pollution source, such as a latrine, then look at options for moving it away from the proposed borehole.

Geophysical Surveys: Where the geophysical survey is carried out by the Driller, the Supervisor should witness the geophysical measurements and make sure that the equipment is working and the readings taken are accurate so that it is not just, as described by one water user: "*a ceremony of laying the cables*".

Sites identified for drilling are marked with painted wooden pegs or piles of stones and shown to the Community representatives. Three such sites should be identified in each community and numbered in the order of priority. The Driller should submit a report with the GPS coordinates of the sites and a community map identifying the sites.

Once the Supervisor is satisfied that the Driller has diligently carried out the survey to find the best sites, he/she approves the report and gives permission to start drilling.

Box 6: What happens if a suitable site for a borehole cannot be found?

A perfect site would have favourable hydrogeology, no nearby pollution threats, available land, and good access for the Drillers and water users. However, this often does not happen, and if no acceptable site can be found, then other sources of water will have to be sought by the Project Manager with the Community.

Table 2: Borehole distance from existing structures (adapted from FGN/NWRI, 2010)

Existing structures	Minimum distance (m) from borehole
Water supply boreholes	50
Hand-dug well	20
Other existing water wells	10
Septic tank/soak away	20
Streams, canals, irrigation ditches	20
Buildings	3
Approved solid waste dump and burial ground	1,000
Coastline	not normally within 1,000 meters

Step 3: Pre-Mobilisation Meeting

Aim: To ensure that the Driller and Supervisor are fully aware of their exact roles and responsibilities and contract details.

Once the contract has been signed, and prior to mobilisation, a meeting between the Client, Driller and Supervisor is essential. At the meeting, all three parties go over the design, materials and procedures for each step in the contract. Roles and responsibilities need to be clarified in detail. This provides an opportunity for any ambiguity to be resolved and the contract amended as necessary.

However, many Drillers do not read the contract, but simply add their prices into the *Bill of Quantities*. The pre-mobilisation meeting ensures that everything set out in the contract is clarified verbally, thus preventing conflicts while on site. Without this, there is always a danger that the wrong equipment or inferior materials will be taken to site, and the Supervisor compromised due to time-pressure.

Step 4: Mobilisation

Aim: To take the drilling project from contract signing to deployment of the drilling crew on site

Checklist 3 (Annex B) sets out the main aspects of this step, starting with liaison and ending up on site. Mobilisation includes the following activities:

1. **Contract:** All borehole projects and supervision are based on a contract agreement. Once the contract has been signed, and pre-mobilisation meeting held (Step 3), the mobilisation phase starts. Procurement and contract management aspects are covered in Adekile (2012).

2. **Programme of works:** The Supervisor should discuss the *technical specifications* and drilling procedure with the Driller, and discuss and agree the target depths. Then the Supervisor should ask the Driller to submit a programme of works. An example is shown in Table 3.

Table 3: Example of Program of Completing Drilling Works for a 5-borehole package

Description	Weeks									
	1	2	3	4	5	6	7	8	9	10
Mobilisation	■									
Borehole siting	■	■								
Drilling, lining & development										
Communities 1 & 2			■							
Communities 3 & 4				■						
Community 5					■					
Pumping test & water quality analysis					■	■				
Pad construction							■	■		
Pump installation									■	■
Demobilisation										■

3. **Community liaison:** It is essential that, before the Driller arrives on site, the Supervisor or Project Manager has had several discussions with the Community about the project and details of the drilling process and their expected obligations and contributions with the main contact persons or Community representatives. The Driller's representative should meet with the Community and agree a start date.

4. **Equipment check:** The equipment that is to be used by the Driller should be checked to make sure that it is all in working condition, and the same as, or equivalent to, what was examined in the inspection step.

5. **Materials check:** In some contracts, the suppliers, manufacturers, or sources of the material to be used, such as *drilling fluid*, *casing* and *screens*, are specified. The Driller should submit samples of the materials for the Supervisor's approval. The slot size and wall thickness should be checked, for example.

Figure 4: PVC screen (left 0.75mm slot, right 1mm slot)

6. **Data collection forms:** The format of drilling data collection to meet the contract requirements should be agreed on. Templates are provided in Annex E of the Code of Practice for Cost Effective Boreholes (Danert et al, 2010). The final version for copying will be agreed on site between the Driller and Supervisor, and signed by both parties once all the stages of the contract are completed.

7. **Project filing system**: Most of the data could be stored electronically, but hard copies are required for field use. A file (in duplicate) should be opened for every community and all records and data for the community stored in the file. Checklists for all stages of borehole construction (Annex B) are printed inside the flap of the folder and ticked as construction progresses. The original is kept in the office and the duplicate in the *Drill Camp* or site office.

8. ***Drill camp* layout:** On large projects where a *Drill Camp* is set up, the Driller should submit a drawing of the camp layout for approval. The main consideration in approving the plan is safety and sanitation: inflammable items should be kept away from likely sources of heat and fire; potential contaminants from water-supply sources and cooking areas; and PVC casing and screens are protected from direct sunlight, which makes them brittle. Where the project covers a large area, *Satellite Fly Camps* may be needed in the more remote parts to reduce the travelling time to a cluster of borehole sites. The same criteria as for the approval of the *Drill Camp* plan apply.

Once all the above have been completed and approved, the Driller and the Supervisor are ready to move to site.

Step 5: Drilling

Aim: To ensure a high-quality borehole is drilled in a way that is safe and well-documented.

Checklist 4 (Annex B) should be used once the Driller has reached the project site. The following aspects are critical:

1. **Safety:** Drilling is a very hazardous activity. Safety of the workers on site is absolutely vital. Responsibilities for ensuring safety should be clearly set out in the contract. The Supervisor must be constantly vigilant to prevent accidents, and to minimise injuries should accidents occur. The Supervisor should look after his or her own safety and be aware of risks to the Driller's crew and the public. A drilling operation is a novelty, and it quickly attracts a crowd, particularly children. Spectators should be kept behind a clearly defined barrier where they cannot be struck by falling objects, such as a drill pipe, or a hose breaking loose from a *compressor* or mud pump - which could be fatal. A community representative can be asked to support the process of policing the barrier tape. The Supervisor should have at least basic first aid training and medical aid kit.

Figure 5: Poor Safety – No Hard Hat – No Clearly Defined Barrier

2. **Rig position:** It is essential that the rig is horizontal and the mast vertical, otherwise a bent hole may result. Verticality of the drill pipe should be checked with a spirit level. The rig should be jacked on a robust wooden block so that verticality remains throughout. The rig should be positioned exactly over the pegged site. This is particularly important when the siting is undertaken by a consultant employed by the Client rather than the Driller. If the borehole is dry, there can be no argument that the borehole was not drilled on the specified location.

   The Driller should ensure that the weight on the drill string is adequate to maintain a straight hole. The use of a heavy drill collar is recommended on at least the first three metres of length behind the hammer. The first drill rod could have welded wings, adding weight as well as scraping to get a circular, straight bore. Also, the Driller should not drill with too much pull-down on the rods.

3. **Monitoring drilling depth:** The Supervisor needs to know the depth of the *drill bit* at all times to ensure that proper data logging is being done, to know the depth at which to tell the Driller to stop and to compare the drilled depth with the depth recommended in the contract. An unscrupulous Driller can try to rip off the Client either by drilling excessively deep, or by pretending that the borehole has been drilled deeper than it actually has. Box 7 describes measuring methods. The Record Taker (Box 3) should be taking notes at all times, in conjunction with the drilling depth.

Box 7: Measuring Drilling Depth (Adapted from Ball 2001)

The drilling depth can be monitored by measuring the length of the drill pipe and multiplying the number of full pipes that have gone down into the hole.

Chalk or grease can be used to mark the drill pipe: with the drilling rig set up with the first length of drill pipe and *bit* fitted, the *drill bit* is lowered to the ground. The drill pipe is marked "0" at the *rotary table* that centralises the drill-pipe, and then chalk marks are made at 1m intervals up the drill-pipe, numbering the marks from 0 upwards. Measured chalk marks are then made on subsequent drill pipes to be added. This procedure allows anyone on the drill team to know at a glance the exact depth of the *drill bit* from the ground surface. Note that if the hammer is changed to a longer one after drilling has commenced, the pipes will need to be remarked.

Figure (above) Drill-rod marking so that samples, penetration rates and air-lift yield can be accurately recorded

4. **Penetration rate:** This is the time taken to drill a particular interval. A fast penetration rate can indicate an *aquifer*, although this is not always the case. Less porous strata, such as fresh granites, are often slower to drill through.

5. **Drilling fluids & air-lift yield:** *Drilling fluids* are used to remove cuttings from the borehole and to stop the hole collapsing during drilling. The type of fluid should match the drilling method:

   - Down-the-hole-hammer: compressed air; water and air; or foam;
   - Rotary drilling: drilling mud (water + additive). Be aware that bentonite clay is commonly used but is outlawed in some countries because it can do permanent damage to the *aquifer*. Biodegradable polymers should be used;
   - Percussion drilling: fluids generally not used;
   - Manual drilling (percussion, auger, sludging, jetting): water.

   Monitoring the *drilling fluid* colour and *viscosity* is the responsibility of the Driller. *Viscosity* is checked by measuring the flow rate of the *drilling fluid* through a Marsh Funnel. The Supervisor should ensure the Driller has a Marsh Funnel and it is properly used. In the case of air-percussion drilling, the air-lift yield should be measured using a V-plate or pipe/container. All observations and measurements are recorded every metre, using the marks on the drill pipe as a guide.

6. **Drill cutting samples:** To collect the samples, the Driller stops drilling, flushes all cuttings in the hole to the surface, resumes drilling, and then collects the cuttings. In air drilling, the samples are caught in a bucket placed in the stream of air jetting from the borehole. In mud drilling the samples are collected by inserting a spade into a small collection pit as the cuttings flow to the main pit. It is the Driller's responsibility to ensure that the mud pump is of such rating and condition that it can lift the cuttings out of the hole. If the hole is not properly flushed, cuttings may become mixed up and not lifted out so that during lining, the casings do not get to the required depth.

Figure 6: Samples are laid out and logged for 1m depth intervals

The drill samples should be bagged in strong transparent bags, labelled with indelible ink, and stored in a position that they will not be contaminated by site conditions or drilling operations. The label should contain the borehole number and location, sample number and depth. The sample could be collected and stored in a sample box. A photograph of the samples should be taken as a permanent record. In mud drilling, the samples would have mixed with the *drilling fluid*. The samples should be washed before bagging, but care should be taken in washing soft rock material, such as clays, as they could disintegrate in water.

The depth interval of collecting samples might have been stated in the *Technical Specification*, but drilling conditions may require that this is reviewed. It might have been specified that samples should be taken at every metre interval. However, in a deep borehole where the formation does not change rapidly, the interval could be increased to three metres. Equally, where there is rapid change in *lithology*, the Supervisor may change the interval to half a metre.

Box 8: Describing sedimentary rock samples

Description is based on identifying and describing:

- the colour
- the texture
- the grain size and shape
- the material
- the rock type

For example, samples from a sedimentary borehole could be described as:

0 – 2 m	dark grey hard CLAY
2 – 4 m	grey brown coarse angular grained loose SAND
4 – 6 m	white medium to coarse partially compacted SANDSTONE
6 – 10 m	white coarse partially compacted SANDSTONE
10 – 23 m	white compacted SANDSTONE

7. **Strata Log:** Drill samples should be described and a strata log prepared by the Supervisor. Different methods are required for describing sedimentary rock samples and crystalline rock samples (Box 8 and Box 9). From the strata description, the Supervisor will prepare a graphic strata log which will form part of the final borehole report.

8. **Final borehole depth*:*** It is the responsibility of the Supervisor to instruct the Driller to stop drilling when the right depth has been reached. The decision to end drilling will depend on the information gathered in the course of drilling. The factors will include:

   - what has been stipulated in the contract, which may be based on Client guidelines with respect to the average borehole depth in the area;
   - depth of the *water strikes/aquifer*;
   - *static water levels*;
   - estimated seasonal fluctuations in water levels i.e. changes in water levels as a result of recharge in the wet season(s) and groundwater discharge during the dry season(s);
   - the estimated yield from the borehole. See Box 10.

The typical signs for adequate yield and drilling depth vary with the type of formation and the drilling method. In the case of a yield which is obviously good, in a well that is to be installed with a handpump the final borehole depth should be at least 5 metres into the *aquifer*. It needs to allow for proper installation of the pump. It also should allow for 3 to 6 metres of sump (blank casing) below the screen as a sand trap.

However, if the yield is not clearly so good, continue to drill to the next strike horizon, until the yield is sufficient. The yield increments should be monitored with the V-plate. A 6m sump may be suitable where sand and silt are a problem. In cases where there is fine *saprolite* in the upper sections, these should be cased off to prevent silt from entering and filling the sump.

Box 9: Description and classification of crystalline rocks based on grades of weathering and dominant minerals

Grade	Classifier	Typical Characteristic
I	Fresh	Unchanged from original state
II	Slightly weathered	Slight discolouration, slight weakening and dislocation
III	Moderately weathered	Considerably weakened, penetrative discolouration Large pieces cannot be broken by hand
IV	Highly weathered	Large pieces can be broken by hand Does not readily disaggregate (slake) when dry sample immersed in water
V	Completely weathered	Considerably weakened Slakes Original texture apparent
VI	Residual soil	Soil derived in situ weathering but retaining none of the original texture or fabric

For example, the log from a granitic terrain might read as follows:

0 – 6 m	orange brown silty CLAY
6 – 16 m	grey brown clayey fine SAND
16 - 23 m	biotite granite GNEISS IV-III+
23 - 30 m	biotite granite GNEISS III+
30 – 43 m	biotite granite GNEISS I

9. **Drill Report:** The data from the drilling should be recorded both for the final design and as a reference for future borehole projects. The Driller needs to keep a daily drilling log which should be signed by the rig operator and the Supervisor at the end of each day. The Supervisor should insist that this is done - as Drillers often consider this an unnecessary intrusion into their work. The Supervisor should keep the record of the drilling activities and all measurements in a field note book. The most important data will go into the Casing and Well Completion Form (Appendix E3, *Code of Practice for Cost Effective Boreholes*), which will be collated, filed or bound together as part of the final project report and deposited with the appropriate office for future reference. Even data from dry or aborted holes needs to be recorded.

Box 10: Indications of adequate yield and depth

***Crystalline basement* geology:** Geophysical survey data should indicate the probable depth to fresh rock. On the *basement* complex of **West Africa**, this is usually not more than 60m because the *regolith* is rarely more than 30m deep and most joints close up by 50m depth. In **East and Southern Africa** the *regolith* may be as thick as 100m.

If the borehole is drilled with air, then *water strikes* will be obvious because the water shoots out of the hole. The yield of the borehole can be estimated as drilling progresses by making a small depression around the hole. The water blown out of the hole is channelled into a pipe. The yield is estimated by measuring the time it takes to fill a bucket of known volume, giving the yield in litres per second (l/s).

A handpump demand is about 0.3 l/s. If the yield is adequate for the demand, then the *static water level* is measured. If the borehole is drilled in the wet season, a depth allowance is added to cover for seasonal fluctuation in water levels. A further allowance is made for the *drawdown* caused by pumping. Thus, a borehole with a *static water level* of 10m might need an allowance of 15m for seasonal fluctuation and *drawdown*. In this case it would be 30m depth well.

The depth at which fresh rock is encountered may be a signal to stop drilling but if this is at shallow depth, not indicated in the geophysical survey it is necessary to continue drilling for another 5 to 10m to rule out the possibility of a boulder or *spheroidal weathering*. Fresh rock in hammer drilling comes out as fine or powdery material, dark or light coloured depending on the parent material.

Some *consolidated sediments* (sandstones, mudstones, shales): Can be highly compacted, hard and have to be drilled with down-the-hole hammer and air. Deciding at what depth to stop follows the same observations as in crystalline rock drilling. Some *consolidated sediments* are not so compacted and will follow the same method as with *unconsolidated* rocks.

***Unconsolidated* formations (gravels, sands):** It is not possible to see the *water strike* as in air drilling because the borehole is drilled with a drilling mud. The yield cannot be estimated until the borehole is lined and cleaned. The final borehole depth will depend on the pre-drilling hydrogeological information from existing boreholes and, sometimes, geophysical logging and the *lithological* types encountered during drilling. Close monitoring of the entire drilling process is required to find the water-bearing layers. Drilling can stop when the borehole reaches a continuously thick band of sand or fissured limestone below the zone of permanent saturation, at a depth correlating with the *aquifer*s screened in other nearby boreholes. It is best to penetrate as much of the *aquifer* as possible.

In *unconsolidated sediments*, careful observation of the drilling process will reveal one or more of the following signs indicating that a good water-bearing layer has been reached:

- sampling of drill cuttings shows a layer of sand or gravel has been reached (this needs careful sampling of drill cuttings)
- increase in the penetration rate
- bouncing of the drill string caused by a bed of gravels
- loss of *viscosity* in the *drilling fluid* (measured with a marsh funnel)
- sudden change of colour of the *drilling fluid*
- noticeable drop in the level of the *drilling fluid*
- *drilling fluid* temperature may drop due to groundwater inflow.

Step 6: On-site Design Modifications

Aim: To ensure that the finished borehole uses the *aquifer* efficiently, gives a long working life and low capital, maintenance and operation costs.

The Code of Practice for Cost Effective Boreholes (Danert et al, 2010) provides illustrations of different borehole designs. The provisional design should precede the signing of the contract, because the design gives rise to the specification. The specification informs the Driller what to bring to site. Any design work on site involves modifications to, or finalisation of, the design.

The Supervisor is responsible for on-site design modifications. Every borehole design is unique because it has to be adapted to the local geology, which cannot be predicted with absolute certainty. Borehole design involves selecting the appropriate dimensions and materials of the borehole, i.e. depth, casing and screen type and diameter, depth intervals of installation, and *gravel pack zone*. Borehole design factors are set out in Checklist 5 and described in further detail below. Most of the parameters listed above would have already been taken into consideration when writing the *technical specifications* of the borehole, but the information gathered in the course of drilling will steer the final design.

1. **Depth:** Taken from the Drill Report;

2. **Formation:** What type of *aquifer* is the borehole taking water from? Use local geological expertise and mapping where possible, but in general the three *aquifer* types are: *Basement Complex*; *Consolidated sediments*; and *Unconsolidated sediments;*

3. **Yield:** A borehole only needs to be drilled to a depth where the required yield can be sustained without contamination from surface water**.** Table 4 gives the ranges of yields from different formations. Selection of the other parameters, such as the borehole diameter and lining, should be geared towards meeting the required yield.

Table 4: Ranges of yields from various *aquifers*

Aquifer type	Rock types	Yield l/s
Consolidated sediments	Sandstones, mudstones	0.1 – 4
Unconsolidated sediments	Sands, gravels	>4
*Basement complex**	Weathered granites	0.1 – 1

* *Basement* complex is also divided into (a) *Saprolite* (which frequently suffers from low yield and is prone to silt influx): (b) *Saprock* (frequently has a high yield) and (c) Bedrock (high yield potential where fractured).

4. **Drilled borehole diameter:** The drilled diameter of the borehole needs to be large enough so that pump, casing, screens, *gravel pack* and sanitary seal can all fit without snagging. For handpump-fitted boreholes there are different schools of thought with respect to diameter, with some favouring smaller diameters, such as 6" to 6.5" and others arguing that this is inadequate to enable *gravel packing* to be properly installed without bridging. Anscombe (2012), a Driller with years of experience in southern Africa, argues that the reality is that most Drillers simply do not use a *tremie pipe* when installing *gravel pack*, with the result that the *gravel pack* is not properly installed. He thus argues that wells need to be drilled at an 8" diameter. This view has cost implications.

Figure 7: Controlling the discharging waters

5. **Casing and screens:** Casings are blank pipes which prevent the borehole from collapsing. Screens are pipes which have slotted openings that allow water to flow into the borehole but prevent sediments from entering the borehole. The lining material can be galvanised steel, Polyvinyl Chloride plastic (PVC), Glass Reinforced Plastic (GRP) or bamboo. The two most often used are PVC and steel, and the choice between them depends on the depth of the borehole and the corrosiveness of the groundwater.

   A 100mm diameter borehole casing will accommodate a handpump. Submersible pumps may require larger diameter casing depending on the required yield. Pump manufacturers usually prepare sets of curves showing the capacity of their pumps in terms of yield at particular depths or pumping heads and the diameter of the borehole that will accommodate the pump. The Supervisor should therefore check the diameter of borehole casing suitable for the intended pump. Generally, for motorised schemes in rural communities, a 150mm diameter is adequate. In the case of boreholes for small town supplies, or agriculture, a larger diameter will be required.

   In boreholes that are deep but have high *static water levels* (i.e. shallow depth of water level), a larger diameter casing, say 300mm, may be installed in the upper reaches of the borehole to house the pump (called the pump chamber), whilst a smaller diameter, 100-150mm, is used to line the lower parts and the *aquifer*.

   In *consolidated rock* - such as the *basement complex* - the depth is rarely more than 60m. PVC casing and screens can withstand the pressure imposed by the formation. There is a school of thought that argues that the lower part of the drilled hole could be stable and can be left open and unlined. In such cases, only the top weathered horizon is lined with a casing. In such holes, the *annulus* between the casing and the drilled hole should be grouted. However, it has been argued that these holes are not always sustainable, with some prone to siltation.

In *unconsolidated* formations, the entire borehole is lined to prevent the borehole from collapsing. Where the *aquifer* is more than 100m deep, the pressure exerted by the water and the rock formation is great, and steel casing and screen should be installed. In deep *aquifer*s with slightly acidic water, Glass Reinforced Plastic may be considered as mild steel could corrode..

The Supervisor should ensure that the casings and screens supplied are new and conform to the specification. If in doubt, the diameter and the wall thickness should be checked with callipers. The Driller should provide a sample of the pipe cut in half, and the measurement taken in the middle. Measuring the thickness at the threaded end will not give the accurate figure. Table 5 gives the dimensions of casings, wall thickness and possible depths of installation from a pipe manufacturer.

It should be noted that drill pipes, casings, screens and other lengths are not always standard. Sometimes they are cut and re-threaded. Often, 3m "standard lengths" are actually 2.95m, or some other length.

Table 5: PVC casing and screen dimensions
(Source: manufacturer Boode b.v Netherlands).

Indication of installation depth m*	Outside x inside diameter in mm	Wall thickness in mm
50 – 75	110 x 103.4 (3½")	3.3
75 – 100	110 x 101.6 (3½")	4.2
200 – 300	113 x 96.6 (4")	8.2
50 – 75	125 x 117.6 (4½")	3.7
75 – 100	125 x 115.4 (4½")	4.8

* Depths of installations mentioned are based on practical experience and may vary with ground condition.

6. **Screens:** are installed in the *aquifer* horizon. A borehole screen is a filtering device that serves as the intake portion of boreholes constructed in *unconsolidated* and semi-consolidated *aquifer*s. The screen permits water to enter the borehole from the *aquifer*, prevents sediments from entering the borehole and serves to support the *aquifer* material. Increasing borehole diameter does not have much impact on water flow into the borehole, but increasing the screen length significantly increases the yield. Therefore, as much of the *aquifer* as cost permits should be screened. There is not much difference in the prices of PVC casing and screen, but stainless steel screens are very expensive and should be used sparingly.

7. **Screen slot size:** The total open area of the screen governs the amount of water that flows into the hole. Slot sizes are not a big issue with handpumps as the required amount of water is relatively small. It is enough to ensure that the *aquifer* material will be retained by the selected screen slot size. This can be checked by doing a sieve analysis of the *aquifer* material, but a quick method is to rub a sample of the *aquifer* material against the screen. An adequate slot size will allow the *fines* to pass through, whilst the coarse material remains outside. It has been noted that in some southern Africa countries, locally available casing tends to be rather coarse (1mm slot size). This will not always be adequate. If the *aquifer* is laden with silt, and the slots allow it to pass through, it can result in the wearing of pump seals, and ultimately in siltation of the well.

   In motorised schemes where a high yield is required, a large diameter screen may be installed as the total open area increases. Water flows freely through a screen with a large intake area compared to one with limited open area. To prevent turbulent flow into the borehole which could cause encrustation and lower the lifespan of the screen, the velocity through the screen should not be more than 0.03 m/s. The minimum open area in the screen to permit non-turbulent flow can be calculated from the formula:

   $A = Q/30$

   where A is the open area in m^2 and Q is the water flow in l/s (Macdonald et al, 2005)

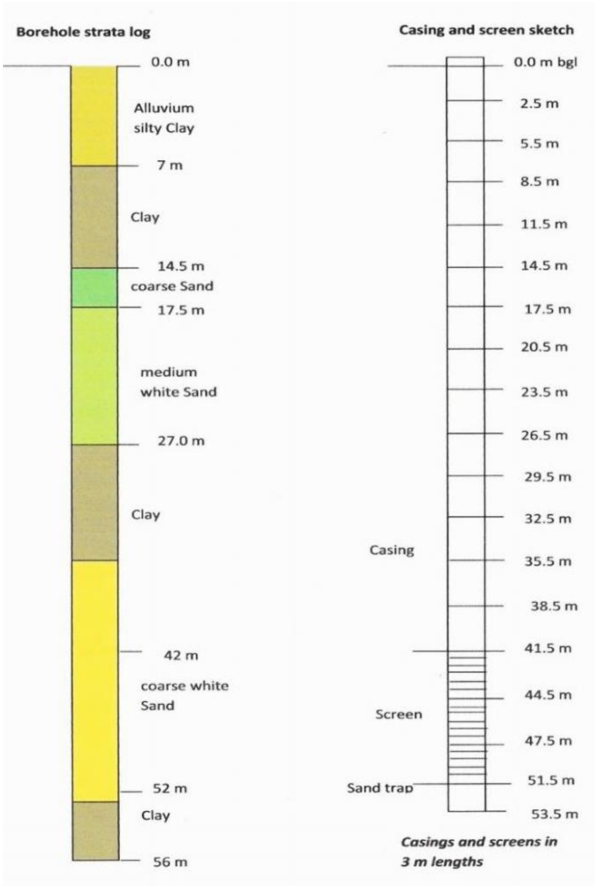
8. **Installing casing and screen** requires great care and attention as it is easy to install blank casing in the *aquifer* horizon. Once the depth of the borehole and the depth interval for screening are known, a sketch of the proposed assemblage of casing and screen should be made. The casings and screens should be laid out according to the sketch and measured individually, totalled and checked that they conform to the sketch. They should be placed next to the drill collar ready to go into the well. The Supervisor should take a photograph of the layout for the record. Figure 8 shows a sketch of a strata log with casing and screen assemblage in a sedimentary terrain. Once all of the materials are inserted, the drilled depth needs to be reconciled against the casing and screen depth. If the discrepancy is more than 3m, there is need to reconsider whether the screen is actually sitting where it is supposed to, or if there has been some collapse of the well. If something is wrong, the contractor must remove the casing, clean the well, and re-insert it until the Supervisor is satisfied.

   Joints should be strong enough to support the entire weight of the casing during installation. Threads should be intact. Both male and female threads should be properly cleaned with a brush and cloth before they are joined. Where non-threaded couplings are used, they should be cleaned and joined together by the solvent cement recommended by the manufacturer. **Before the casing is lowered into the borehole, the Supervisor should ensure that the recommended time for the cement to set and form a water tight seal is observed.**

   This is critical, but sometimes the Driller may be in a hurry to leave the site and so shorten the time. Steel casing and screen should be joined by threaded joints that are watertight. Where welding is used, the weld should be fully penetrating and continuous. If possible, welding of casings should be avoided as the weld can be a point for rusting and casing failure. It is also time-consuming and can put the casing out of true line. In addition, steel casings which are torch slotted on site corrode much easier than those which are bench slotted beforehand.

   The casing and screen assembly should be lowered into the hole under the force of gravity. They should never be driven down. In fact, they should be lifted slightly (by 100mm) when they reach the bottom and held there while the gravel is inserted (see point 9). This ensures that they are straight in the hole and not spiralled. In some cases, centralisers are used to align the casing in the hole. A 3m length of sand trap should be part of the well design when boreholes are cased to the bottom and the bottom casing sealed with an end cap.

Figure 8: Casing and screen sketch in comparison to strata log



9. **Gravel pack:** is installed in the annular space between the borehole screen and the wall of the drilled hole. Often, the *aquifer* material is allowed to collapse against the screen, and the *fines* are washed out during development. This enables natural development to take place. Where the *aquifer* material is coarse and mobile, it is the preferred method. However, where this is not possible, artificial gravel packing is used. There are two types with different functions:

   - The **formation stabiliser** is coarse sand or river gravel installed in the hole to prevent the caving of formation material and damage to the screen. The material should be carefully chosen and sieved to make sure it is of uniform size and bigger than the slot size of the screen and will not flow into the borehole. It should not contain mica, clay or laterite. Large pieces should be sieved out as they can bridge in the *annulus* and prevent subsequent gravel from reaching the bottom. Granite chippings should not be used as *gravel pack* as they tend to be angular and may contain mica or harmful material that leach into the water. The material should be washed and carefully introduced into the hole through a *tremie pipe* to avoid bridging. It should extend several meters above the screened interval but stop at least 6m below ground surface.
   - A **filter pack is** installed around the screen in fine grained *unconsolidated* formations where an appropriate screen slot size cannot be found. The grain size of the filter pack material has to be selected in relation to that of the formation material. It should be coarser than the *aquifer* sand. The relationship, called the pack-aquifer ratio (P.A. ratio), is calculated from the formula:

     Pack Aquifer ratio = 50% size of gravel pack/50% size of *aquifer* material

     The ratio should be between 4 and 6. For the procedure for sieve analysis and selection of appropriate filter material the reader should consult Driscoll, 1986: 406-409.

     It is essential that the casing, screen and *gravel pack* are available on the site once drilling commences. Once the drilling pipes are withdrawn, the hole has a potential to collapse. Thus the casing and *gravel pack* need to be placed without delay. Under no circumstances should this wait until the following morning. In the words of Anscombe (2012): "*Rods out – casing and gravel in – fast and efficient*".

10. **Geotextiles**: In some cases, *geotextiles* can be used to prevent fine materials from entering the screen.

Step 7: Borehole development and site completion

Aim: To prepare the borehole for use and install the pump and ancillary headworks and structures

Checklist 6 (Annex B) sets out the key aspects of borehole development and site completion:

1. **Borehole Development Method:** Borehole development is about cleaning the area of the *aquifer* immediately around the screens. The method of development should be stated in the *technical specification*. Figure 9 shows an example of *air lifting*. Air jetting can use a galvanised pipe, plugged at one end, with 8mm holes along the length so that the air-jet streams in the borehole are horizontal. This pipe, connected to the *compressor*, is raised and lowered repeatedly over the screen section, finishing in the sump.

Figure 9: Cleaning the borehole with an air-jetting tool

2. **Borehole Development Success:** The Supervisor's duty is to ensure that eventually, the water coming out from the borehole is clear of mud and is sand free. Samples of the water are collected in a clear container and checked to see that there are no sediments collecting at the bottom of the container. As part of this, the Supervisor needs to decide whether a borehole should be accepted or declared abortive. If the borehole is to be aborted, the Supervisor also needs to determine whether the Driller should re-drill the borehole at his own expense or not. This will depend on the terms and conditions of the contract.

   Although some contracts specify the duration of development (the minimum number of hours that must be spent on developing the hole), this actually depends on the time it takes for the water to be clean. Development should continue until the Supervisor is satisfied that the water coming out of the borehole is clean and sand free. Some boreholes clear within a couple of hours, some may take days to several weeks. Some only clear after several months of pumping. The latter is likely if air-percussion drilling has been used in very loose, clay-rich, silty, micaceous and saturated conditions – in other words not the right drilling technique.

3. **Sanitary seal:** It is essential to prevent contamination of the *aquifer* and to ensure that the users obtain safe, clean drinking water. When the Supervisor is satisfied with the yield, and development has settled the formation stabiliser or filter pack, then the *annulus* of the borehole is back-filled with the cuttings, or clayey soil, up to 6m below the ground surface. A *sanitary seal* is placed in the top 6m to prevent surface water which may be polluted from flowing down the borehole *annulus* into the *aquifer*. The *sanitary seal* should be cement slurry in the mixture of 25l of water to 50kg of neat cement, or bentonite.

4. **Pumping test** provides the means to determine the likely success of the borehole in terms of yield and *drawdown*. It provides information on the properties of the *aquifer* and on the borehole itself.

   Two types of pumping test can be conducted. A constant-discharge or *aquifer* test should always be carried out. This gives information about the *drawdown* resulting from a specific pumping rate (usually a little greater than the design discharge). The test data can also be interpreted in terms of the *aquifer* properties. For a handpump, a 3- to 6-hour constant discharge test is adequate. If the borehole is going to serve a large population and a high yield is required, then a longer test of say 24 to 72 hours, or even longer (up to 14 days) may be undertaken.

   A constant discharge test provides information about the *aquifer* in the vicinity of the well. The results of the constant discharge pumping test enable the short term performance of the well to be determined. However, it does not provide any information about recharge, seasonal fluctuations or long term performance. In other words, the pumping test does not give information about the long-term (multi-year) sustainable yield of the borehole. The long-term yield is the subject of groundwater resources evaluations, which focus on recharge and its variability from year to year.

   The second type of test is a variable-discharge or well test, also known as a step-test. This type of test is used to determine the hydraulic performance of the well. The data from a step-test can be used to calculate the well efficiency. Step tests are rarely carried out on low-discharge (e.g. handpump) wells. However, in the case of a production well or for motorised schemes, the step test is very useful. Provided that the data are kept, undertaking another step test say five years later can enable a comparison to be made. Thus it is possible to find out whether the well has clogged up over time.

   In a step-test the well is pumped at a succession of increasing discharges, each carried out for the same duration, typically one or two hours. There will usually be at least four steps, such as at 1/3, 2/3, 1 and 4/3 of the expected design pumping rate of the well.

   National or international standards (e.g. BS ISO 1468:2003) should be used in the design of both constant-discharge and step pumping tests. These standards specify test pumping duration, discharge and other aspects of the conduct of the test, including measurement methods.

   During the pumping test, the Driller usually measures the water levels, discharge and time. The Supervisor is responsible for ensuring that the pumping test is carried out correctly. The Code of Practice for Cost Effective Boreholes (Danert et al, 2010) provides guidance on pumping tests, including a recording format in Annex E7. The pumping rate and the water level are measured at the same time and recorded along with the time of measurement. The pumping rate can be measured with a flow meter, but it can also be established by recording the time it takes to fill a container of known volume. This is measured several times during the test.

   There are several ways of analysing pumping test data, and some are quite complicated. However, for the purpose of this guidance note, what is important to the Supervisor is whether the borehole will deliver the required amount of water for the required pumping duration or not. The *specific capacity* of the borehole, which expresses the relationship between the yield and the *drawdown*, is the most important quantity, i.e.

   Specific Capacity=yield /drawdown (m^3/h per m drawdown)

   This enables the Supervisor to predict the likely drawdown at different pumping rates and whether the borehole can deliver sufficient water. By calculating the drawdown incurred by different pumping rates, and comparing that drawdown to the available vertical interval between the rest water level and the top of the well-screen (while allowing for likely seasonal water level variations, the effects of extended dry periods, and the interval occupied by the pump itself) it is relatively easy to determine a viable discharge for the well as drilled. A *specific capacity* of around 1 m^3/h per m suggests that a borehole would be adequate for a handpump – a typical hand pump, drawing 1m^3/h would incur only 1m of drawdown in this example.

5. **Water quality testing**: Groundwater from boreholes is often of good quality, but sometimes it may contain contaminants which render it unsuitable for domestic use without treatment. The contamination could be due to minerals dissolved into it from the rocks through which it flowed but re-

sults more often from biological contaminants owing to human activities. If the borehole has been properly sited and constructed, it should be possible to eliminate biological contaminants.

The technical specification would have given the parameters to be tested. It is the Supervisor's duty to ensure that the samples are taken by the Driller in a clean bottle of at least 1l volume. Where the facilities are available, the sample should be analysed on site and then taken to an approved laboratory for further analysis. Note that some parameters change between sampling and reaching the lab and so need to be tested on, or close to the site (including pH, EC, dissolved oxygen, iron and micro-organisms).

Figure 10: Checking iron content at the wellhead

In taking the sample, the bottle is rinsed several times with the water being sampled, filled and securely corked and labelled. Some countries have developed drinking water quality standards, and the Supervisor should analyse the results of the water quality testing on that basis. Where there are no country standards, the WHO standards should be used.

Particular attention should be paid to the values of the pH, conductivity, iron, manganese, nitrates, fluoride, arsenic and thermo-tolerant coliforms (TTCs). Groundwater containing iron is often reddish brown or black if manganese is present. It may also taste bitter. It poses no threat to health, but the taste and colour of such water may make it unacceptable to the consumer. Acidic water corrodes metallic plumbing material. High conductivity indicates a high level of dissolved solids, Consumption of groundwater high in fluoride, arsenic and nitrates is toxic.

6. **Borehole disinfection** The borehole should be **disinfected** after construction to kill bacteria that might have entered during construction. Chlorine is normally used as the disinfecting agent, leaving a residual in the disinfectant water. The amount of chlorine required depends on the volume of water in the borehole. WHO (2012) recommend that a litre of 0.2% chlorine solution is used for every 100 litres of water in the borehole. This corresponds to a concentration of 20 mg/l. After adding the disinfectant, the borehole should not be pumped for at least 4 hours, if not longer. Care must be taken when mixing and adding chlorine to the borehole as it is poisonous when not diluted.

7. **Successful or abortive boreholes:** The Supervisor will decide whether a borehole should be accepted or declared abortive; and depending on the terms of the contract whether the Driller should re-drill the borehole at his/her own expense or not. The success and suitability of a borehole for acceptance will depend on the following:

   a) The **depth to pumping water level** is critical for handpumps as the maximum depth from which it is practical to lift water with a handpump is 80m. RWSN (2007) provides an overview of the operation depths of the various public domain handpumps. Since some allowance must be made for water level drawdown, for a hand pump, the *static water level* must be less than 80m below ground level. The *static water level,* together with national pump standards, will determine the handpump to be installed. Depth to static water level is beyond the control of the Driller and he/she should not be penalised for it. Such deep water levels may be encountered in sedimentary terrains. In the case of deeper water levels, motorised rather than hand pump will be required.

   b) A dry borehole or one with a lower yield than the desired should be declared abortive. This may not be the fault of the Driller, but if the agreement is that the Driller is only paid for successful boreholes, then re-drilling is at his/her own cost. However, even after attempting drilling in 3 locations in a community, the yield from the borehole may fall short of the minimum allowed. At this stage, a major reassessment of the drilling strategy may be required, with appropriate contracts drafted.

   In the meantime, where the shortfall is less than 30% of the minimum specified, and there are no other safe sources of water, then the Supervisor may decide to accept the borehole and complete it if there is no alternative to improve the water supply. However, this may not be a viable long-term solution for the community.

   c) The **sand content** of the water should not be more than 10 parts per million by volume. The Supervisor should collect three 20l samples at the end of the pumping test. The volume of sand in the samples should not exceed 0.2 cubic centimetres. If a borehole should be abandoned because of excessive sand content, then the Driller shall be responsible for constructing another borehole at his/her own cost. The wrong drilling technique or poor *gravel packs* and well development cause this.

   d) The **turbidity** of the water should not exceed the stipulated limit. In some circumstances, excessive turbidity is due to the characteristics of the *aquifer* and thus beyond the control of the Driller, who should not be held responsible.

   e) Every borehole should be cased **straight and vertical**. The Supervisor may ask the Driller to carry out a test for straightness and verticality. The Driller should provide the *plumb* and carry out the test. Should the *plumb* fail to move freely throughout the length of the casing to the required depth or should the borehole vary from the vertical in excess of two-thirds of the inside diameter of part of the borehole being tested per 30 metres of depth, the borehole should be re-drilled by the Driller at his/her own expense.

f) The Supervisor will determine whether the **chemical and bacteriological quality** of the water is adequate to serve as potable water supply. If the borehole becomes contaminated because of an action or inaction by the Driller, the Driller should be asked to disinfect the borehole and if necessary construct a new borehole at his/her own cost.

9. **Platform casting*:*** All boreholes need a concrete apron around the length of casing above the ground for protection against soil erosion and surface water flowing into the borehole. Handpumps also need a concrete platform to hold the pump stand, to drain away spilled water, and for water users to stand upon. There are several designs of pump platforms, some being circular and others rectangular (Figure 11). Some incorporate a drinking trough for animals or a wash pad for laundry. Platform casting is usually undertaken by a dedicated construction team and may take place after *demobilisation* of the drilling equipment. However, the Supervisor will be responsible for ensuring that platform is built to the design specified by the Client in the contract and that the quality of the materials and the construction is good and durable. For more information on platform design, see RWSN (2008) Platform Design for Handpumps on Boreholes - Construction Guidelines.

Figure 11: Rectangular pump platform (for wheelchair access)

Step 8: Demobilisation

Aim: To leave the site clean, safe and ready for use

On completion of the pump installation, the Supervisor must issue a Work Completion Certificate. For this, he has to ensure that the Driller has complied with all the stages, including the final ones, of the contract specification. See Checklist 7 (Annex B).

Before *demobilisation*, the Supervisor should check that the borehole record has been completed and all information filled in. Annex E of the Code of Practice for Cost Effective Boreholes provides a template for recording the borehole data.

Step 9: Complete documentation and handover

Aim: To provide a clear documented record to help future operation, maintenance and repairs and hand over the completed facility to the Community

The finalisation and submission of drilling records (to the appropriate national authority and local government) is essential. The submission of borehole construction data is Principle 8 of the Code of Practice for Cost Effective Boreholes (Danert et al, 2010). This should be an integral part of the drilling contract, and thus require approval before payment of the invoice.

When the Supervisor is satisfied that the borehole is ready for use, a day is set aside for **handing over** the borehole to the Community or the Client. It is common practice for the handing over certificate to be signed by three people: the Supervisor, the Driller and the Community representative.

During the **defects liability period**, the Supervisor will monitor and liaise with community members on the functionality of the boreholes during periodic visits. If there are any defects, they will instruct the Driller to make repairs at his own cost, depending on what is specified in the contract.

Final Remarks

At first, the drilling site is a mystery and a challenge to a new Supervisor, but after the first few boreholes, he/she will get to grips with the procedures and become more confident. Later, the drilling routine may seem monotonous - one of continuously lowering and pulling out of drill rods, watching rods rotate and cleaning mud pits - but there are continuous changes. The Supervisor therefore needs to be watchful at all times. There could be arguments later on, and if the Supervisor has not been vigilant, then he/she could be cowed or hoodwinked by experienced or unscrupulous Drillers.

Not all issues can be resolved on site and some may have to be deferred until later. To help, the Supervisor should make notes of all the different opinions on the issue and get them signed by all the parties. Although the Supervisor represents the Client, he/she is expected to display great professionalism and act with honesty and impartiality in any dispute over the contract.

A two-way relationship between the Supervisor and the Driller is necessary for an efficient and successful outcome to the project. The Supervisor should therefore strive to understand the Driller's technique, avoid being overbearing and not try to teach the Driller how to drill. Where cooperation is established, the Driller can give the Supervisor important information that is not always recorded in the driller's log, for example, a change in the sound of the drill string, a juddering, an abrupt fluctuation in penetration rate not always seen on the penetration rate log, a change in the level of the drill fluid in the mud pit. However, if a Driller is smarting from perceived injustice by the Supervisor (probably a younger person!), he/she will be less inclined to be helpful, which may be detrimental to the project.

Supervision of drilling is a vital aspect of borehole construction and as much support as possible should be given to the young drilling Supervisor. Occasional visits to the drill sites by senior project personnel will reinforce the Supervisor's authority with the Driller.

Glossary

Air Lifting – pumping water from a borehole with compressed air.

Annulus – the space between the two tubes, where one is inserted into the other, i.e. drilled hole and the lining material or drilled hole and the drill pipe.

Aquifer – an underground layer of water-bearing rock from which groundwater can be usefully abstracted via a well or borehole.

Backfill – putting back the material removed from the hole during drilling.

Basement Complex/Crystalline Basement – any rock below sedimentary rocks or sedimentary basins that are igneous and metamorphic in origin.

Bill of Quantities - a list of quantities of materials and activities. This is used to provide prices for itemised activities and materials.

Bit, or drill bit – the earth or rock cutting tool in a drilling rig or equipment.

Borehole – a small diameter water point made by drilling rather than digging.

Circulation pit – a pit in which the *drilling fluid* is mixed and from which it is pumped into the drilled hole and into which cuttings from the hole settle (sometimes referred to as settlement pit.

Compressor – a machine that produces compressed air providing pressure used in drilling.

Consolidated sediments – sediments cemented or compressed into a compact mass e.g. sandstone, mudstone.

Demobilisation – clear-up of drilling site, return of the drilling crew and equipment to their headquarters. Cleaning, repairing and storing equipment and completing paperwork.

Drawdown – the difference between the *static water level* and the pumping water level.

Drill Camp – the main base, crew accommodation and storage area for the duration of the drilling campaign. If more than a few hours' travel is involved, the drill crew may establish a *Satellite Fly Camp* while completing an individual borehole.

Driller – the Drilling Contractor, generally refers to the person responsible for decision-making.

Drilling fluid – material, either gas or liquid used to remove the cuttings and to support the hole from collapsing during drilling.

Fines – small grained particulate material, such as silt and sand.

Global Positioning System (GPS) – Dedicated GPS electronic devices, and some mobile phones, are able to give the users precise grid references for their location by using signals emitted from satellites in orbit around the Earth.

Geotextiles – permeable fabrics that can be used as a filter over the screen of a borehole.

Gravel pack – coarse sand or gravel placed around the borehole screen to prevent smaller particles from the formation migrating into the borehole.

Lithology – rock type e.g. granite, gneiss, mudstone.

Mobilisation – getting drilling crew and equipment ready, purchasing materials and deployment to the *Drill Camp*.

Plumb – a lead weight, usually suspended from a line, used for measuring water depth or for testing the verticality of a well or borehole.

Rotary table – a guide that centralises the drill pipe.

Regolith – the layer of weathered rock overlying bedrock, also called weathered mantle, consisting of saprolite and soil.

Sanitary seal – the top part of the borehole *annulus* filled with cement grout or bentonite to prevent surface water infiltrating into the *gravel pack* and screened depth.

Saprock – fracture bedrock with weathering restricted to the fracture margins

Saprolite – in situ chemically weathered bed rock.

Satellite Fly Camp – temporary camp used by the drill crew for the duration of drilling a borehole.

Shoe plug – A stopper at the base of the borehole casing.

Specific capacity – a measure of the productivity of the well calculated by dividing the yield by the drawdown.

Specifications or echnical specifications – the particulars of how a borehole should be drilled, lined, developed and completed to achieve its functions.

Spheroidal weathering – weathering in which concentric layers of decomposed rocks are successively separated from a block of rock resulting in a formation of rounded boulder.

Static water level – the level of water in a borehole that is not being pumped.

Tremie Pipe – A funnel and pipe to direct gravel into *the annulus* so that the gravel does not get stuck part way down, creating gaps in the *gravel pack*.

Unconsolidated sediments – loose sediments not compacted, such as gravels, sands and clays.

Viscosity – the property of a substance to offer resistance to flow.

Water strike – depth at which water is encountered during drilling usually observable in hammer air drilling.

Figure 12: Drill rig with drilling fluid channel

Annex A: Project Checklist for the Driller

Step	Checklist
1. Pre- contract	☐ Driller's equipment approved
	☐ Driller's personnel approved
	☐ Driller's field operation observed
2. Pre-Mobilisation Meeting	☐ Contract checked
	☐ Questions asked and clarifications made
3. Mobilisation	☐ Community has been mobilised
	☐ Programme of work submitted and approved
	☐ Materials checked and approved
	☐ Driller has been shown the site
	☐ Data collection forms approved
	☐ Filing system set up
4. Siting	☐ Geophysical equipment checked and approved
	☐ Siting supervised
	☐ Report submitted and approved
5. Drilling	☐ Rig location approved
	☐ All safety measures taken
	☐ Samples are collected and kept
	☐ Drilling completed
	☐ Borehole logged
6. Borehole design	☐ Casing and screen installation approved
	☐ Gravel pack installation approved
	☐ Sanitary seal approved
7. Borehole development	☐ Water sample checked for sand content
	☐ Pumping test carried out
	☐ Borehole disinfected
	☐ Water quality analysed
	☐ Borehole successful or abortive
8. Demobilisation	☐ Site restored to its original state
	☐ Circulation pits *backfilled*
	☐ Abandoned borehole sealed
	☐ All pieces of equipment removed from site
	☐ Rubbish disposed of properly
9. Complete documentation	☐ The Driller has carried out all tests and submitted the reports.

Annex B: Checklists of Drilling Steps for the Supervisor

Checklist 1: Pre-contract checklist

Equipment	**Checklist**
☐ Drilling rig	Year of Manufacture:
	Manufacturer:
	Lifting capacity:
	☐ Raise mast.
	☐ Start and run for an hour without problem.
	☐ Check for oil leaks and get any fixed before giving approval.
☐ Compressor	Year of Manufacture:
	Manufacturer:
	☐ Start and run for an hour without problem.
☐ Mud pump and generator	☐ Check rating against estimated borehole depths.
	☐ Test pumps and generator.
☐ Water tanker	☐ Check for leaks.
☐ Support trucks	☐ Check that the Driller has the necessary working support vehicles.
☐ Drill pipes	☐ Check that there are adequate lengths of drill pipes to drill the deepest hole.
☐ Drill bits (and hammer depending on the type of drill rig)	☐ Correct diameter.
	☐ Right drill bits available for likely ground conditions.
	☐ Check condition.
☐ Geophysical surveying equipment	☐ Geophysical equipment working correctly
	☐ Personnel competent in use of geophysical surveying equipment
Personnel	**Checklist**
☐ Drilling manager	Years of experience:
	Experience of similar assignments:
☐ Hydrogeologist	Qualifications:
	Years of experience:
	Experience of similar assignments:
☐ Rig operator	Years of experience:
☐ Driver	Years of experience:
☐ Mechanic	Years of experience:
☐ Rig assistants	Number of assistants:
	Years of experience:
☐ Record Taker	Years of experience:

Checklist 2: Siting

Activity	Checklist	
☐ 1. Water User priorities – based on Community engagement	☐ Proximity to point of use:	
	☐ Equitable access for all water users, especially women and most disadvantaged in the Community	YES / NO
	☐ Land ownership and access rights for users and maintenance teams established and confirmed in writing	YES / NO
☐ 2. Geological favourability - based on hydrogeological assessment	☐ Sufficient yield for the intended purpose:	YES / NO
	☐ Sufficient renewable water resources for the intended purpose Appropriate water quality for the intended purpose	YES / NO
	☐ Interference with other groundwater sources and uses avoided	YES / NO
	☐ Interference with natural groundwater flows avoided	YES / NO
	☐ Chance of success (Annex 1 of *Siting of Drilled Water Wells*)	HIGH / MEDIUM LOW
☐ 3. Contamination risk	☐ Is the *aquifer* confined?	YES / NO
	☐ No potential pollution sources within minimum distances	YES / NO
☐ 4. Drilling logistics	☐ Access allowed and possible for Driller team, equipment and vehicles	YES / NO

Checklist 3: Mobilisation

Activity	Checklist
☐ 1. Contract	☐ Contract Signed
☐ 2. Programme of work	☐ Programme of work submitted and approved
☐ 3. Community liaison	☐ Explain details of drilling process.
	☐ Community member roles, contributions and responsibilities
	☐ Exchange details of main contact persons or community representatives.
	☐ Driller's representative introduced to the Community
☐ 4. Equipment is appropriate and in working condition	☐ Drill rods are adequate
	☐ Hammers and bits are of the right diameter (measure).
	☐ Temporary casing diameter is correct.
☐ 5. Samples of materials meet with technical specifications	☐ Drilling fluid
	☐ Sample box
	☐ Casing and screen (measure length and diameter)
	☐ Filter pack and gravel materials
	☐ Screen
☐ 6. Data collection forms	☐ Format of data entry forms agreed (Refer to Annex E of Code of Practice for Cost Effective Boreholes, RWSN 2010)
☐ 7. Project filing system	☐ Driller given Master Project Checklist (Annex B)
☐ 8. *Drill Camp / Satellite Fly Camp* layout	☐ Location of vehicle and rig parking ☐ Maintenance garage ☐ Site office and living accommodation ☐ Fuel storage and spillage control measures ☐ Water supply source ☐ Sanitation facilities ☐ PVC casing and screens protected from direct sunlight

Checklist 4: Drilling

Activity	Checklist
☐ 1. Health and Safety	☐ Rig set up away from traffic hazards and power transmission lines
	☐ Rig and support vehicle not positioned on a steep slope
	☐ Public safety barrier (bright coloured tape).
	☐ Drilling team wearing personal protective clothing: boiler suits, hard hats, boots, eye protection and gloves
	☐ Inflammable items such as petrol or chlorine etc should be kept in approved containers, properly marked and stored away from sources of heat.
	☐ Mast not raised during thunderstorm (lightning strike risk)
	☐ Lifting of very heavy or bulky loads which could lead to back strain should be avoided. Lifting should be done using the legs and not with the back.
	☐ Equipment should be kept in good working order.
	☐ Area around the drilling rig is kept tidy.
	☐ Borehole should be securely capped on completion to prevent tools and other debris falling into the hole and children throwing stones and corn stalks into it which could render it useless.
	☐ On completion, the site should be restored as far as possible to what it was before the drilling, mud pits filled in and compacted.
	☐ Drill crew should drink plenty of fluids regularly to prevent dehydration, which can lead to poor judgement.
	☐ First Aid kit checked
	☐ Emergency procedure in case of major injury and need for hospitalisation
☐ 2. Rig position	☐ Rig positioned over pegged site.
	☐ Rig drill mast vertical (checked with spirit level).
	☐ Check ground stability for softness that could entrap the rig or cause it to tilt during drilling
☐ 3. Drilling Depth	☐ Depth measurements being conducted and logged properly
☐ 4. Penetration Rate	☐ Penetration rates being measured properly
☐ 5. Drilling Fluid	☐ Type of drilling fluid being used:
	☐ Driller using Marsh funnel to measure drilling fluid viscosity
☐ 6. Drill Cutting Samples	☐ For Rotary mud-flush drilling, check that the circulation mud pits (or portable tanks) have a volume that is at least three times the volume of the borehole – see Annex D.
	☐ Ensure that the Driller prevents sample contamination due to poor circulation, borehole erosion or caving.
	☐ Ensure that mud pits are kept clean to prevent re-circulation of cuttings.
	☐ Samples taken at regular intervals and properly washed, bagged, labelled, logged and stored in sample box.
	☐ Photograph samples
☐ 7. Strata Log	☐ Use samples to prepare a Strata Log.
☐ 8. Final borehole depth	☐ Water table depth (m):
	☐ Final borehole depth (m):
☐ 9. Drill Report	☐ Daily drilling log signed by rig operator and Supervisor.
	☐ Record necessary data and information required to complete a Casing and Well Completion Form (Appendix E3, *Code of Practice for Cost Effective Boreholes*).

Checklist 5: Borehole Design

Design Criteria	Value
☐ 1. Borehole Depth (metres):	
☐ 2. *Aquifer*/Rock Type	Basement/Consolidated/Unconsolidated
☐ 3. Yield (litres per second)	
☐ 4. Drilled borehole diameter (mm)	
☐ 5.a Type of borehole casing and screens:	PVC / GRP / Steel / Bamboo / Other:
☐ 5.b Wall diameter and thickness (mm) check diameter and wall thickness with callipers	
☐ 5.c Quantity of borehole casing & screens (m)	
☐ 6. Screening length (m)	
☐ 7. Screen area (m^2)	
☐ 8. Installation of casing and screens	☐ Produce sketch of proposed assemblage of casing and screen.
	☐ Layout casing and screening on the ground, check against sketch and photograph.
	☐ Check joints between casing pipes.
☐ 9. Gravel Pack	☐ Ensure that gravel pack design is adhered to (formation stabiliser or filter pack).
	☐ Check that formation stabiliser does not contain mica, clay or laterite.
☐ 10. Sanitary Seal	☐ Check sanitary protection design, proper depth and material composition.

Checklist 6: Borehole development and site completion

Activity	Checklist	
☐ 1. Development method used	Use Annex E4 and E5 from Code Practice for Cost Effective Boreholes.	
☐ 2. Borehole development success	☐ Duration of development:	
	☐ Borehole development successful (water runs clear):	YES / NO
	☐ If NO then should the Driller re-drill the borehole?	YES / NO
	☐ If YES a re-drill is needed, should it be at the Driller's cost?	YES / NO
☐ 3. Platform casting	☐ Shuttering is properly anchored and layout matches designs. ☐ Correct sand : cement : aggregate ratios (1:2:4) ☐ Correct drainage slope (1:50) ☐ Surface towelled smooth ☐ Borehole number, date of completion, yield and water levels embedded in the wet concrete ☐ Concrete kept moist for 72 hours to allow proper curing ☐ Is the finished platform acceptable?	YES / NO
☐ 4. Pump Testing	Use forms in Annex E7 of the Code Practice for Cost Effective Boreholes).	
☐ 5. Water Quality Testing	Use forms in Annex E5 of the Code Practice for Cost Effective Boreholes).	
☐ 6. Borehole Disinfection	a. Depth to static water level unacceptable?	YES / NO
	b. Dry borehole or inadequate yield?	YES / NO
	c. Unacceptable sand content of pumped water?	YES / NO
	d. Unacceptable turbidity of pumped water?	YES / NO
	e. Borehole straight and vertical?	YES / NO
	f. Unacceptable chemical or bacteriological quality of the pumped water?	YES / NO
	FINAL DECISION ON BOREHOLE: SUCCESSFUL / ABORTIVE	

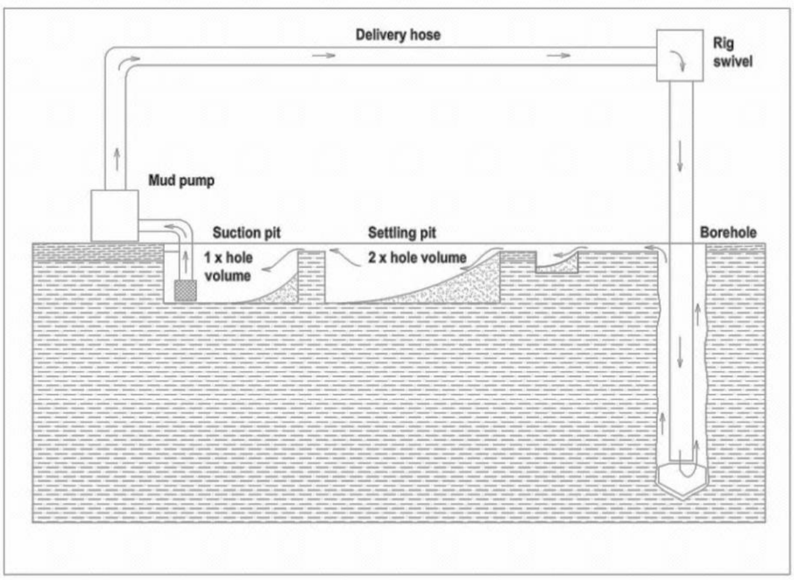
Checklist 7: Demobilisation

Activity	Checklist
☐ 1. Work complete	☐ All installation work complete and approved by Supervisor
	☐ All testing completed and documentation and data handed over to Supervisor
☐ 2. Drilling site cleared	☐ All litter, liquid and solid waste disposed of responsibly so as not to cause nuisance
	☐ Circulation pits filled in
	☐ Equipment cleaned and packed away
	☐ Unused materials taken away (check with contract who owns or pays for unused materials, such as casing, filter packs etc.)
	☐ Public barrier taken down.

Checklist 8: Development and Site Completion

Activity	Checklist
☐ 1. Reporting	☐ Drilling report completed and copies given to Client, the Community and the Regulator/Government water or geology ministry
☐ 2. Handover	☐ Agree handover date with Driller, Community and Client. ☐ Organise signed handover of borehole to the Community or Client.
☐ 3. Defect Liability Period	☐ Agree monitoring schedule. ☐ Undertake site visits to check that pump is still working and that there are no problems with the borehole performance. ☐ Report any problems found, or reported by the Community to the Client. If necessary, mobilise the Driller to undertake repair work.
☐ 4. Invoicing and payment	☐ At end of defects liability period, submit supervision invoice to Client and give approval for final payment to Driller (depending on contract).

Annex C: Circulation/Settling pits layout



References and Bibliography

ADEKILE, D (2012) *Procurement and Contract Management of Drilled Well Construction: A Guide for Supervisors and Project Managers,* RWSN Field Note 2012-4, Rural Water Supply Network, St Gallen, Switzerland

ADEKILE, D. and BALL, P. (2006) Training local technicians in borehole drilling –Waterlines Vol.24 No4. Practical Action, UK

ADEKILE, D. and KWEI, C. (2009) *The Code of Practice for Cost Effective Boreholes in Ghana – Country Status Report*, Consultancy Report for the Rural Water Supply Network, St Gallen, Switzerland

ADEKILE, D. and OLABODE O. (2008) *Study of Public and Private Borehole Drilling in Nigeria*. Consultancy Report for UNICEF Nigeria Wash Section and Rural Water Supply Network, St Gallen, Switzerland

ANSCOMBE (2012), *Personal Communication with the editors* when reviewing this publication, August 2012.

ARMSTRONG, T. 2009. *The Code of Practice for Cost Effective Boreholes in Zambia – Country Status Report*, Consultancy Report for UNICEF and Rural Water Supply Network, St Gallen, Switzerland

BALL, P (2001) *Drilled Wells* SKAT, Swiss Centre for Development Cooperation in Technology and Management, St Gallen, Switzerland

BALL, P. (2004) *Solutions for Reducing Borehole Costs in Africa* WSP/Rural Water Supply Network, St Gallen, Switzerland

BOODE Water Well Systems (2011) *PVC Screen and casing standard type 1" to 3" lengthwise slotted.* Available from: http://www.boode.com/index2.html/

CARTER, RC., CHILTON, J., DANERT, K. & OLSCHEWSKI, A. (2010) *Siting of Drilled Water Wells - A Guide for Project Managers*. RWSN Field Note 2010-5, Rural Water Supply Network (RWSN) , St Gallen, Switzerland,

CARTER, RC. (2006) *Ten-step Guide Towards Cost-effective Boreholes*. Rural Water Supply Network, St Gallen, Switzerland

DANERT, K., ARMSTRONG, T., ADEKILE, D., DUFFAU, B., OUEDRAOGO, I. & KWEI, C. (2010) *Code of Practice for Cost Effective Boreholes*. British English Version, June 2010, Rural Water Supply Network (RWSN), St Gallen, Switzerland.

DANERT, K., LUUTU, A., CARTER, RC., OLSCHEWSKI, A ((2010) *Costing and Pricing - A Guide for Water Well Drilling Enterprises*. RWSN Field Note 2010-6, Rural Water Supply Network (RWSN), St Gallen, Switzerland,

DRISCOLL, F. (1986) Groundwater and Wells, St Paul: Johnson Division

ELSON B and SHAW R (2011) *Simple Drilling Methods* WEDC Technical Briefs 43, WEDC Loughborough University http://www.lboro.ac.uk/well/resources/technical-briefs/43-simple-drilling-methods.pdfa [accessed 2 August 2011]

FUREY, S (2012) *Sustainable Groundwater Development: use, protect and enhance*, Rural Water Supply Network (RWSN).

FEDERAL REPUBLIC OF NIGERIA/NATIONAL WATER RESOURCES INSTITUTE. 2009. *National Code of Practice for Water Well Construction in Nigeria***,** National Water Resources Institute, Kaduna, Nigeria

MACDONALD, A. DAVIES, J. CALOW, R. and CHILTON, J. (2005) *Developing Groundwater. A guide for Rural Water Supply*, ITDG Publishing

MICHAEL, A.M. and KHEPAR, S.D. (1989) *Water Well and Pump Engineering* Tata McGraw – Hill Publishing Company Limited, New Delhi

NATIONAL WATER RESOURCES INSTITUTE. (2010) *Short Course 2 Borehole Construction and Management* Rural water Supply and Sanitation Centre

RWSN (2007) *Technology Selection – and Buyer's guide for Public Domain Handpumps for Drinking Water,* Rural Water Supply Network

RWSN (2008) *Platform Design for Handpumps on Boreholes - Construction Guidelines (Revision 1-2008*), Rural Water Supply Network

RWSN (2009) *Hand Drilling Directory*, Rural Water Supply Network.

UNICEF (2010a) UNICEF WASH Technology Information Packages (TIPs), Available from http://www.unicef.org/supply/index_54301.html

UNICEF (2010b) Professionalising the Manual Drilling Sector, UNICEF, Available from http://www.unicef.org/wash/files/1._Professionalizing_Manual_Drilling_lo_res.pdf

WATERLINES (1995) *Technical Brief No. 43 Simple Drilling Methods*, Waterlines Vol. 13 No. 3, January 1995. Available from http://www.lboro.ac.uk/well/resources/technical-briefs/43-simple-drilling-methods.pdf

WE Consult 2011 *Supervision tables* Water, Environment & Geo Services Ltd Kampala Uganda

WHO (2012) Cleaning and Disinfecting boreholes, WHO Technical Note for Emergencies No 2, Available on http://www.who.int/water_sanitation_health/hygiene/envsan/tn02/en/ [Accessed 3 August 2011]

WHO (2008) *Guidelines for Drinking Water Quality*, Incorporating First and Second Addenda to Third Edition, Volume 1 Recommendations, World Health Organisation, Geneva, Switzerland. Available from: http://www.who.int/water_sanitation_health/dwq/gdwq3rev/en/ [accessed 22 June 2012]

WHO/UNICEF (2011) *Drinking Water: Equity, Safety and Sustainability*, JMP Thematic Report on Drinking Water 2011. Available from: http://www.wssinfo.org/fileadmin/user_upload/resources/report_wash_low.pdf [accessed 26 May 2012]

WHO/UNICEF (2012) Joint *Monitoring Programme Report 2012 Progress on Water and Sanitation and Drinking Water*. Available from http://www.wssinfo.org/fileadmin/user_upload/resources/JMP-report-2012-en.pdf [accessed 24 May 2012]

About the Author

Dotun Adekile is a Nigerian consultant with over 30 years of experience siting and supervising borehole construction, as well as training field geologists and technicians. He has contributed to developing the Code of Practice for Cost Effective Boreholes in three countries and the preparation of several guidance notes.

Contact

The Rural Water supply Network (RWSN) is a global knowledge network for promoting sound practices in rural water supply.

RWSN Secretariat
SKAT Foundation
Vadianstrasse 42
CH-9000 St.Gallen
Switzerland

Phone: +41 71 228 54 54
Fax: +41 71 228 54 55
Email: ruralwater@skat.ch
Web: www.rural-water-supply.net

Support and Acknowledgement

Although this document derives from the author's years of drilling supervision, similar works on the subject were consulted in its preparation. Some of the authors are mentioned in the text but for brevity of presentation others are not. All the sources consulted are listed in the bibliography. The author gratefully acknowledges their contribution.

Particular gratitude goes to Kerstin Danert, Ron Sloots, Robin Hazell, Richard Carter, André Olschewski and Jim Anscombe who reviewed this document.

This document was supported by UNICEF and Skat Foundation

The document was edited by Sean Furey and Kerstin Danert

Layout was undertaken by Martin Laeng

Photo Credits: The author, Richard Carter, Hazel Jones, WEDC and Jim Anscombe.

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development and Cooperation SDC

unicef

skat_foundation

ISBN: 978-3-908156-42-0