RWSN

Rural Water Supply Network

Cost-Effective Boreholes

British English Version

June 2010

Code of Practice for Cost Effective Boreholes

Summary

Sustainable groundwater development is fundamental in order to provide universal access to safe drinking water. This document, *The Code of Practice for Cost Effective Boreholes* provides a basis for the realisation of economical and sustainable access to safe water. The term "*cost-effective*" means optimum value for money invested over the long term. Boreholes are drilled to function for a lifespan of 20 to 50 years. Thus, the lowest cost is not always the most cost-effective, particularly if construction quality is compromised to save money. Cheap drilling or poor construction quality can lead to premature failure of the well or contamination of the water supply. Boreholes that are subsequently abandoned by the users are clearly not cost-effective.

The Code of Practice sets out nine principles that relate directly to the practicalities of borehole construction (see below). They should be adhered to in order to provide cost-effective boreholes. Each principle is broken down into sub-principles which recommend procedures to be followed and call for the definition of and adherence to minimum standards.

The Code of Practice thus provides a framework to analyse the strengths and weaknesses of existing policies and practices. It is intended to be used as the foundation for the development of national protocols for cost-effective borehole provision. It provides a basis for stakeholders to examine whether they are working in accordance with international practices, and it can be used by donors to examine funding conditionalities.

Nine Principles for Cost-Effective Boreholes

Principle 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.

Principle 2: **Siting** - Appropriate siting practices are utilised and competently and scientifically carried out.

Principle 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.

Principle 4: **Procurement** - Procurement procedures ensure that contracts are awarded to experienced and qualified consultants and drilling contractors.

Principle 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.

Principle 6: **Contract Management, Supervision and Payment** - Adequate arrangements are in place to ensure proper contract management, supervision and timely payment of the drilling contractor.

Principle 7: **Data and Information** - High quality hydrogeological and borehole construction data for each well is collected in a standard format and submitted to the relevant Government authority.

Principle 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.

Principle 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.

Contents

Glossary

Apron – a concrete floor surrounding a drilled water well to provide a relatively clean environment and control the drainage of spilled water away from well.

Borehole - a water well or hole which is drilled in the ground and partially or fully lined for the abstraction of groundwater.

Borehole design - choosing the depth, diameter and lining materials of the borehole and the drilling technique to be used.

Borehole development - the act of cleaning a borehole after construction by flushing or other means until the water from the hole is clean and free of fine materials.

Borehole siting - the selection of the optimal location of the boreholes by the community as well as with either hydro-geological and/or geophysical means to ensure the design yield.

Biofouling - Bacteria in the aquifer mediate the deposition of iron and other metals, resulting in the formation of a biofilm on the well screen and casing. When the accumulation of this biofilm causes problems of incrustation or corrosion of the well screen and casing of the water well, the process is known as biofouling.

Community selection process - the process by which communities are selected to benefit from a borehole.

Community sensitisation generally refers to the process whereby water users in a community are informed of the technical options for a water source improvement and the requirements that they have to fulfil in order to benefit from one.

Community mobilisation – is the process of preparing a community for the arrival of the contractor (or NGO) who will construct the improved water supply (e.g. a drilled water well) and arranging for the subsequent management and maintain of the source. Community mobilisation may also include the collection of a cash or in-kind contribution towards construction by the local government, NGO or donor involved.

Data - all facts about a borehole collected before and during, drilling, borehole development, completion and pumping test.

Derogation is the effect of pumping a well on the seasonal flow from springs, the drawdown in nearby wells, or the drying of wetlands.

Drawdown refers to water level lowering caused by groundwater pumping.

Drilling contractor is a private company or NGO engaged in the drilling of boreholes for water supply boreholes.

Drilling technology - the method of construction and equipment used in making the drilled water well.

Engineers Estimate – a reflection of a fair and reasonable price for the construction work, as determined by a professional (including labour, equipment, materials and a reasonable value for overheads and profit).

Gravel pack – an artificially placed permeable annular backfill, which is placed around the screen of drilled water well. It needs to be at least 70cm thick to be effective. If it is thinner then it is actually a formation stabiliser (see below).

Formation stabiliser - if a well can be developed naturally, or the annular space around the screen is limited, or both a permeable backfill, known as a formation stabiliser, is placed simply to fill the annular space and prevent the formation from collapsing onto the screen.

Hydrogeological consultant – the professional company or individual responsible for water well siting and design.

Interference - the effect that pumping from a well has on the drawdown in neighbouring wells

Lease to purchase agreement – a rental agreement with an exclusive option of the right of first refusal to later purchase the item.

Method statement - a document that clearly sets out the details of how the work will be carried out.

Monitoring - the periodic checking of the functionality of boreholes, pumps and aprons and community management of the water source as well as water levels and water quality.

Operation and maintenance - running and repairing the water well, pump and apron so that sufficient clean water can be pumped at all times throughout its designed life and the general area of the well is kept clean. It also encompasses wellhead protection, post-construction support and access to spare parts for the pump and well maintenance.

Planning at community level – a pre-project assessment of the existing water and socioeconomic situation of the community to determine the most suitable water facility.

Procurement - the process of selecting a drilling contractor, hydrogeological consultant or supplier to undertake a particular service or construction.

Quality control - ensuring that both the pumps and spare parts supplied and well construction adhere to the specifications.

Yield – this is a term which is very often misused. Drilling contractors often refer to yield when they actually mean (a) the flow measured during air-flush drilling or (b) the rate at which the water was pumped during the pumping test. In reality the deliverable well yield depends on the aquifer geometry and hydraulic properties, combined with the maximum permissible drawdown in that particular situation. It should be noted that this definition takes no account of renewable groundwater resources.

Assumptions

A rural well serves 100 to 300 people 20 litres/person/day, and is pumped for ten hours per day. This is an average pump rate of 0.1 to 0.3 litres/second, corresponding to 360 litres/hour. A small town well serves 2,000 to 10,000 people a total of 40 litres/person/day and is pumped for ten hours per day. This is an average pump rate of 2 to 10 litres per second, corresponding to 7,200 to 36,000 litres/hour.

Chapter 1 Introduction

It is estimated that 884 million people do not have access to an improved water supply for drinking water of which 84% of whom live in rural areas (WHO/UNICEF 2010). Although the world is on track to meet the Millennium Development Goal (MDG) Target to "*halve, by 2015 the proportion of the population without sustainable access to safe drinking water*", the target is very unlikely to be met in rural sub-Saharan Africa. It is also worth noting that in striving to meet the above targets, there has been a tendency to focus public funds on construction of water supply infrastructure at the expense of institution-building, the development of human resources and monitoring systems or full consideration of long-term viability of improved supplies (RWSN 2010).

Improved groundwater supplies (particularly drilled and hand dug water wells) provide a significant proportion of rural dwellers with access to safe water within a reasonable distance of their home. It is estimated that about 60,000 boreholes per year need to be drilled in sub-Saharan Africa alone to meet the MDG Target. Groundwater is almost ubiquitous in nature and can be developed relatively cheaply and progressively to meet demand. It often has a lower capital cost than surface water, generally has excellent natural quality and can normally be used without treatment. Groundwater usually has at least some cover to protect it from the threat of pollution from human activities. However, concerns have been raised about varying construction quality and high costs of drilled water wells. Given the massive need for improved water supplies coupled with limited investment, there is an urgent need to fully understand the extent of these concerns, build on strengths and address weaknesses.

In some developing countries, emergency situations prevail, while others are in transition or reconstruction and some are implementing long-term development interventions. In many countries the role of Government is shifting from that of service provider to that of policy making, planning, resource mobilisation, regulation and facilitation. The private sector and NGOs are providing services, including the construction of boreholes. The capacity of the public sector as well as the maturity and professionalism of the private sector varies. However, inadequate legal frameworks and weak Government institutions mean that national standards and procedures with respect to borehole drilling are often lacking. Alternatively, if standards and procedures have been defined, then adherence and enforcement tends to be poor.

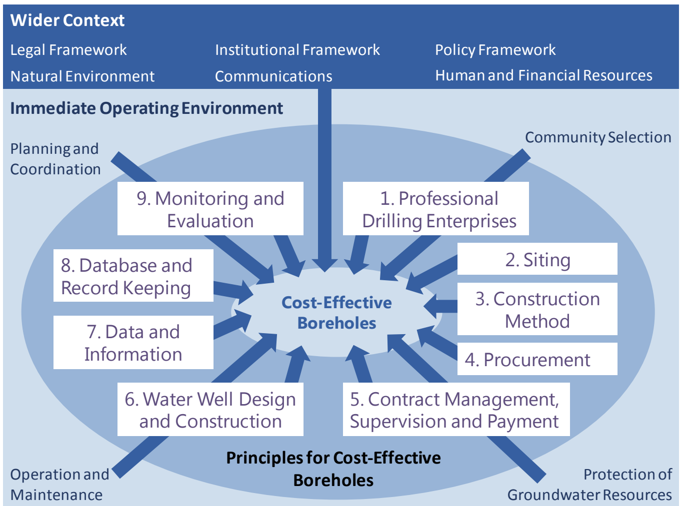
This document sets out a Code of Practice (COP) for Cost-effective Boreholes based on international practice. The term "cost-effective" means optimum value for money invested over the long term. Boreholes are drilled to function for a lifespan of 20 to 50 years. Thus, the lowest cost well is not always the most cost-effective, particularly if construction quality is compromised to save money. Cheap drilling or poor construction quality can lead to premature failure of the well or contamination of the water supply. Boreholes that are subsequently abandoned by the users are clearly not cost-effective.

In order for boreholes (sometimes referred to as drilled water wells or tubewells) to be cost-effective they need to be appropriately specified, properly sited and drilled using suitable methods and equipment. Where the private sector is used, competent procurement and contract management procedures need to be followed. Drillers, as well as supervisors need to ensure adequate construction quality.

The focus of the COP is on nine principles which relate directly to the practicalities of water well construction (Figure 1). These principles should be adhered to in order to provide cost-effective wells. Each principle is broken down into a set of sub-principles which recommend procedures to be followed and call for the definition of and adherence to minimum standards.

The COP recognises the context in which borehole drilling construction programmes operate. In particular four aspects of the immediate operating environment (planning and coordination, community selection, operation and maintenance and protection of environmental and groundwater resources), as set out in Figure 1, are discussed briefly. These are essential for the long-term functioning of newly constructed supplies. The wider context of the legal, institutional and policy frameworks, the natural environment, communications and human, as well as financial resources are also important, but are beyond the scope of the COP. The wider context is therefore only discussed in direct relation to the nine principles.

Figure 1. Scope and Focus of Code of Practice



The Code of Practice can be used as follows:

- Firstly, it provides a systematic framework for national Governments and their development partners to analyse the strengths and weaknesses of existing policies and practices. Such analysis provides a basis for informed stakeholder dialogue and action to improve the situation and can lead to decisions to develop particular standards or guidelines and even capacity-building activities.
- Secondly, the COP is intended to be used as the foundation for the development of national protocols[1] for cost-effective borehole provision. The protocols would encompass well-accepted procedures and be adhered to by all sector players as they plan and implement water supply programmes that include borehole drilling. National protocols will differ and need to be flexible and broad enough to take account of local or regional differences. Neither should they be too rigid to prevent innovation.
- Thirdly the COP enables international organisations, private enterprises and NGOs to examine whether they are working in accordance with best international practices.

[1] In some countries the protocol is referred to as a strategy or a code of conduct.

- Fourthly, it can be used by donor organisations in order to reflect on the relevance of their funding conditionalities and enable the identification of key areas for donor support, knowledge exchange and technical assistance.

Chapter 2 of this document looks more closely at the immediate operating environment in which borehole drilling programmes take place. The nine principles for Cost Effective Borehole Construction are set out in Chapter 3. The annexes provide relevant guidance materials and references.

Chapter 2 Operating Environment

This chapter briefly discusses the four issues of planning and coordination; community selection; operation and maintenance and groundwater resources. These issues are extremely important and should be considered at the project or programme design stage as they provide a foundation for the long-term sustainability of newly constructed facilities. This has a direct bearing on the cost-effectiveness of borehole construction. Unfortunately, these issues are often overlooked by agencies implementing water well construction programmes.

Planning and Coordination

Ideally planning and coordinating of water supply infrastructure improvements should be undertaken by the lowest appropriate level of Government. All donors, NGOs and other Government institutions should inform local Government and consult with them from the planning of investments through to infrastructure development.

Local Government should develop a workplan which incorporates the social components (i.e. community sensitisation, mobilisation and training) with water well siting and construction works. Potential contractors must be informed of the workplan. Efforts should be made to consolidate the plans, tenders and contracts for water well construction by water, education and health departments at local level. Multi-year development plans at local government level can form the basis for multi-year contracts.

Community Selection

The process of community selection for improved water supplies should be well-defined and transparent. In countries where there is some form of decentralisation, this process should be led by local government with external agents providing support and inputs. National systems for prioritisation and community selection (e.g. demand responsive; pro-poor; equitable access) should be adhered to by all agencies involved in rural water supplies.

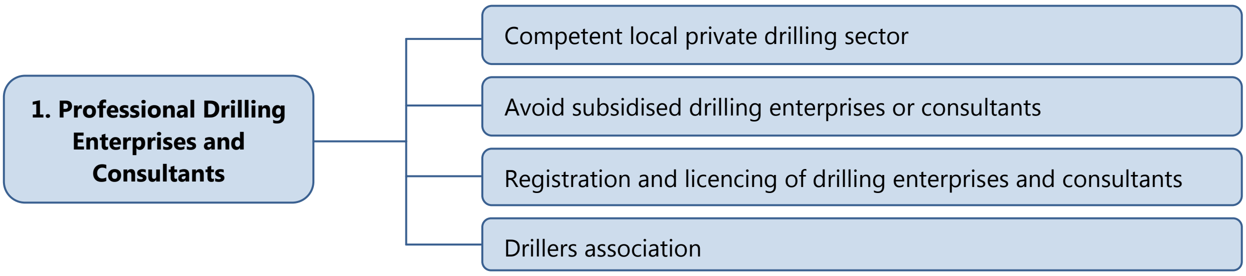
Operation and Maintenance

The long-term operation and maintenance requirements for the full lifetime of the technology should be fully considered during the planning stage. At a bare minimum, there is need for a national operation and maintenance strategy, or framework which ensures that:

- water users, caretakers, mechanics, suppliers and local Government have the right equipment and skills and are aware of their roles and responsibilities in relation to others;
- a clear process of community contribution or full payment for construction is adhered to by all stakeholders working in a particular area/district/country;
- the collection of user fees for maintenance is adhered to by all stakeholders working in a particular area/district/country. Procedures for changes to fees and fundraising for major repairs or system extension should also be set out;
- there is a reliable and competitive supply chain for spare parts, equipment and water well maintenance services. In addition, it is essential that a quality control mechanism for pumps and spare parts is in place and adhered to. This should include pre-shipment inspection and testing, certification and consignee end inspection.
- a robust and adequately financed system of post-construction support to water users' needs is in place. The type of support required will vary, depending on whether the systems are managed by the community, or managed commercially by a private company/individual or utility.
- In cases where the original design is found to be inappropriate for the community situation, it may need to be altered accordingly. If the end users do not fulfil their obligations with respect to operation and maintenance then re-training and improvement of management should be undertaken rather than new construction.

Environmental and Groundwater Resources

- Measures should be taken to manage and monitor environmental and groundwater resources and protect vulnerable resources from over-exploitation. There is need for adherence to the environmental protection regulations as stipulated by the relevant national environmental authorities.
- Water quality should be checked at key times of the year for bacteriological and chemical contamination in accordance with national guidelines (e.g. arsenic, nitrate, fluoride, iron, manganese). Groundwater levels as well as continued adherence to groundwater protection measures need to be monitored. Users should be aware of the risks associated with consumption of water from highly contaminated sources. Specific monitoring of particularly vulnerable groundwater resources should be undertaken.
- Note that although emergency situations may require short-term solutions with immediate results, the subsequent transition to a development situation should also be considered.



Chapter 3 Principles

Each of the following nine sections comprises an overall principle **(in bold)**, followed by sub-principles and further explanatory text. National protocols may follow this overall structure, modifying principles as appropriate and even adding or removing specific principles where necessary.

1. Professional Drilling Enterprises and Consultants

Principle 1 Construction of boreholes and supervision is undertaken by professional and competent organisations which adhere to national standards and are regulated by the public sector.

This breaks down into the following sub-principles:

- Construction of drilled water wells and installation of pumps should normally be undertaken by local private sector firms (or NGOs) rather than by Government or donor agencies.
- Subsidised drilling by public/state drilling enterprises and NGOs should be avoided. If considerable drilling is undertaken directly by the public sector or the private sector drilling capacity is weak, stakeholders should develop a strategy for achieving local private sector involvement in a time-bound manner.
- Similarly, the siting and design of boreholes and supervision of construction should normally be undertaken by local private sector consultancy firms. Subsidised consultancy services by public/state enterprises and NGOs should be avoided. If considerable work is undertaken directly by the public sector or there is limited capacity within private sector consultants, stakeholders should develop a strategy for improving local private sector involvement.
- Drilling enterprises and consultants should be registered and issued with a licence or permit, or be recognised by a national or international engineering board, council or institution. They should be registered as a company with the relevant authorities, including for tax purposes. The permit should be renewed annually (or every 2 to 3 years) provided that conditions are met, including the submission of drilling completion reports as specified, and even successful completion of further training. Consultants will also need to demonstrate their experience and competence.
- A national drillers association should exist and be active in discussing and expressing drillers' concerns.

The public sector has tended to undertake the construction of boreholes in many countries. However, the preferred option is for construction to be undertaken by the local private sector (or NGO) with Government responsible for planning, resource mobilisation, policy making and regulation. Government and donor support agencies as well as NGOs are therefore encouraged to provide support to build up the local private sector, rather than to purchase state-owned drilling equipment.

If the local private sector is particularly weak, the asset base and capacity may take a decade or more to be built. Investment requirements for large drilling equipment are hundreds of thousands of dollars and it takes several years to build up skilled drillers. The use of mechanisms whereby an enterprise leases equipment with the first right of refusal to purchase it over a period of one to three years is one way to build the asset base. Such mechanisms should be considered as they enable the capital cost of drilling equipment to be progressively recovered over time from contract payments. However they require the establishment of honest, open and transparent processes.

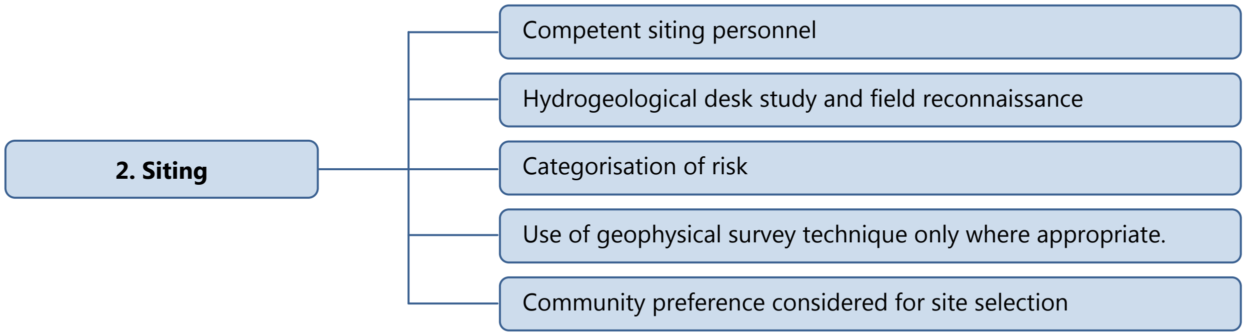
In cases where support agencies have already supplied drilling equipment there is a need to ensure that there is support in the form of spare parts, tools, management support and training, for a ten-year period (estimated rig life), following the rig commissioning. If support agencies provided drilling rigs to Government within, a rig information management system (Box 1) should be established, utilised and reported on. Private enterprises are also encouraged to utilise a rig information management system to record key information.

Box 1. Outline for Rig Information Management System

A rig information management system (RIMS) enables information regarding the utilisation, maintenance and repair of drilling equipment to be recorded, stored and analysed. It can be in paper-format or software-aided. A RIMS enables drilling programme managers to monitor equipment productivity, track equipment use and reduce misuse or abuse by recording the following:

- Details of drilling rigs, compressors and support vehicles (all equipment has a unique identification number and description).
- List of the Region/State, Local Government and Village/ Community of operation (with identification codes).
- Details of each borehole drilled (i.e. location with grid reference, e.g. from a GPS, borehole identification number, start date, completion date depth drilled, drilling time and idle time on site). Note that this does not replace a national groundwater database.
- Distance travelled (initial mobilisation as well as between individual sites) and downtime (due to idleness, maintenance and repair).

The RIMS needs to enable information to be retrieved regarding drilling activities for particular equipment, the local authority, community or period of time as well as maintenance and repair activities for particular equipment. A RIMS underpins the equipment maintenance plan.



2. Siting

Principle 2 Appropriate siting practices are utilised and competently and scientifically carried out.

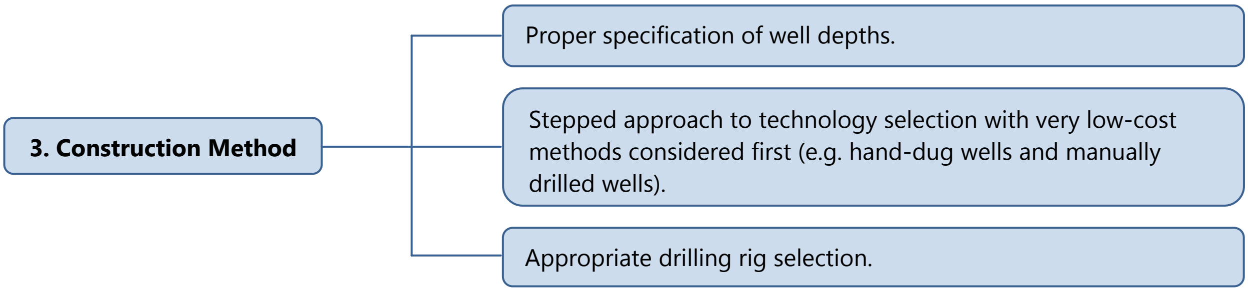
This breaks down into the following sub-principles:

- Borehole siting should be undertaken by competent personnel.
- Prior to preparing any well construction contract, a hydrogeological desk study and field reconnaissance need to be carried out and the method of siting the wells agreed upon, based on expert opinion.
- The risk of drilling an unsuccessful borehole should be categorised. In proven areas where the geology is well understood and borehole success is high (say over 70%), it may not be necessary to site wells using geophysical survey techniques.
- Geophysical surveys should only be undertaken where the costs of drilling an unsuccessful well may justify the expense.
- The site selection needs to take into account community preferences with respect to convenience.

Determining the best site for a borehole requires consideration of technical, environmental, social, financial and institutional issues. The siting process should show which groundwater conditions dominate the project area and enable the borehole(s) design to be specified. Professional siting involves desk and field reconnaissance, and makes full use of existing data. In order to determine the best place for a borehole ten factors are of particular importance:

- **Sufficient yield for the intended purpose:** The groundwater aquifer should have a sufficient yield for a rural water supply handpump (around 0.1-0.3 l/sec), for a small town water supply (2-10 l/sec), or for a larger scale need such as a significant irrigated area[3]. This information is sometimes available from existing documents or can be derived by performing a pumping test (see forms in Annex E).
- **Sufficient renewable water resources for the intended purpose**. Although a well may be capable of delivering a certain yield in the short to medium term, if the groundwater is not regularly replenished by infiltration from rainfall or river flow, then that yield will not be sustained over the long term. It is therefore important to evaluate the likely recharge to the aquifer, and how this might vary with time. This estimate can be based on a water balance of an area calculated in a conceptual water model.
- **Appropriate water quality for the intended purpose.** Different water uses impose different water quality requirements. Domestic water must be free of disease pathogens (which are carried in human excreta) and low in toxic chemical species such as arsenic or fluoride. When using groundwater for irrigation the level of salinity has to be checked. Well siting must therefore take account of knowledge of the occurrence of such undesirable substances. Water from the completed and developed well should be tested with the results tested against national standards. Where these are not available, the WHO guidelines may be used (WHO 2008).
- **Avoidance of potential sources of contamination.** It is essential to avoid point contamination sources such as pit latrines, septic tanks, livestock pens and solid waste dumps. There may be national guidelines on separation distances or groundwater protection zones. If these do not exist, they need to be developed.
- **Engagement with the community** to agree on the well location is essential and requires some negotiation to explain technical constraints whilst taking community preferences into account. Full consideration of the needs of women, who tend to be responsible for water collection, is essential. Land ownership issues also need to be considered.
- **Proximity to the point of use.** Within the constraints of geology, groundwater resources and groundwater quality, wells should ideally be sited as close as possible to the point of use. This means that walking distances to collect water from rural point sources (e.g. handpump wells) and energy costs for electric or fuel driven pumps and piped supplies should be minimised. Walkover surveys should be undertaken to prepare a map of the community. Interviews with householders will help to understand the community's preference for well location. In general the community would be expected to indicate three preferred well sites in their locality, in order of priority.
- **Access by construction and maintenance teams.** In the case of wells constructed by heavy machinery, access by drilling rigs, compressors and support vehicles is crucial. Even when lighter equipment is used, vehicle access for construction and for maintenance is important. Site selection must therefore take account of these needs.
- **Avoidance of interference with other groundwater sources and uses.** In areas where some groundwater development has already taken place, the construction of a new well can lead to increased drawdown[2] in existing sources. This in turn can lead to greater pumping (energy) costs in both the existing well and the new well, reduced yields, changes in groundwater quality and potential conflict between users. In an early phase of the siting process possible interference[2] and risks of derogation[2] have to be described and discussed. This means that the radius of influence of existing wells should be calculated and new wells located outside this zone. In high-risk situations possible alternative siting areas should be evaluated.
- **Avoidance of interference with natural groundwater discharges**. In a similar way, the construction of a well too near to natural springs, watercourses or wetlands can lead to a reduction of water levels, potentially drying up these important water sources and ecosystems and affecting uses and users dependent upon them. The intrusion of salt-water due to too high abstraction of groundwater near the coast could lead to irreversible decline of water quality.

[2] See Glossary



- **Risk.** As part of borehole siting, the risk of drilling a dry borehole should be categorised (e.g. high, medium and low risk as set out in Annex C). In the case of boreholes which are to be fitted with handpumps in areas with known hydrogeology, geophysical techniques (e.g. resistivity, conductivity) are rarely required so long as a desk study has been undertaken of the general hydrogeology in the area. Drilling small-diameter exploratory wells (e.g. with a small hand auger) can also be a suitable siting method for shallow wells. However, this hole should be properly sealed afterwards to avoid aquifer contamination.
- If skills for borehole siting are lacking in the country, efforts should be made to build long-term capacity in this regard.

3. Construction Method

Principle 3 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.

This breaks down into the following sub-principles:

- Well depths should not be unnecessarily over-specified or under-specified.
- A stepped approach to technology selection should be followed. Very low-cost methods, including protected hand dug wells and manual drilling, are considered first, if they are feasible, before mechanised drilling.
- Subsequently, the use of small rigs, which provide the specified diameter and well depth and reach remote locations, should be considered.
- Finally, the use of larger drilling rigs should be considered.

It is important that well designs are properly specified. Stakeholders should avoid over-specifying depths and diameters on a 'just in case' basis as this then over-specifies the drilling rig required. This results in the mobilisation of excess equipment and raises costs. However, under-specification is also a problem. It can sometimes result in a failed borehole or in the need to mobilise a different drilling rig. Past experiences should be used to help determine the design by comparing previous contract specifications with actual drilled depths.

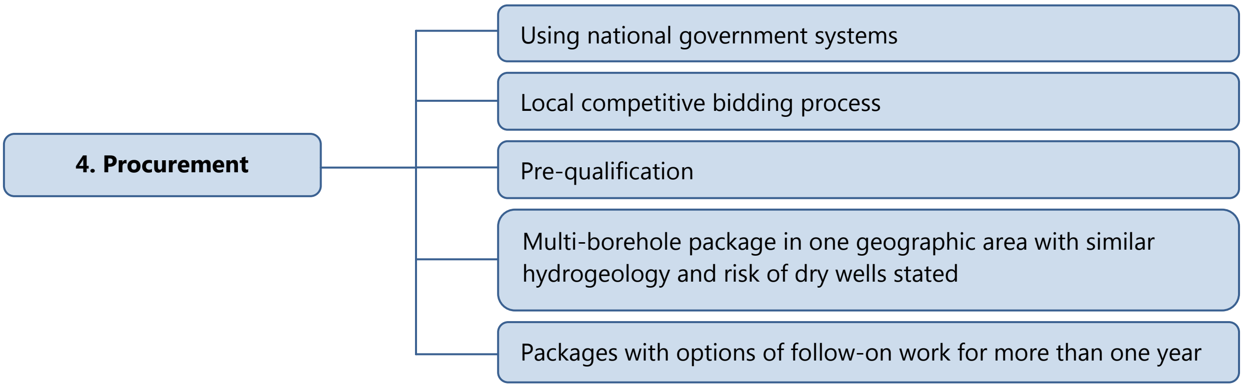
Tender and contract documents should enable the least expensive, but suitable drilling equipment to compete against larger, more expensive rigs. Tenders should specify the final product (i.e. the drilled water well) and thus avoid over-specifying the drilling equipment. Small, low-cost, mechanised rigs, which drill at lower cost than large rigs, can often be transported on the back of a four-wheel drive pickup or single axle trailer and can reach more remote locations, particularly where road networks are poor. If stakeholders do not know about small mechanised drilling technologies, explicit efforts should be made to raise their awareness.

It should however be noted that drilling with a smaller rig may be slower, and will thus require longer supervision. This needs to be fully considered when planning contract management and supervision requirements.

Hand-dug and manually drilled wells are an option in specific environments (soft formation and shallow groundwater). In areas where such techniques can provide water wells in significant numbers, they should be fully considered. However, borehole verticality needs to be good enough to enable the installation and operation of the specified pump, and wells need to be deep enough to sustain supplies in prolonged dry periods and successive dry years. Therefore the use of such methods needs to incorporate an appropriate level of supervision and quality control.

Dissemination of information, exchange visits, pilot projects, support to the local private sector, and in-country studies may be necessary in areas where hand dug wells or manual drilling techniques are not well known or not commonly used.

The conventional mechanised drilling techniques to construct drilled water wells suitable for rural and peri-urban water supply projects are rotary drilling with mud-circulation, cable tool percussion drilling, and down-the-hole (DTH) air-percussion drilling. Combinations of these drilling techniques can also be used depending on the geology (e.g. mud-circulation rotary drilling through collapsible over-burden to hard rock, then air percussion drilling). Selection of the most suitable equipment depends on the depth of the well and the lifting capacity of the rig to pull out drilling tools and temporary casings, too. Annex C provides guidance with respect to drilling method selection.



In order to improve the availability of spare parts for drilling equipment in countries with low levels of industrialisation the private sector should be encouraged to partly standardise on their drilling equipment. It may be easier to discuss this with a drillers association (if it exists). However, the final decision must remain within the hands of the private contractors and the danger of creating a monopoly for suppliers needs to be considered.

4. Procurement

Principle 4 Procurement procedures ensure that contracts are awarded to experienced and qualified consultants and drilling contractors.

This breaks down into the following sub-principles:

- Procurement should be undertaken through national government systems rather than those of the donor or support organisation. If national government systems are particularly slow or weak, a mix of approaches should be used in order to improve the national systems, at the same time as achieving results in the field. There will also be cases where procurement is best undertaken directly by the end-user of the well (e.g. community or institution).
- The engagement of consultants and construction companies for borehole provision should be through a national (or local) competitive bidding process, involving pre-qualification. Engineers' estimates and recent tenders for similar works or services should be used for comparison against the tender prices. This should avoid contracts being awarded to tenders that are significantly below the estimated cost price.
- Procurement should be for a multi-borehole package, in a fairly close geographic area, with similar depth and hydrogeology. Lots could be for a reasonably high number of boreholes, depending on the need to provide opportunities to smaller drilling companies in order to build in-country capacity.
- In order to draw upon and build in-country capacity, and enable smaller enterprises to compete with larger companies, mechanisms of awarding packages which include an option for follow-on work should be considered. Alternatively, a contract which spans a number of years (subject to clear performance measurement) should be considered.

Where in-country tender and contract award procedures (i.e. the constituted public procurement system) are weak, these should be strengthened and utilised. In order to ensure that contracts are awarded to experienced and qualified consultants and drilling contractors a process of pre-qualification, tender and contract award is recommended:

- Human resource needs and equipment capability requirements should be clearly defined. These should be in line with well design, construction method and contract size.
- A transparent and thorough pre-qualification process should be based on the company profile, equipment and staff skills, turnover, experience and past performance as well as on adherence to national regulations with respect to drilling permits, licensing and membership of national professional associations. Pre-qualification, which can be undertaken every one to three years, should include visits to the company premises and, if possible, their on-site operations during and after completion of a recent borehole installation. The list of pre-qualified contractors should be published.
- The tender or award process involving the submission of a method statement should only be open to pre-qualified contractors.
- Tender documents, drawings and specifications should be based on the findings of the well siting and design process and should be endorsed by Local Government and other key stakeholders prior to tendering.
- The required outputs (e.g. locations, depths, drilling conditions) should be clearly defined at the tender stage. If this is not possible then an open negotiated agreement, based on typical costs, as set out in the sample bill of quantities (Annex A), can be undertaken.
- A tender meeting should be held whereby a hydrogeologist who is intimate with drilling conditions in the area describes the scope of work and *"categories of risk"*. This is discussed further under Principle 4 on Siting.
- A clear and transparent contract award process with clearly defined evaluation criteria, programme of key dates, public opening of tenders, evaluation to include clarification and discussion with tenderers, notification of results and award and procedures for disputing the result.

Contract packaging in terms of boreholes within close proximity is intended to reduce mobilisation costs and to facilitate contract supervision. It is advisable to package wells together; bearing in mind the total number of wells in a programme and the possibility that when too many wells are in a package this may exclude small local contractors.

5. Design and Construction

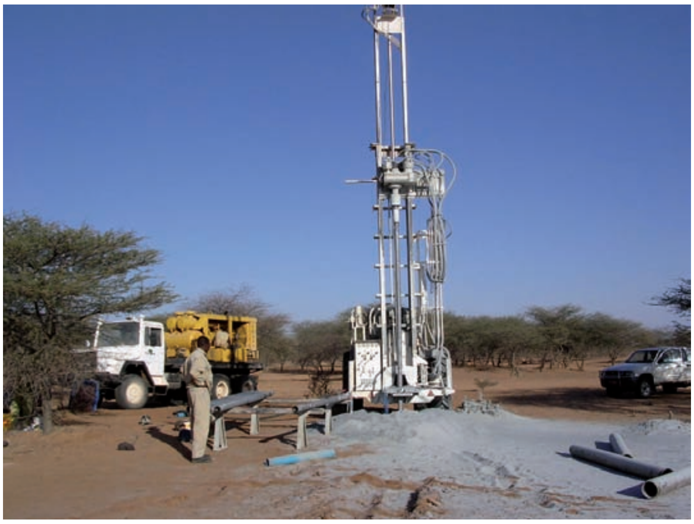
- Minimum specification for *„fit for purpose"* well (e.g. yield, diameter, depth, casing and screen, gravel pack/formation stabiliser, verticality, drilling additive and sanitary seal).
- Appropriate well development
- Suitable pumping test requirements
- Water quality analysis

Packaging can be a particular challenge in countries operating in a highly decentralised manner. However, innovative solutions can be considered such as rolling budget allocations from one year to the next or drilling every 2 to 4 years in order to bulk up the numbers. Contracting out wells of similar depth and hydrogeology in one lot facilitates the use of smaller, less costly rigs where appropriate.

A mechanism to enable small companies to participate is to award packages to a pool of drillers, with the option for follow-on work i.e.:

- Pre-qualify a number of contractors and undertake the bidding process.
- Identify contractors to be included in a pool of drillers for a specified term.
- Negotiate and set drilling prices for an agreed area.
- Award packages (of say 10 to 30 wells) to several contractors in the pool of drillers.
- As the packages are completed, subsequent work can be awarded depending on the performance of the contractor.

Such a mechanism enables contractors to work for more contracts as high quality and timely construction wins new work. Contractors with multiple rigs can take on several packages; those with one rig can work according to their capacity. The client has control over works being implemented.



5. Design and Construction

Principle 5 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.

This breaks down into the following sub-principles:

- Minimum specification for "fit for purpose" well in terms of yield, diameter, depth, casing and screen, gravel pack/formation stabiliser, verticality, drilling additive and sanitary seal. Over-design of boreholes, especially excessive depth or diameter, is wasteful and should be avoided.
- The procedures for well development are agreed and clearly specified in the drilling contract. The drilled well must be developed until the water is free of solids and fine materials (fines) and any turbidity for a continuous period of 30 minutes.
- The procedures for well development and for pumping tests are agreed and clearly specified in the drilling contract. Pumping test requirements for a handpump should be realistic and not over-specified.
- Water quality testing for specified chemicals and microbiological content is undertaken, particularly for areas at risk and boreholes serving institutions (e.g. health centres and schools).

A fit-for-purpose design is summarised below. In the case of motorised systems (if deemed cost-effective), design must account for the precise requirements of the system.

- In terms of **deliverable well yield** for a handpump, $1m^3$/hour is sufficient, although this may be dropped to 400 litres per hour in areas where groundwater is difficult to find[3]. Wells should only be drilled to the required depth for this output. Requirements for motor pumps depend on the system design, which is based on user requirements and can be significantly higher than that of a handpump.
- Handpump borehole **diameter** requirements and the small diameter pumps now on the market mean that 4" (~100mm) internal diameter cased boreholes are sufficient for the handpump cylinder and rising main. Normally uPVC casing/screen is specified which has a minimum internal diameter of 103mm and an outside diameter of 113mm. Motorised boreholes may require more space to permit the installation of a submersible pump, and can be completed with a casing/pump housing of 4" or 5" nominal diameter.

[3] See Assumptions

- **Depth**: Firstly, the current rest water level needs to be measured. Then the low rest water level as a result of seasonal or longer term fluctuations needs to be determined. The expected drawdown due to pumping needs to be factored in, together with the requirements for screen length and sump. This will enable the total depth to be calculated. In locations where superficial weathered formations are likely to be of a sufficient thickness, permeability and storage to support the required yield, and deal with fluctuations in the water level, the use of a relatively shallow well (screened and installed with gravel pack or formation stabiliser), constructed by a small drilling rig, or manually drilled may be cost-effective.
- **Plain casing and screen**: The screen should be installed in the water-bearing formation and should have sufficient open area (determined by slot size and length) to allow the water to flow freely into the well. Screen length should not be compromised to save cost as it can result in a dry borehole. In locations where boreholes are drilled into stable basement formation, it is possible to make savings by casing the collapsing formation only. However, the interface between the collapsing formation and hard formation must be sealed (e.g. with grout). Plastic (uPVC) casing and screen should be used in preference to steel where wells are less than 100-120m in depth.
- **Gravel pack**[4] or **formation stabiliser**[4] should have a proper grading with a quality of >95% silica. It needs to be installed slowly and carefully, preferably with a tremie pipe and funnel.
- **Verticality and alignment** need to be specified as a condition of the well being denoted as successful (e.g. <100mm for every 30m). Verticality and alignment should be such that the pump and rising main can be lowered into the well without meeting any resistance.
- Chemical foam and biodegradable mud should be utilised as **drilling additives** in preference to bentonite and other non-degradable mud. Once the drilling progresses below the water table, bentonite should not be used as a drilling mud as it tends to clog the inlet of the water bearing formation and is very difficult to remove.
- **Backfill** of the annulus with drilling spoil is essential.
- A **sanitary seal** of grout to a depth of at least 5m from the ground level is required. It is essential that no contaminated water (e.g. from the surface or from pit latrines) can leak into the well or the aquifer.
- A **concrete apron/platform** is required which drains spilt water away from the borehole. Drainage ditches, as well as a fence to keep out animals are also necessary.

Annex D sets out sample borehole designs for the major hydrogeological formations.

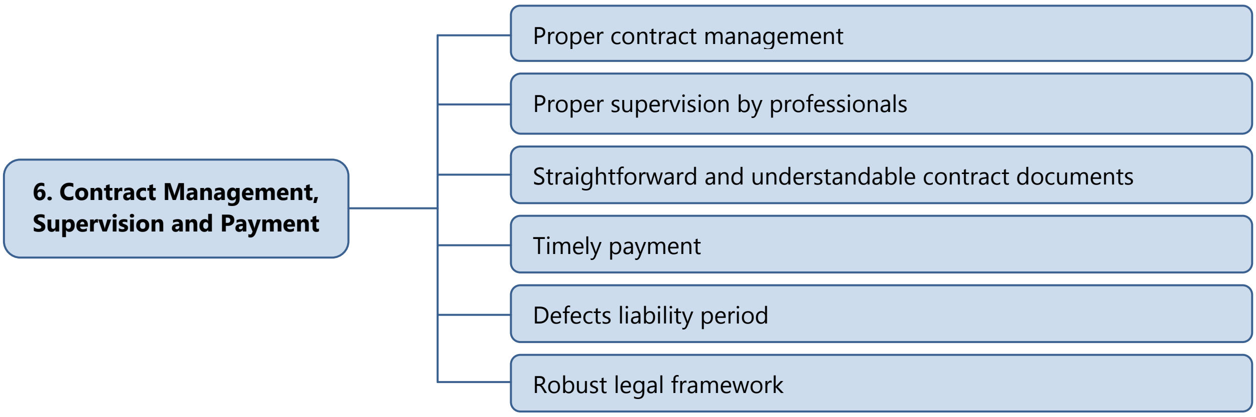
Well development must be undertaken before the drilling contractor moves to the next site. If the screen surrounding formation/gravel pack area is not properly flushed, well efficiency can drop and the screen can block over time. Wherever possible, natural well development should be utilised. Well development is best undertaken with compressed air or water jetting thoroughly applied to all of the screened areas. Surging with a bailer may also be suitable. The borehole should be flushed until it is free of fines and turbidity for a continuous period of 30 minutes. Chlorine can also be introduced before well development to help break down the drilling polymer. Once the lifted water is clear, then the amount of water being voided from the well by the air-lift should be quantified and the measured "airlifted yield" recorded.

Pumping tests are undertaken to establish well efficiency and assess the aquifer properties. Requirements appropriate for a hand pump are continuous pumping for 3 to 6 hours. Normally, the discharge rate should be at least 10% above the design discharge for a successful borehole. Recovery should be measured. National or international standards (e.g. BS ISO 1468:2003) should be used here). In the case of motorised wells, more comprehensive drawdown and recovery tests should be undertaken (e.g. step drawdown and 24-hour constant discharge pumping tests).

Water quality analysis in line with national guidelines should be undertaken and results submitted to the appropriate authority. On site testing of temperature, pH, turbidity, conductivity, colour, taste, arsenic, iron, manganese, total coliform and E. coli should be undertaken when possible.

Pump installation: The pump choice should be in line with national standards and specifications, if these exist. The pump should be positioned at the correct level above the screened section, taking into account the drawdown and seasonal variations. This is generally 2m below the lowest dynamic water level.

[4] See Glossary.



6. Contract Management, Supervision and Payment

Principle 6 Adequate arrangements are in place to ensure proper contract management, supervision and timely payment of the drilling contractor.

This breaks down into the following sub-principles:

- Normally, contract management should be based on Government systems. These should follow international best practice and use standard contract forms.
- Contract documents need to be straightforward and readily understandable by the drilling contractors.
- 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 building expertise over the long term.
- Payment for construction works should be timely.
- A defects liability period should be considered whereby a financial retention (of about 10%) is held in an insurance bond, bank guarantee or cash.
- Ideally a robust legal framework that supports compensation, financial retention mechanisms, and audit and compliance procedures is required.

Expertise and experienced personnel for the design, management, supervision and scheduling of drilling programmes is essential to ensure that the wells drilled are of high quality and that drilling costs are reasonable. For example, downtime at the drill site while waiting for decisions to be made can raise the overall drilling costs considerably. Likewise planning drilling during the rainy season may lead to other costly delays.

Contracts for borehole drilling can be paid according to a Bill of Quantities (BoQ – see Annex A) or as a lump sum. Although lump sum contracts are simpler to manage, it is still essential that supervision is competent. In general, the contract must ensure that it is in the driller's interest to construct a high-quality borehole. Lump sum contracts are more appropriate under conditions where there is no payment for dry wells, although this can also be written into a contract which is paid according to a BoQ. However this requires a categorisation of the risks of drilling a dry borehole and appropriate payment mechanisms, such as set out in Annex C. Contracts may either bundle the pump installation with the borehole construction or handle this separately, for procurement and installation by local mechanics.

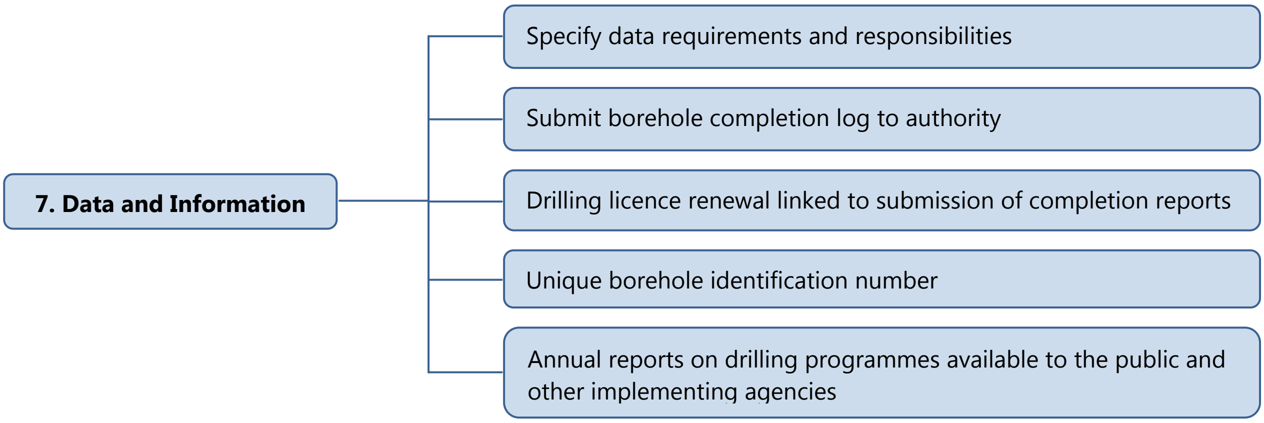
In cases where performance bonds from a bank can only be secured through cash payments, it is preferable that Contracts insist on insurance bonds from a reputable company.

Proper supervision is a good investment that ensures high quality construction and that wells are not drilled deeper than necessary and prevents boreholes from being abandoned prematurely. However, there is a need for regulation of drilling supervision. Borehole drilling works should preferably be supervised full-time by skilled and qualified personnel in order to ensure high quality construction. Part time supervision should only be undertaken when there are significant resource constraints. In such cases it is still essential that there is supervision of the pumping test and that the borehole depth is measured.

Staff of the client organisation or private sector consultants should undertake drilling supervision. In both cases they need to have adequate skills and financial resources as well as sufficient time. Supervisors need to be well-trained and operate independently from the driller in terms of finance and logistics. A remote location should not be an excuse for not undertaking supervision. Typical outcomes of poor drilling supervision are:

- Drilling contractor claims borehole is deeper than in reality;
- borehole of smaller diameter than specified is drilled;
- borehole drilled deeper than necessary (e.g. if drilling contractor is paid against a bill of quantities and tries to maximise revenue);
- incorrect screen placement or use of non-specification screen materials;
- insufficient or use of non specification gravel;
- lack of grout;
- insufficient borehole development;
- drilling contractor claims well success, but in reality it is dry. This is often the case when drilling is undertaken soon after a rainy season. The well may go dry during the dry season as water levels fall;
- installation of non-specification pumps (either oversized or undersized).

Community monitoring of the construction and supervision should also be considered. If properly trained, communities can, for example monitor the number of casing pipes installed, number of bags of cement used by the contractor and presence of the supervisor.



Boreholes which are signed off as successful often go dry within a short time due to poor construction. In order to deal with this a defects and liability clause, with about 10% retention of contract value, can be included in the Contract and enforced. Towards the end of the 12-month period, under the terms of the Contract, supervisors are obliged to visit each completed site for the final sign-off, which includes confirmation of viability with the water users. It is essential that the Contract clearly stipulates who is responsible for the pump quality within this period.

Payment for works should be made within one month of completion and should not extend to more than three months. Delays longer than this are not acceptable for drilling contractors to maintain their liquidity (cash flow) and should incur penalty/interest payments within the terms of the contract.

Third party monitoring, paid for by the client but undertaken by an independent trained professional following construction can also be undertaken as a control mechanism. This requires a well-defined and consistent checklist for every water-well drilled, with the results published.

In cases where the required legal framework and public institutions to underpin contract management procedures are weak, there is need for considerable emphasis on building the required systems through legislation and improving capacity.

7. Data and Information

Principle 7 High quality hydrogeological and borehole construction data for each well is collected in a standard format and submitted to the relevant Government authority.

This breaks down into the following sub-principles:

- The data to be gathered during borehole drilling is specified in the drilling contract and responsibilities for data collection between the contractor and the supervisor are clear.
- Information, in the form of a national borehole completion report should be submitted to the appropriate government authority after drilling (even in the case of dry boreholes).
- Renewal of drilling licences should be linked to the submission of borehole completion reports.
- Each borehole drilled in the country should have its own unique identification number.
- Government and other water sector stakeholders should collate data on borehole drilling programmes annually, and make the reports available to the public.

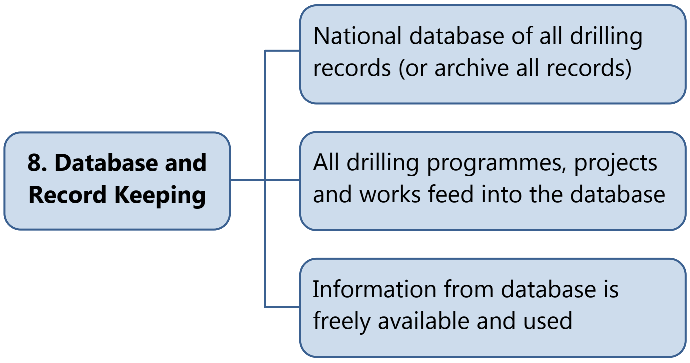
Formats for borehole completion records need to include information on the location, drilling operation, casing and well completion, lithology, well development and pumping test and water quality. Annex E provides a recommended format for borehole completion records. It is essential that this information is submitted to the appropriate centralised Government authority within 30 days of well completion, and that each project or programme does not merely hold on to its own data, but shares it with other implementing agencies.

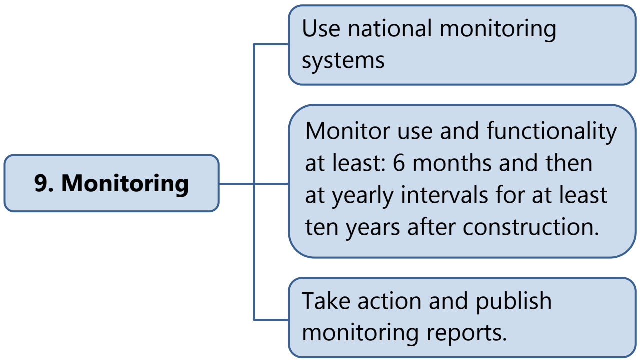
The importance of regulation and licensing of drilling contractors is noted under Principle 1. As a condition of annual drillers licence renewal, it is recommended that it is made obligatory for drillers to submit to the appropriate authority a bound compilation of their completion reports for their annual workload from the preceding year.

Each unique borehole identification number should be stamped onto a metal plate on the hand-pump base and also engraved into the pump platform or well head apron. In order to avoid the unplanned and unmonitored drilling of boreholes, permits to drill should be issued by the appropriate authority.

There should be transparent sharing of key information on drilling programmes by Governments, NGOs and other stakeholders. Reports should be placed in the public domain and thus be readily available to parliament, monitoring units within Government, civil society and other agencies. Key areas to be reported include:

- programme outputs (with associated costs) in terms of skills, knowledge and organisational capacity raised as well as the numbers of people trained;
- boreholes drilled (i.e. numbers, well depths, and locations with borehole numbers and GPS references);
- supervision summary reports;
- prices of each well installation, with details on what is included and excluded, (e.g. profit and overheads, siting, mobilisation, drilling, supervision, pumps, power supply, storage and distribution systems, training of the community). Include an explanation of how costs are derived (e.g. cost of package of 10 wells in a particular contract package divided by 10). Information needs to be structured in a way that enables comparisons between regions and /or districts to be carried out;
- details of private sector involvement including names of companies, contract summary and amount, date paid for construction and defects liability payment;
- findings of monitoring and evaluation missions.





8. Database and Record Keeping

Principle 8 Storage of hydrogeological data is undertaken by a central Government institution with records updated, information made freely available and used in preparing subsequent drilling specifications.

This breaks down into the following sub-principles:

- A national (or regional level) database of all borehole drilling records should be established and kept up-to-date. If no such national database exists, sector stakeholders should keep and archive records of all borehole drilling work undertaken until it is established.
- The data from all drilling programmes and projects in the country should feed into this database.
- Data from the database should be made available free of restriction.

The cumulative knowledge of groundwater resources provided by adequate and accessible data archives greatly enhances the chances of successful drilling and borehole construction. Borehole logs, completion reports and pumping test data (as specified in the drilling contract) must always be submitted to the relevant national (and/or) local authority. Information from "dry" or unsuccessful boreholes is just as important as that from the successful ones.

There is need for specific key data to be abstracted from the drilling completion reports and entered into a national database for borehole drilling. Such a database needs to be properly established, kept up to date, be readily accessible to all, and ensure that there is no duplication of data entry (i.e. by using a unique borehole identification number and GPS information). If there is no national database, drilling data should be archived by sector stakeholders until such a mechanism, with a responsible agent, is established. Government and external support organisations should be encouraged to enforce data gathering, establish groundwater databases and build the national capacity in this regard.

It is internationally accepted that to assess progress and status of national groundwater development and guide future planning, it is necessary to maintain good records of borehole drilling, and index and archive original documents so that they can be readily accessed. Records should include:

- pre-qualification and tender evaluation reports;
- reports of community mobilisation and training;
- schedules of construction supervision;
- monitoring reports.

9. Monitoring

Principle 9 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.

This breaks down into the following sub-principles:

- The monitoring systems of Government should be utilised (and strengthened if necessary) rather than the development of parallel systems.
- Monitoring of functionality, including analysis and action-taking should be undertaken at: 6 months, and then at yearly intervals for at least ten years after construction.
- The findings of the monitoring work should be linked to action and made public.

It is essential that the procedures for monitoring as set out by Government are respected, and/or improved, with all information collected communicated to the relevant authorities. Monitoring activities should complement established systems for operation and maintenance (discussed in Chapter 2).

Monitoring of functionality should consder both the water users and the water supply. Ideally, information should be collected on management of the source including revenue collection, maintenance funds and user satisfaction. Technical aspects of pump yield, static and dynamic water levels and water quality should be monitored. A sanitary inspection should be carried out, with reasons for any breakdowns and repairs made noted.

Findings should inform actions at the community and local Government level, and may inform national policies and programmes with respect to infrastructure development and operation and maintenance. Actions taken should be in line with any local by-laws and national policies.

Annex A Samples of Bill of Quantities (BoQ)

Table A1: Sample (i) Bill of Quantities for 10 wells: each with an average depth of 50m, i.e. total depth 500m.

	Description	Qty	Unit	Unit Price	Total Price
1	Borehole Siting	10	each		
2	Establishment of Base Camp	1	LS		
3	Mobilisation and demobilisation of equipment and personnel	500	km		
4	Set up of rig and move between sites	400	km		
5	Drilling borehole of 125mm (5”) nominal diameter in soft over-burden	200	m		
6	Supply, install and withdraw temporary casing	10	each		
7	Drilling borehole of 125mm (5”) nominal diameter in basement rock	300	m		
8	Sampling and Borehole Logging at 3m intervals	10	each		
9	Supply and installation of 110mm outside diameter, uPVC casings of 10 bar pressure rating	400	m		
10	Supply and installation of 110mm outside diameter, uPVC screens of 10 bar pressure rating. (Slot size 0.5mm)	100	m		
11	Supply and place approved filter pack around screens[5]	0.8	m^3		
12	Supply and installation of inert backfill	10	each		
13	Borehole cleaning & development till water is silt free	30	hour		
14	Pumping Test according to specification	10	each		
15	Provide and place cement grout	10	each		
16	Water Quality Analysis and borehole disinfection	10	each		
17	Well capping	10	each		
18	Installation of India II hand-pumps in accordance with specs.	10	each		
19	Completion Reports	30	each		
20	Waiting (or standing) Time		hour		
	Sub-total				
21	Overheads and profit -15%				
22	Value Added Tax (VAT)- 20%				
	Total				

In Table A2, items have been streamlined and the margin (profit plus overheads) is incorporated into the rates for the various items.

Table A2: Sample (ii) Bill of Quantities for 10 wells: each with an average depth of 50m, i.e. total depth 500m.

	Description	Qty	Unit	Unit Price	Total Price
1	Mobilisation	1	each		
2	Moving between sites	9	each		
3	Drilling	500	m		
4	Casing and Completion	500	m		
5	Gravel Pack and Development	100	m		
6	Pumping Test	10	each		
7	Backfill and well completion (including water quality analysis)	10	each		
8	Installation of handpump and accessories.	10	each		
9	Completion Reports	30	each		
	Sub-total				
	Value Added Tax (VAT)- 20%				
	Total				

It is essential that considerable care is given to the development of BoQs.

[5] This is the annular volume between the drilled hole and outer casing: 150mm diameter hole; 110mm diameter outside casing = 8 litres/metre, which is equivalent to 0.8m^3 for 10 wells each with 10m of filter pack.

Annex B Model to Categorise Risk and Payment Structures

Table B1 below provides a model to categorise risk of drilling a dry well and set out appropriate payment structures. It provides a particular approach which utilises different contract and payment arrangements, depending on the risk of drilling a dry well.

In all of these cases, the drilling contractor is responsible for the success of the borehole. It should be noted that this model is not intended to be prescriptive, but that it illustrates a way of dealing with one of the key challenges of borehole drilling; the risk of dry wells. An alternative method is for the client to take responsibility for the siting and pay the contractor for successful and dry holes according to a Bill of Quantities (BoQ).

In a particular country, or region, it may be possible to classify the drilling potential into three (or more) categories as set out in Table B1.

Table B1: Model to Categorise the Risk of Drilling a Dry Well with Example of Payment Structures

Category	Success Rate*	Assumptions	Proposed Payment Arrangements
A High Success	>75%	Geophysical survey not necessary. Drilling at any site has a high chance of success. First preference of community is likely to be successful.	The risk of dry drilling is denoted as small and dry boreholes are not paid to the contractor, under any circumstance. The driller is to select a site within the areas nominated by the community and his unit rates should include the risk of dry boreholes.
B Moderate Success	50 - 75%	The drillers themselves may elect to survey (either themselves or by their appointed hydrogeologist) and select the actual drill-sites within the given preferred areas of the community. Government guidelines for siting should be followed. In some cases it is advisable to specify a minimum drilling depth in the Contract.	Limited payment is made to the Contractor for dry boreholes to a certain depth, according to formula set out below: • 1st borehole success: 100% paid; move to new location. • *If 1st borehole is dry: No payment* • 2nd borehole success: 100% paid, move to new location. • *If 2nd borehole is dry*: Calculated fair percentage of a productive borehole is paid which accounts for works completed, or pay according to Bill of Quantities (BoQ). • 3rd borehole success: 100% paid, move to new location • *If 3rd borehole dry: Calculated fair percentage of a productive borehole is paid which accounts for works completed, or pay according to Bill of Quantities (BoQ). Move to next community* In the event of three dry boreholes, then no further drilling is undertaken in this community until further investigations are complete. In effect this location will now become a Category C risk and requires expert hydrogeological survey to be commissioned by the Employer in order to define the site(s) for any further drilling.
C Low Success	<50%	Client to commission independent siting including use of geophysics (Resistivity profiling *and* Electromagnetic [EM] assessment. Sites selected and designed by the consultant should be drilled by the contractor to minimum depth indicated.	The client has determined the actual site and depth; payment is made for both wet and dry boreholes.
*The suggested percentages applied above can be varied to suit local conditions, for example 90%, 40-90% and >40% respectively.			

Annex C Drilling Method Selection

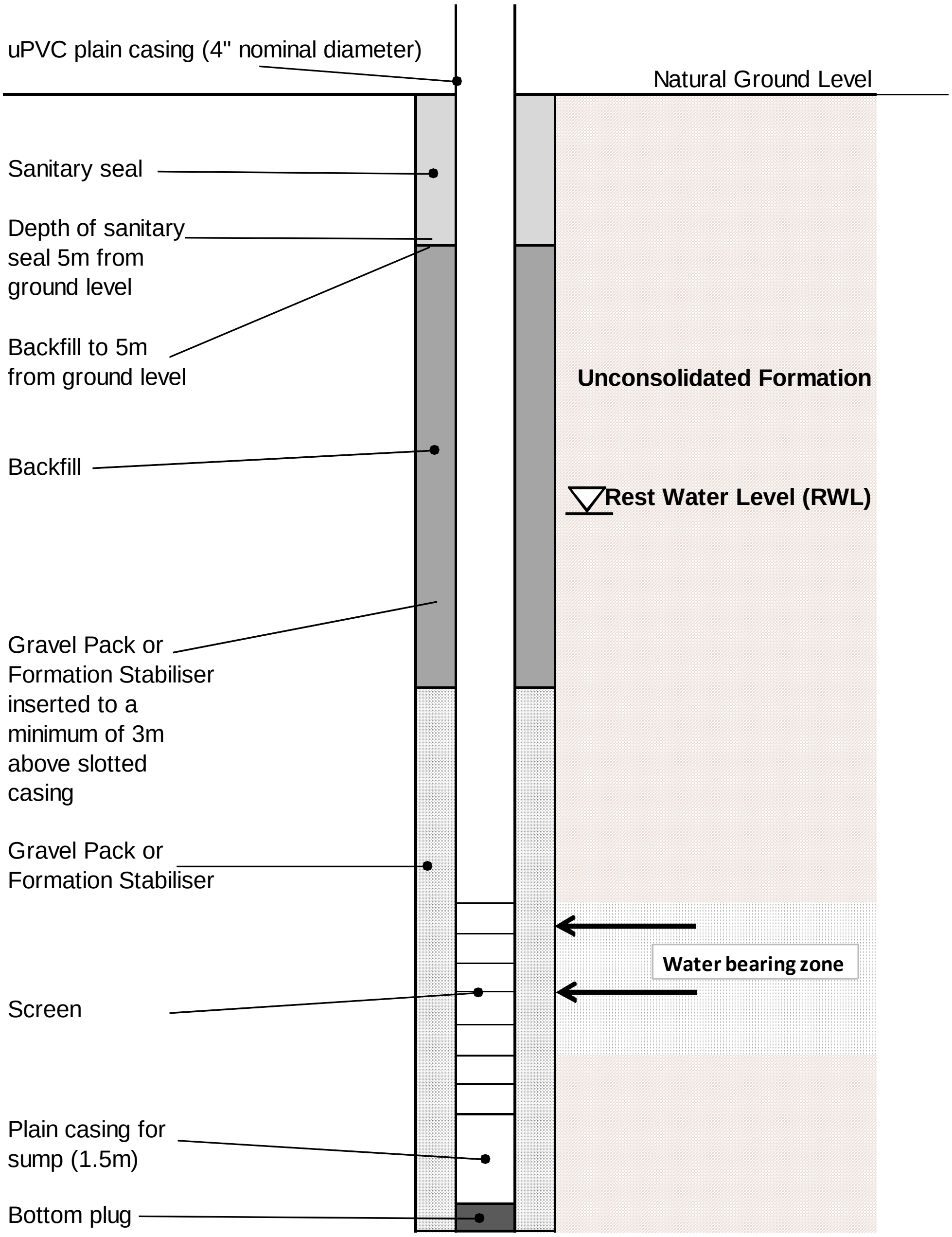
Formation		Manual Methods					
					Mechanised Methods		
		Hand-auger drilling	Sludging	Jetting	Percussion drilling	Down-The-Hole per-cussion drilling	Rotary drilling with flush
Gravel	Unconsolidated formations	**X**	**X**	**X**	✓**?**	✓**?**	**X**
Sand		✓	✓	✓	✓**?**	✓**?**	✓
Silt		✓	✓	✓	✓**?**	✓**?**	✓
Clay		✓	✓	**?**	✓**slow**	✓**slow**	✓
Sand with pebbles or boulders		**X**	**X**	**X**	✓**?**	✓**?**	**X**
Shale	Medium to high-strength formations	**X**	**X**	**X**	✓	✓**slow**	✓
Sandstone		**X**	**X**	**X**	✓	✓	✓
Limestone	Low to medium strength formations	**X**	**X**	**X**	✓**slow**	✓	✓**slow**
Igneous (granite, basalt)		**X**	**X**	**X**	✓**slow**	✓	**X**
Metamorphic (slate, gneiss)		**X**	**X**	**X**	✓**v slow**	✓	**X**
Rock with fractures or voids		**X**	**X**	**X**	✓	✓	✓**!**
Above water-table		✓	**X**	**?**	✓	✓	✓
Below water-table		**?**	✓	✓	✓	✓	✓

✓= Suitable drilling method ✓**?** = Danger of hole collapsing ✓**!** = Flush must be maintained to continue drilling
? = Possible problems **X** = Inappropriate method of drilling

Source: Waterlines 1995

Annex D Sample Borehole Designs

Figure D1: Sample Well Design (un-consolidated formation to depth of 100-120mm; at greater depths use steel casing)



Drilled diameter: 7 to 8" if gravel pack needed; can be 5 to 6" if formation stabiliser used.

Casing diameter must accommodate the external diameter of the pump cylinder.

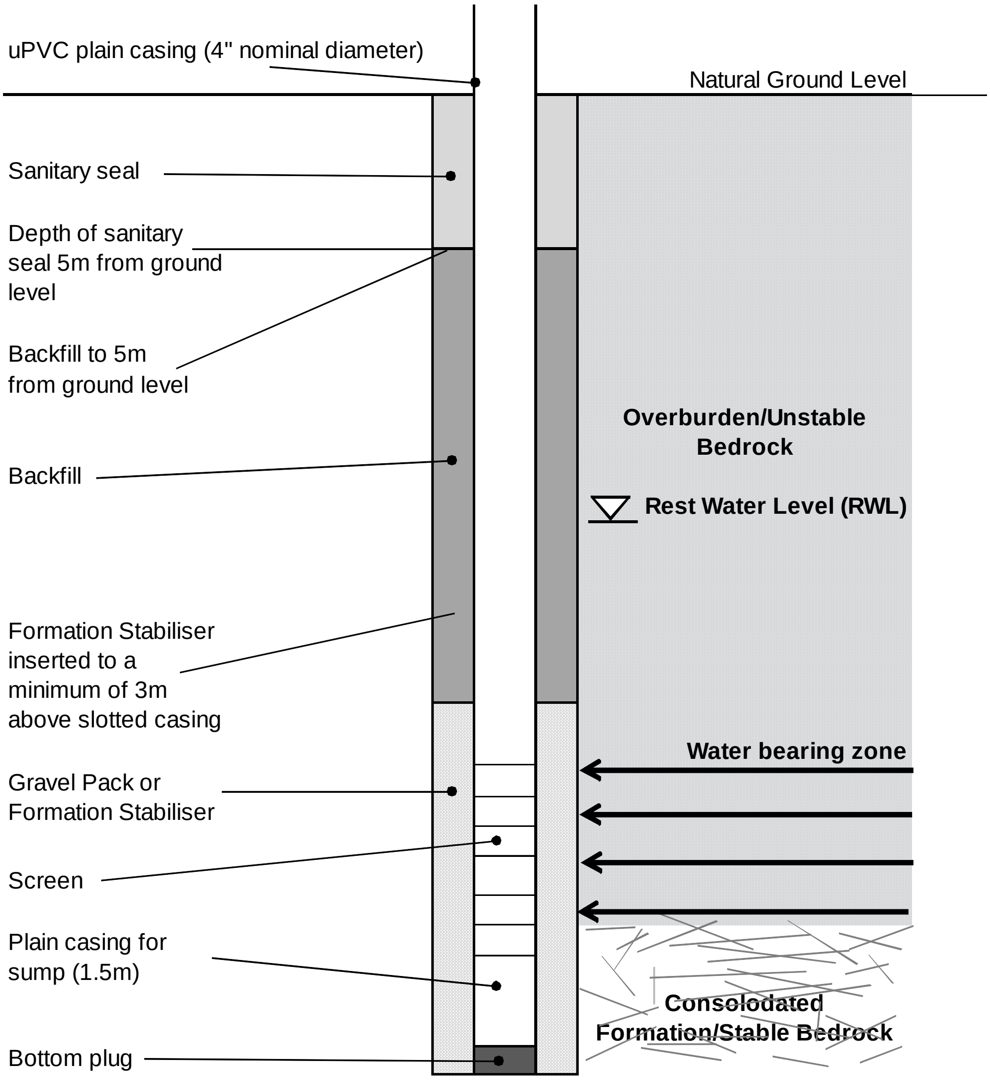
The **pump** should be positioned at the correct level above the screened section, taking into account the drawdown and seasonal variations. This is generally 2m below the lowest dynamic water level.

Gravel pack or formation stabiliser*: Drilling diameter needs to accommodate 2-4" thick gravel pack, or thinner formation stabiliser. The thickness of the gravel pack depends on the nature of the formation. A thick (3-4") annulus will be required in the case of very fine materials such as mica, which will require a larger drilling diameter (7-10"). Alternatively, it may be possible to use a geotextile filter sock depending on the risk of biofouling.

*See glossary for definition of gravel pack and formation stabiliser

Not to Scale

Figure D2: Sample Well Design (semi-consolidated formation with risk of collapse to 100-120m; at greater depths use steel casing)



Drilled diameter: 7 to 8" if gravel pack needed; can be 5 to 6" if formation stabiliser used.

Casing diameter must accommodate the external diameter of the pump cylinder.

The **pump** should be positioned at the correct level above the screened section, taking into account the drawdown and seasonal variations. This is generally 2m below the lowest dynamic water level.

Gravel pack or formation stabiliser*: Drilling diameter needs to accommodate 2-4" thick gravel pack, or thinner formation stabiliser. The thickness of the gravel pack depends on the nature of the formation. A thick (3-4") annulus will be required in the case of very fine materials such as mica, which will require a larger drilling diameter (7-10"). Alternatively, it may be possible to use a geotextile filter sock depending on the risk of biofouling.

*See glossary for definition of gravel pack and formation stabiliser

Not to Scale

Figure D3: Sample Well Design (consolidated formation – casing and screen in bedrock - 100-120m; at greater depths use steel casing)

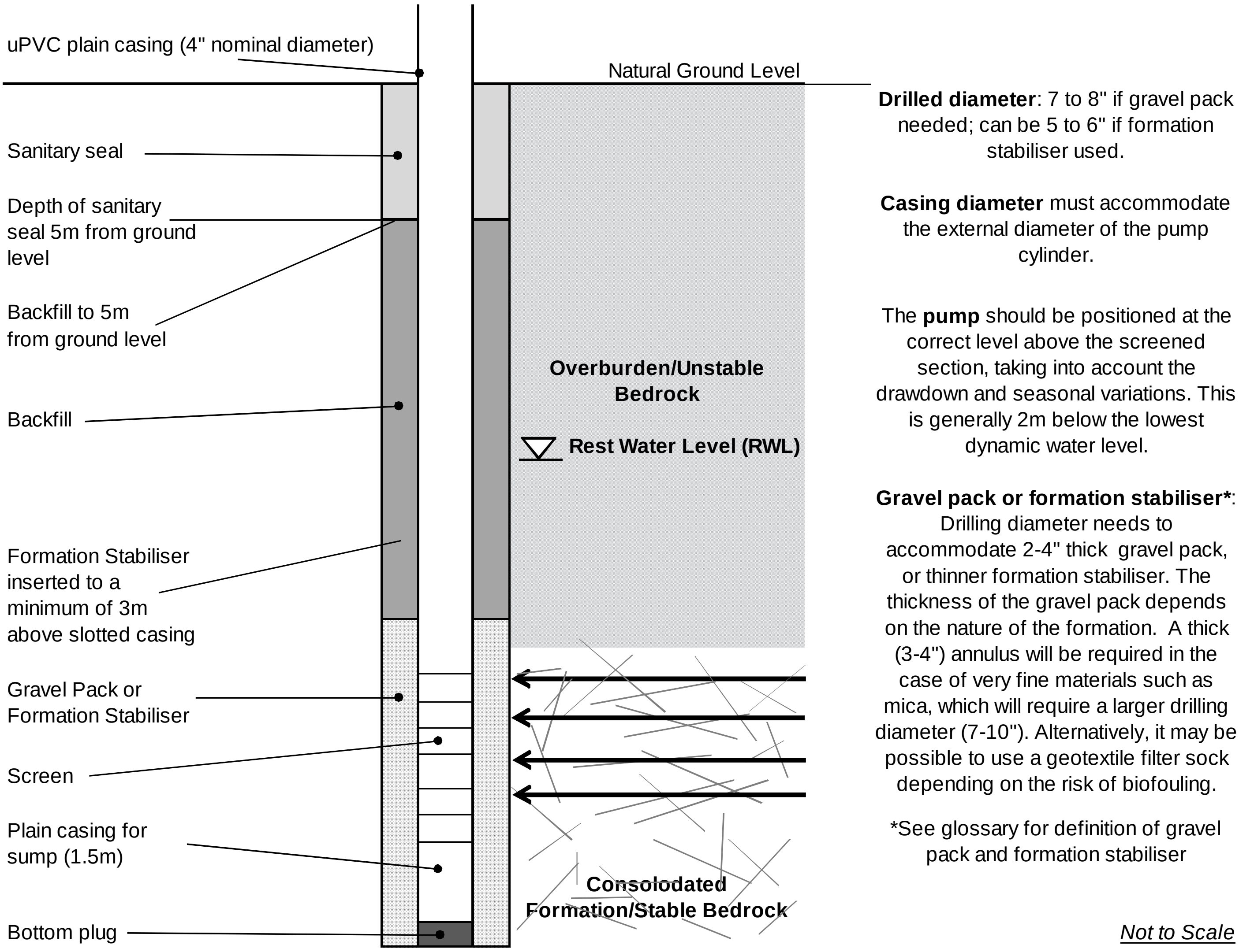
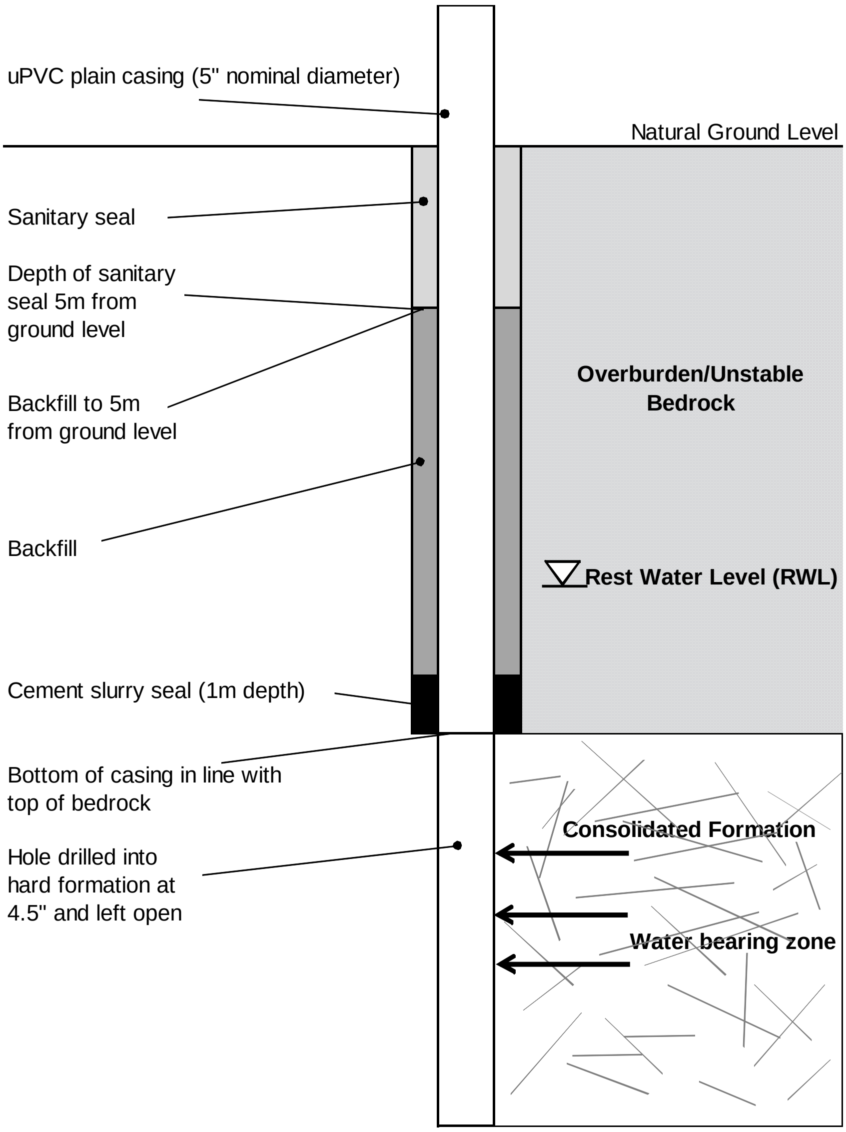


Figure D4: Sample Well Design (consolidated formation – open hole to 100-120m; at greater depths use steel casing)



Drilled diameter: 6.5" through the weathered material to rock, install 5" casing and then drill at 4.5" into rock; leave as open hole. There may be cases where telescopic drilling is required. This will require the drilling to commence with a much larger diameter, e.g. 10" to 12".

Casing diameter must accommodate the external diameter of the pump cylinder. There may be cases where telescopic/multi-diameter casing is required.

The **pump** should be positioned at the correct level above the screened section, taking into account the drawdown and seasonal variations. This is generally 2m below the lowest dynamic water level.

*See glossary for definition of gravel pack and formation stabiliser

Not to Scale

Annex E Suggested Format for Borehole Completion Record

Contents

<table>
<tr><th colspan="3">1. General</th></tr>
<tr><td colspan="2">Water Well/Borehole Reference No:</td><td>Use: ☐ Community ☐ Household/Private Compound
☐ Health Facility ☐ Education Facility
☐ Company Premises ☐ Test Well ☐ Other</td></tr>
<tr><td colspan="2" rowspan="2">Location:</td><td>Owner Name:</td></tr>
<tr><td rowspan="2">Owner Address:</td></tr>
<tr><td>Coordinates/
GPS Reference:</td><td>Grid Ref:
Long. E Lat. N</td></tr>
<tr><td colspan="3">Financing Programme/Project/Private:</td></tr>
<tr><td>Well Permit No:</td><td>Date Issued:</td><td>Issuing Authority:</td></tr>
<tr><td colspan="2">Name of Drilling Enterprise:</td><td>Driller’s License No:</td></tr>
<tr><td colspan="3">Address of Drilling Enterprise:</td></tr>
<tr><td colspan="3">Sketch Map

Approximate Scale:</td></tr>
</table>

2. Drilling Operation

Start Date:	Total Depth: m Main Water Strike: m	Drilling method(s): ☐ Hand Drilled (specify type) ____________________ ☐ Percussion ☐ Mud Rotary ☐ Air Rotary ☐ DTH ☐ Combination (details):____________________ Rig make: ____________________ Compressor make: ____________________
Completion Date:	Static Water Level: m Dynamic Water Level: m (when pumping at ____m^3/hr)	

Average Penetration Rate:_____ m/h (at diameter ____mm/inch)

Average Penetration Rate:_____ m/h (at diameter ____mm/inch)

Average Penetration Rate:_____ m/h (at diameter ____mm/inch)

Average Penetration Rate:_____ m/h (at diameter ____mm/inch)

From	To	Drilling Diameter ☐ inch ☐ mm	Method	Penetration Rate (m/h)
m	m			
m	m			
m	m			
m	m			
m	m			
m	m			
m	m			
m	m			
m	m			
m	m			
m	m			
m	m			
m	m			
m	m			
m	m			
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m	m			
m	m			
m	m			
m	m			
m	m			

3. Casing and Well Completion

Casing Material: ______________________

Casing Joints: ☐ Threaded ☐ Glue and Socket

Screen Open Area (%) ______

Bottom Plug: ☐ Yes ☐ No

Casing

From	To	Diameter ☐ inch ☐ mm	Type
m	m		
m	m		
m	m		
m	m		
m	m		
m	m		

Screen

From	To	Diameter ☐ inch ☐ mm	Type	Slot Size
m	m			
m	m			
m	m			
m	m			
m	m			
m	m			

Gravel ☐ **natural** ☐ **artificial**

From	To	Grain Size	Volume used
m	m		
m	m		

Backfill and Sanitary Seal

From	To	Diameter ☐ inch ☐ mm	Type and details (Backfill/Sanitary Seal)

Alignment and Verticality Test Remarks:

Well head and Platform

Well Cap: ☐ Yes ☐ No

Apron:

☐ Concrete slab

☐ Drainage

☐ Soak-away Pit

☐ Fence

Pump: **Pump Installed:** ☐ Yes ☐ No

☐ Stand

☐ Fitted around casing

☐ Welded on Casing

Pump Type:____

Comments: ____

4. Well Development and Pumping Test Summary

Development:

☐ Air-lift

☐ Over-pumping

☐ Surging

☐ Backwashing

☐ Jetting

Duration _____________hr

Comments: ____________________________________

____

Pumping Test:

☐ Air-lift capacity evaluation

☐ Constant Rate Test (CRT)

☐ Step Drawdown Test

Duration _________hr

Discharge ________l/s

Dynamic water level: _________m

Drawdown: _________m

Comments: ____________________________________

____

4. Well Development and Pumping Test Summary

Development:

☐ Air-lift

☐ Over-pumping

☐ Surging

☐ Backwashing

☐ Jetting

Duration _____________hr

Comments: ____________________________________

____

Pumping Test:

☐ Air-lift capacity evaluation

☐ Constant Rate Test (CRT)

☐ Step Drawdown Test

Duration _________hr

Discharge ________l/s

Dynamic water level: _________m

Drawdown: _________m

Comments: ____________________________________

____

5. Water Quality Summary

Sample taken: ☐ Yes ☐ No

Date_____________

Field Parameters:

☐ Clear

☐ Turbid

Colour_______ Taste_______ Odour ______
Turbidity______NTU Temp. ______˚C TDS______mg/l
EC_______µS-cm pH ______

Chemical Quality:

pH:________________

Laboratory: __________

(for more parameters see separate sheet)

Bacteriological Quality:

Faecal coliform: ____________cfu per 100ml

Laboratory: ________________________________

Comments: ____

6a. Lithological Logging

Water Well/Borehole Reference No:		
Location:		Owner Name:
Coordinates/ GPS Reference:	Grid Ref: Long. E Lat. N	Owner Address:
Financing Programme/Project/Private:		
Well Permit No.	Date Issued:	Issuing Authority
Name of Drilling Enterprise:		Driller's License No:
Well Logged by:		

Depth (m)	Description	Colour*	Grain size*	Texture*	Degree of weathering*	Sorting*	Roundness	Stratigraphic unit (if known)*	Remarks (e.g. consolidation, porosity, mineralogy, structures and features, drilling, water)	Penetration rate (min/m)	Discharge	EC (*µS/cm*)	TDS (*mg/l*)

Data to be recorded at a minimum of 1 meter intervals- add more sheets if required; * See overleaf for description.

6b. Characteristics to be evaluated and assessed during logging of drilling samples

(Source Misstear et al, 2006; MacDonald et al, 2005)

Standard procedures for sample description such as British Standards Institution (1999) or the American Society for Testing and Materials (2000) should be followed.

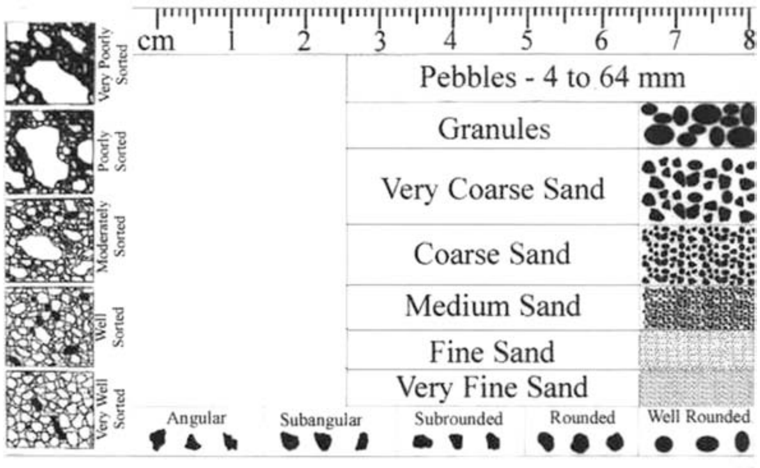
Colour

In order to aid objectivity, a definitive colour chart, e.g. Munsel® Colour Chart may be used for classification. Munsel® colours are referred to by two or three words such as brownish yellow, or light bluish grey and a number.

Grain Size

The visible grains can be compared with a comparator diagram such as the one given below, a grain sample card or the naked eye. A hand lens or microscope may be required to see grains which are not visible to the naked eye.

Figure Grain Size, Sorting and Roundness Chart(Source: University of Wisconsin, 2010)



Texture

Is the sample compact and dense, or light and friable? Is it granular or plastic? Can it be moulded or rolled? Can the fragment be scratched with a steel blade or fingernail? Moh's Scale of Hardness is an indicator.

Degree of weathering

The extent of weathering of rocks affects the availability of groundwater. Essentially, the weathering profile comprises the three basic units of soil, weathered rock and fresh rock. Rock weathering is described in terms of distribution and relative proportions of fresh and discoloured rock, decomposed and disintegrated rock.

Degree of Sorting

Sorting describes the variability of attributes such as rounding and grain size. In well-sorted materials the component grains are mostly of a similar size, shape and roundness. Sorting can be classified as very well sorted, well sorted, moderately sorted, poorly sorted and very poorly sorted as set out in the grain size and sorting chart above.

Roundness

Grains are usually classified as angular, sub-angular, sub-rounded, rounded or well rounded as shown in the chart above.

Formation / Stratigraphic unit (if known - add codes based on the local stratigraphic nomenclature)

An experienced geologist or driller may be able to identify stratiographic units. However it is important to distinguish between *interpretation* and *observation.* Thus the basic raw data (above) as well as his or her interpretation should be recorded.

7. Pumping Test Details

7a. Step Drawdown Test (for mechanised borehole supply)							
Water Well/Borehole Reference No:				**Water Well Name:**			
Start Test Date:				**Time of Day:**			
Static Water Level before Test: m			Pump Intake: m				
Datum for measurements			Pumping Well/ Observation Well (Tick Appropriate)				
Time			**Water Level**		**Discharge (Q)**		**Remark**
Real Time	Hrs	Min	Depth to Water	Drawdown	Volumetric Method	Flow Meter	TDS, Temperature, pH and any other observation
			(m)	(m)	(l/s or m3/h)	(l/s or m3/h)	

Time			Water Level		Discharge (Q)		Remark
Real Time	Hrs	Min	Depth to Water	Drawdown	Volumetric Method	Flow Meter	TDS, Temperature, pH and any other observation
			(m)	(m)	(l/s or m3/h)	(l/s or m3/h)	

Time			Water Level		Discharge (Q)		Remark
Real Time	Hrs	Min	Depth to Water	Drawdown	Volumetric Method	Flow Meter	TDS, Temperature, pH and any other observation
			(m)	(m)	(l/s or m3/h)	(l/s or m3/h)	

7b. Constant Rate Test (note that 3 to 6 hours is sufficient of a handpump supply)							
Water Well/Borehole Reference No:				**Water Well Name:**			
Start Test Date:				**Time of Day**			
Static Water Level before the Test: m Datum for measurements			Data in this table is for: Pumping Well/ Observation Well (Tick Appropriate)				
Average Discharge (l/sec)			Obs Well No.		Distance (m)		Depth (m)
Time			**Water Level**		**Discharge (Q)**		**Remark**
Real Time	Hrs	Min	Depth of Water	Drawdown	Container Method	Flow Meter	TDS, Temperature, pH and any other observation
			(m)	(m)	(l/s or m3/h)	(l/s or m3/h)	

Time			**Water Level**		**Discharge (Q)**		**Remark**
Real Time	Hrs	Min	Depth of Water	Drawdown **(S)**	Container Method	Flow Meter	TDS, Temperature, pH and any other observation
			(m)	(m)	(l/s or m3/h)	(l/s or m3/h)	

7c Recovery Test

Water Well/Borehole Reference No: | **Water Well Name:**

Start Test Date: | **Time of Day:**

Water Level Before the Test m | Pumping Well/ Observation Well (Tick Appropriate)

Description of pumping test undertaken prior to recovery test:

Datum for measurements:

Time			**Water Level**		**Time**			**Water Level**	
Real Time	**Hours**	**Min-utes**	**Depth to Water**	**Residual Drawdown**	**Real Time**	**Hours**	**Min-utes**	**Depth of Water**	**Residual Drawdown**
			m	m				m	m

8. Water Quality Analysis (critical/regular parameters)*			
Water Well/Borehole Reference No:			**Maximum Permitted Level According to National Standards/Guidelines or WHO Guidelines (WHO 2008)**
Constituents	**Unit**	**Concentration**	
PHYSICAL			
Colour	*mg/l Pt (TCU)*		
Odour			
Taste			
Temperature	*°Celcisu*		
Turbidity	*FTU*		
Electrical Conductivity	*µS/cm*		
CHEMICAL			
Chloride (Cl-)	*mg/l*		
Sulphate (SO_4^{2-})	*mg/l*		
Nitrate (No_3^-)	*mg/l*		
Fluoride (F^-)	*mg/l*		
Sodium (Na^+)	*mg/l*		
Potassium (K^+)	*mg/l*		
Calcium (Ca^{2+})	*mg/l*		
Magnesium (Mg^{2+})	*mg/l*		
Arsenic (As)	*µg/l*		
Iron (Fe)	*mg/l*		
Manganese (Mn)	*mg/l*		
Nitrite (No_2-)	*mg/l*		
pH			
Total Dissolved Solids	*mg/l*		
Microbiological			
Thermo-tolerant Coliform (E. Coli)	*Count/100ml*		
Faecal Coliform	*Count/100ml*		
Total Coliform Count	*Count/100ml*		

* Refer to National Standards/Guidelines for Drinking Water Quality or WHO Guidelines (WHO 2008) for list of general parameters.

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Development and Endorsement

The preparation of this document was led by Dr Kerstin Danert of Skat who managed a UNICEF/USAID funded project to develop a Code of Practice for Cost-Effective Boreholes. The project included a review of the history of UNICEF's involvement in borehole drilling, followed by country studies in Burkina Faso, Ghana and Zambia. Ongoing work to develop national drilling protocols, better understand the drilling sector and professionalise private drilling enterprises in Burkina Faso, Ethiopia, Ghana, Niger, Nigeria, Uganda and the Sudan was also drawn upon for the work.

The Code of Practice for Cost-Effective Boreholes has been officially endorsed by the German Federal Institute for Geosciences and Natural Resources (BGR).

Endorsed by the National Ground Water Association (USA) as useful contributory literature.

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