Rural Water Supply Network
Field Note 2010-5
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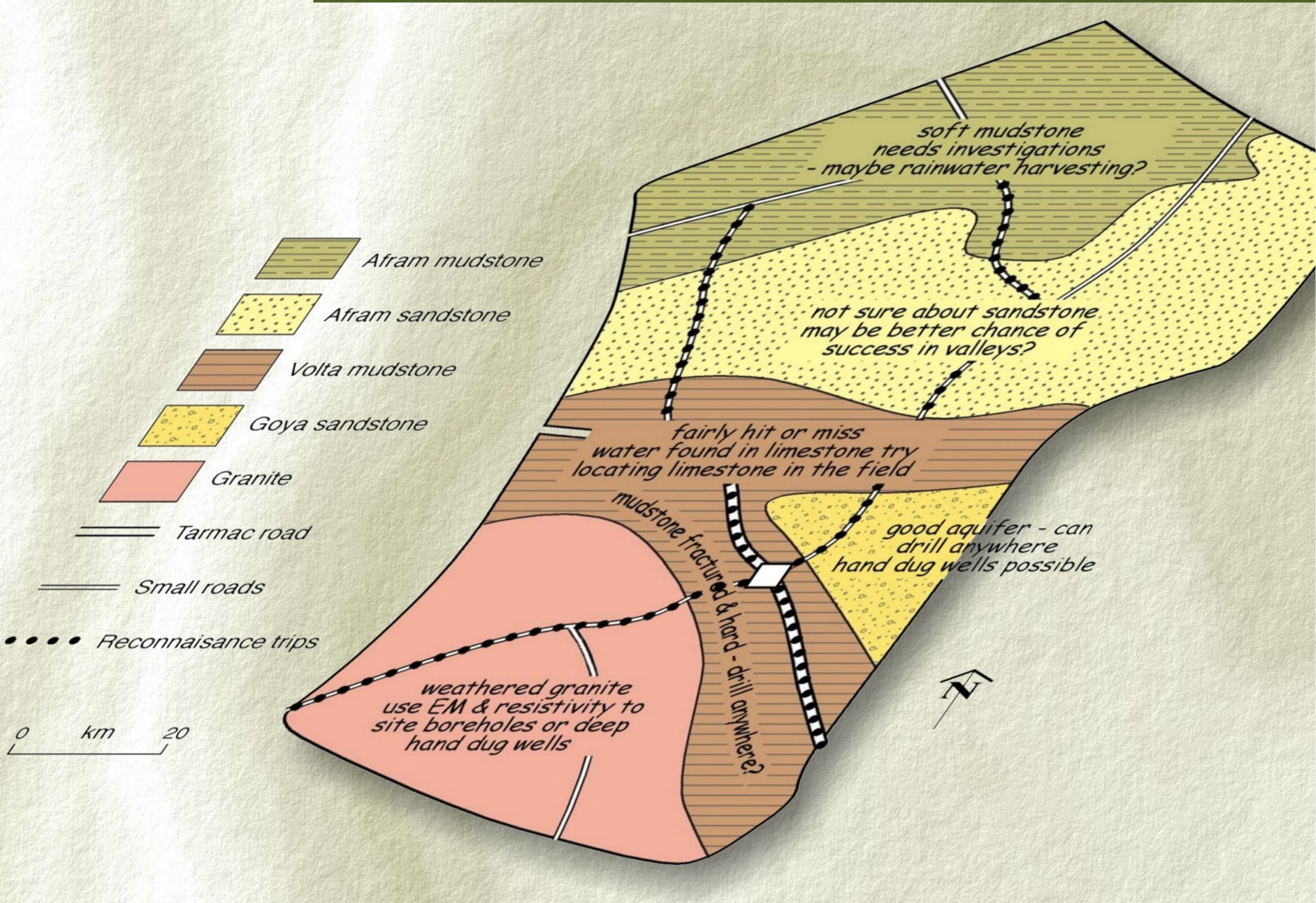
Cost-Effective Boreholes

Siting of Drilled Water Wells

A Guide for Project Managers



Summary

This field note has been written for managers of water supply programmes and projects. It provides a step by step guide on the siting of drilled water wells. As a first step, the essential requirements for a simple groundwater model are set out, including some basic explanations to help the reader establish a sound understanding of hydrogeology.

The field note subsequently explains what needs to be taken into consideration when selecting a suitable site for drilling. This includes the requirements of the water well, and a comprehensive set of instructions on how the most suitable site should be determined. Key considerations with respect to the tender and contract documents are also set out, as well as some basic information regarding field work and contract management.

The field note essentially takes the reader through the process from consideration of the user needs right up to the process of engaging a drilling contractor to construct the drilled water well.

Contents

Glossary

Anthropogenic – man-made.

Aquifer – an underground layer of water-bearing material from which groundwater can be usefully extracted via a water well.

Borehole - generally used to refer to a small diameter water point constructed by drilling.

Cone of depression – when water is pumped from a well, the water table (in the case of an unconfined aquifer) or piezometric surface (in the case of a confined aquifer) near the well is lowered. This area is known as a **cone of depression**. The land area above a cone of depression is called the **area of influence**.

Confined aquifer – has a confining layer of clay or low-permeability rock that restricts the flow of groundwater from one formation to another. A confined aquifer is thus not in direct contact with the atmosphere.

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.

Hydraulic conductivity (K) is the rate of movement of water through a porous medium (e.g. soil or an aquifer). It is defined as the flow volume per unit cross-sectional area of porous medium. The units are usually m^3/m^2/day or m/d. Sometimes hydraulic conductivity is referred to as permeability but permeability refers to all fluids, not just water.

Geophysical surveys (or techniques) measure the physical properties of rocks (resistivity, conductivity, magnetic fields and sonic properties). The measurements are interpreted in relation to geological features that are expected to facilitate groundwater storage and movement.

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

Impermeable material – a material such as clay through which water does not readily flow.

Permeability – see hydraulic conductivity**.**

Potentiometric surface is the level to which water in a confined aquifer will rise in a well. In an unconfined aquifer the potentiometric surface is the water table.

A **rock formation** is an identifiable body of natural earth material. It may be **unconsolidated** (eg loose sand or gravel) or **consolidated** (e.g. a sandstone or granite).

Storativity.- the amount of water that can be removed from the aquifer for a given lowering of water level.

Transmissivity is the product of hydraulic conductivity and saturated aquifer thickness.

An **unconfined aquifer** (also known as a *water table* or *phreatic* aquifer) does not have a confining layer which separates it from the surface. In other words, the upper boundary is the water table, or phreatic surface. The aquifer is in direct contact with the atmosphere.

The **unsaturated zone** is the formation in which water occurs but all the pores are not completely filled (saturated) with water. This zone is above the water table.

A **water table** is the free water surface in an unconfined aquifer.

Well is either used to refer to a hand-dug shaft, or it is used more generically to mean any small- or large-diameter vertical groundwater abstraction point other than a spring, regardless of method of construction.

A **well field** is a cluster of wells supplying water for a large-scale need such as a town, an irrigation scheme, or a refugee camp.

Introduction

It is estimated that world-wide, almost 900 million people do not have access to an improved drinking water supply, of whom 84% live in rural areas (WHO/UNICEF 2010). Although the world as a whole 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"*, this goal is very unlikely to be met in rural sub-Saharan Africa.

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. 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 always has some cover which protects it from the threat of pollution from human activities. This is because the processes of natural attenuation in the unsaturated zone (i.e. above the water table) work to reduce or eliminate contamination of the groundwater system (ARGOSS 2001).

There have been considerable developments since the 1960s in water lifting technologies, with numerous high-quality, affordable pumps available on the market. In addition, the water-well drilling industry is growing in many countries. However, there are still major concerns regarding the construction quality and cost of drilled water wells in many developing countries.

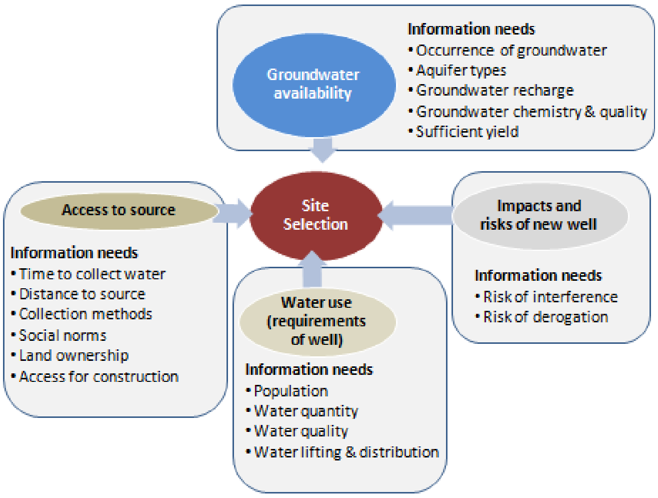
The *Code of Practice for Cost Effective Boreholes* (RWSN 2010) provides a comprehensive and systematic framework for analysing the key strengths and weaknesses of water well construction in a particular country or organisation. It recommends adherence to nine principles spanning regulation of the drilling industry through procurement and contract management and construction techniques. The utilisation of appropriate siting practices is one of these principles.

This field note builds on the Code of Practice. It provides a practical guide for water-well siting, including tendering and contract management, for both technical and non-technical programme or project managers. It is intended for donors, government authorities and NGO's which are responsible for siting and for the development of water supply activities. The focus of this field note lies in the technical, as well as the social and organisational aspects of siting assignments. The field note should enable the readers to set clear priorities, adequately define the required tasks and prepare and successfully manage a siting contract.

Proper siting of an improved groundwater supply provides a foundation for its success and long-term sustainability. Determining the best site for wells requires consideration of a number of inter-related aspects, as shown in Figure 1. The prevailing geology and available groundwater resources are fundamental since they determine what is possible. The use or uses of the water and the users themselves are important factors as they strongly affect the location where water is needed. The impacts and risks of a new well need to be considered so as not to adversely affect existing and new abstractions. Last but not least, there is need to consider access to the source, not only for the drilling itself, but also in the long term.

Thus, sound knowledge and practice of well-siting procedures have important implications for the economics of water development, as well as for the environmental and functional sustainability of groundwater abstraction.

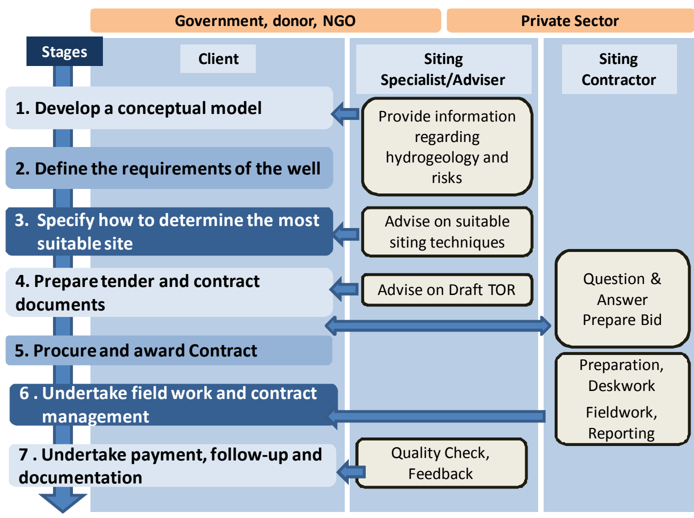
Figure 1: Combining Different Aspects for Site Selection



There are many techniques for well siting, each requiring different skills as well as investments in technology. These techniques are appropriate, either singly or in combination, for different geological and user settings. It is important that the appropriate techniques are utilised. Of particular mention is the fact that water-well siting in Africa tends to use geophysical surveys[1], even though they are not always necessary.

Based on extensive experience, we strongly recommend that a stepwise approach (Figure 2) be followed for the comprehensive planning and management of a successful siting assignment. The field note is structured according to the stages in Figure 2, and each of the subsequent sections focuses on one stage.

Figure 2: Work Flow for Water-Well Siting



[1] See Glossary

1 Conceptual Model

In order to plan and implement effective water-well siting, it is necessary to gather available knowledge of local groundwater occurrence and conditions, including climate data and the effect of pumping and groundwater recharge. It is useful for this information to be set out as a simple conceptual model illustrating the understanding of groundwater conditions.

The model may comprise a basic map of geology (plus information on rivers, settlements, land use). It can be interpreted with the use of existing knowledge, supplemented wherever possible by information obtained on reconnaissance visits. Areas of good and poor groundwater availability and water quality constraints can be highlighted. Simple cross-sections of the type shown in Figure 4 can help in the selection of siting techniques and well-construction methods.

This section provides the reader with the basic information and definitions required to develop a simple groundwater model. The text below is intended to be understood by non-technical as well as technical readers and thus help programme managers who are not familiar with hydrogeology, but are responsible for water-well drilling programmes. It should enable them to better understand what is involved in developing a groundwater model. If the in-house expertise to develop a simple groundwater model is not available, experienced expert support should be sought.

1.1 Occurrence of Groundwater

Sufficient specific knowledge of the prevailing modes of groundwater occurrence and uses in the project area is needed from the planning stage so that adequate well-siting capacity can be built into programmes from the beginning.

Groundwater is held in the pore spaces or natural openings in rock formations[1]. There are two common ways in which groundwater occurs and both can be found together in the same formation:

- In unconsolidated rocks[2] and sediments groundwater is held in the spaces between the grains, known as the inter-granular pores. This mode of groundwater occurrence is referred to as primary porosity (see Figure 3a and 3b);
- In consolidated[2] and cemented hard rocks groundwater can occur in fractures or cracks, which may or may not be inter-connected. This is referred to as secondary porosity (see Figure 3c and 3d). Inter-granular pore space can also occur in hard rocks, and the relative importance of inter-granular water and fracture water varies between rock types.

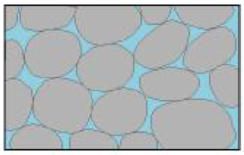
The proportion of pore space in rocks determines how much water they can store and how productive an aquifer[2] will be. One major objective of the siting is to provide relevant information on the dominant hydrogeological conditions in a target area (shown in Figure 4) that allows further exploration to be planned with low risk of failure.

If groundwater is known to occur in inter-granular pores or is held in fractures which are ubiquitous (i.e. in chalk formations), then siting requirements are normally not very complex. On the other hand, if groundwater is held only in fractures, then specific techniques for locating the fractures are usually needed. Failure to find fractures can mean failure to find water, and expensive dry wells.

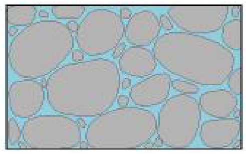
Figure 3: Primary and secondary porosity

Source: MacDonald et al 2005

Primary porosity

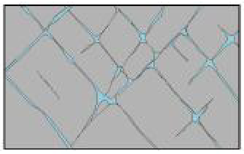


(a) high porosity unconsolidated sand or gravel

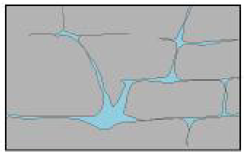


(b) porosity reduced by cementation or the presence of clays and silts

Secondary porosity



(c) consolidated crystalline rock rendered porous by the presence of fractures (e.g. christiline basement)



(d) consolidated fractured rock with porosity increased by dissolution (e.g. limestones)

1.2 Aquifer Types

The siting process should give evidence of which aquifer types dominate in the project area in order to best plan the drilling campaign and exploration for groundwater. There are a number of conditions in which groundwater can be found, as shown in Figure 4:

- Aquifers that are covered by impermeable materials (such as clay) may hold water under pressure. In this case, they are referred to as confined aquifers. When water is struck during drilling into a confined aquifer, the water level will rise under this pressure (Figure 4d) or even overflow (Figure 4a).
- Aquifers in which the water table[2] is in continuity with the atmosphere (through air-filled pore space) are known as unconfined. Unconfined aquifers of limited lateral extent and thickness are known as perched aquifers (Figure 4b). When siting, perched aquifers (Figure 4b) are normally to be avoided, since their water storage is limited, and they are prone to drying up.

Unconfined aquifers are prone to contamination from the surface (e.g. from pit latrines, slurry pits, pesticides and fertilisers, urban run-off, industrial waste). While they are usually shallow and productive and therefore relatively cheap and attractive to develop, their use for water supply in densely populated areas may not be ideal from a pollution risk perspective. Aquifers which are overlain by low-permeability material are best from a groundwater protection point of view.

Different aquifer types can exist in the same spot, occurring at different depths underground. The water quality in the different aquifers can also vary.

[2] See Glossary

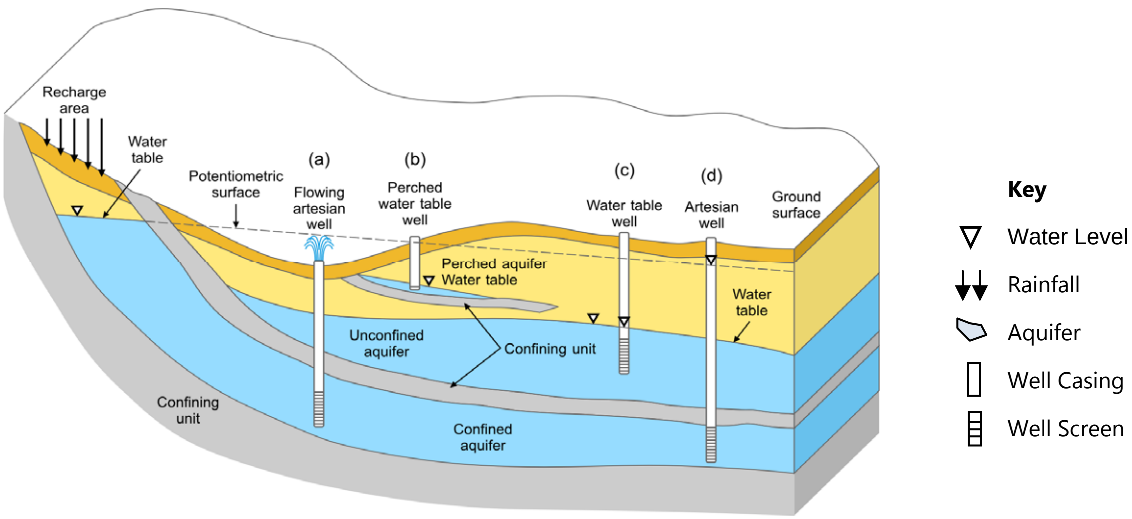


Figure 4: Groundwater - schematic image

Source: Todd et al 2005

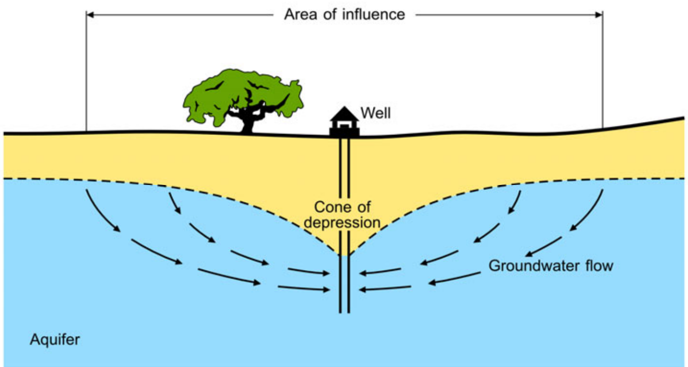
1.3 Effect of Pumping

When water is pumped from a well in an unconfined aquifer (Figure 4c), the water level in that well falls, and a cone of depression[2] spreads out into the surrounding aquifer (Figure 5). During pumping, groundwater flows towards the well within the cone of depression. Pumping can change the natural direction of groundwater flow within the area of influence around the well.

At some distance from the well (anything from a few tens of metres to a few kilometres), the water level will be relatively unaffected, even after many hours of pumping. The extent to which the water level in the well is drawn down and the radius of influence of the well are dependent on the transmissivity and storativity of the aquifer (Box 1).

Figure 5: Area of Influence

Source: Amended from Oregon State 2010



Box 1: Transmisivity and Storativity Explained

Transmissivity is a measure of the ease with which water can move through an aquifer via the inter-granular pores or the fractures. **Storativity** quantifies the amount of water that can be removed from the aquifer for a given lowering of water level over an area. The relevance of these parameters to well siting is that we are generally seeking as high a transmissivity as we can find, especially in the case of large-scale water requirements. This means that we are looking for a part of the formation which is highly permeable, or thick, or both.

If a well is placed too close to an existing water source or to a spring, stream or wetland, there is a risk that the pre-existing source or the natural groundwater-surface water connection will be adversely affected. In the case of two pumped sources sited too close to one another, the increased drawdown experienced by each well is called "interference". The adverse effect on the yield of other wells and springs, on dry season flow in streams, and the drying of wetlands is referred to as "derogation".

1.4 Groundwater Recharge

Wherever possible, well siting should pick out areas where potential recharge by, for example, rain or rivers takes place regularly, as determined by the local rock outcrops, slopes, soil conditions and vegetation. This aspect is often overlooked in siting, but failure to take it into account can result in the longer-term demise of water sources – with consequent additional costs.

Aquifers provide large (but not infinite) volumes of water storage. In many climates, aquifers receive natural replenishment or recharge during one or more seasons. In wet climates, recharge may take place annually or more often, while in drier climates there may be sequences of years when recharge fails to take place.

Recharge occurs either by direct infiltration and deep percolation of rainfall (Figure 4) or by localised infiltration from surface water courses. The proportion of rainfall that becomes recharge varies greatly according to many factors, in particular geology, topography, soil type, vegetation, rainfall intensity and climate.

Groundwater which is no longer recharged at the present day and has been without recharge for a long time is sometimes called fossil groundwater. Fossil groundwater exists in arid areas in very deep rock formations. Even very large fossil groundwater resources can be consumed quickly if abstraction rates are high.

1.5 Groundwater chemistry and quality

The quality of groundwater used for community water supplies should be in compliance with relevant national or international standards or guidelines. During the siting process, all relevant information on groundwater chemistry should be taken into account.

In certain circumstances, groundwater is not suitable for drinking without treatment. Groundwater chemistry can be influenced by the geology but also by anthropogenic (i.e. man made) factors, such as inadequate sanitation practices, industrial pollution or leachates from agriculture (e.g. pesticides, nutrients).

Groundwater in some parts of the world shows high natural contents of arsenic, fluoride and iron. Arsenic and fluoride are toxic in high concentration, and their occurrence is related to the hydrogeological conditions. These can often be anticipated for a project area (but not predicted at community scale), so extra care will be needed in well siting.

The presence of iron in groundwater, while not health-threatening except in very high concentrations, may cause users to reject a particular safe groundwater source in favour of an unsafe surface-water source which tastes better and which does not stain clothes and cooking utensils. Dissolved iron is very common in groundwater which has almost no oxygen and is slightly acid. Its presence can therefore often be anticipated and planned for (e.g. by the use of pumps with plastic below-ground parts which do not corrode or by installing iron removal plants).

Groundwater beneath urban and peri-urban areas is often contaminated with pathogens and chemicals derived from faecal and other solid waste and industrial pollution. The existence of these contaminants in urban groundwater is a direct consequence of high population density, poor environmental and waste management and the shallow unconfined nature of the aquifers.

To avoid anthropogenic pollution, siting near settlements should avoid latrine areas and local depressions, dry water courses and channels liable to seasonal flooding.

High groundwater abstraction rates near the coast can lead to the intrusion of saltwater into the aquifer. The pollution of groundwater by saltwater is an almost irreversible process.

For many regions, there is already an abundance of information regarding groundwater chemistry and quality. Permanent treatment of water is expensive. Ideally, any known problem areas for groundwater quality should be avoided, whether they relate to microbiological, chemical or aesthetic (taste or odour) aspects. However, in some places, treating water to remove high concentrations of arsenic or fluoride may be preferable to using faecally contaminated surface waters.

2 Requirements of the Water Well(s)

Prior to siting one or more wells, the requirements in terms of water use, population to be served, water quantity and quality as well as water-lifting and distribution mechanisms need to be considered. This section sets out the implications of six different types of water supply on siting.

2.1 Rural water supply handpumps

Siting of handpump wells needs to take careful account of both physical access by users and access according to socio-economic class, caste, disability and other factors which can exclude certain user groups. It is necessary to clearly define the user population, and to identify any sub-groups within that population which differ in terms of wealth, power, position or influence. It is almost inevitable that the poorest and those from lower caste or class tend to be marginalised by those with more power or influence. In many situations, the most powerful individuals try to exert undue influence to have the well sited for their own convenience. As it is mainly girls and women who are engaged in carrying water for domestic uses, they are the ones who are the most affected by the newly installed water supplies and therefore by the siting.

To overcome such problems of marginalisation, some organisations deliberately site wells in low-income sections of the community in order to positively discriminate in their favour, whilst not excluding wealthier or more powerful users. Participatory decision-making methods can be used for this.

2.2 Motorised abstraction with reticulation

Abstraction using motorised pumps, overhead storage and piped reticulation systems is common in some countries (e.g. Senegal). Siting in this case requires that the well is reasonably close to the users to minimise pumping lift and the capital and recurrent costs of the reticulation system, near to the electricity supply or accessible for fuel deliveries, and readily accessible for maintenance. Siting of public standposts (if included) must take account of similar considerations as for handpump supplies.

2.3 Small town water supply and camps

In the case of small town supplies from groundwater, two extra considerations apply: (a) the greater likelihood of groundwater contamination beneath urban centres, and (b) the greater demands for water as a consequence of high population densities. For both these reasons, well fields serving small towns tend to be located out-of-town in high-yielding aquifers where groundwater contamination is less problematic, with transmission mains to bring water to the consumers.

In camps for refugees and internally displaced persons (IDPs), population densities may be as high as in towns, but water supply requirements are usually significantly lower (the Sphere standard is 15 litres per person per day, whereas in a town with piped water to the home, a figure nearer 100 litres is more usual). Abstraction points may be sited much closer to the users, and this makes them vulnerable to contamination especially in long-term settlements.

2.4 Agricultural uses

Agricultural production is responsible for 70% of freshwater demand (UNESCO 2009). Medium- and large-scale irrigation schemes require very large quantities of water, which may be sourced from high-yielding aquifers often using diesel-driven submersible pumps. Small schemes, and especially farmer-managed irrigation systems, need larger numbers of smaller wells. Well-siting requirements are likely to be more stringent in the former case compared to the latter. Deep drainage from intensive agricultural areas can lead to pollution of groundwater by nutrients and pesticides.

An important and often overlooked aspect of agricultural water demand is water for livestock. Livestock need larger quantities of water than human beings, but the water quality requirements are less exacting. Without careful management of water points, use by livestock can easily result in groundwater contamination and land degradation. This is a particular problem in pastoralist areas, where seasonal movement of livestock is practised.

2.5 Multiple use

It is increasingly being recognised that people use water for multiple purposes, and they use multiple sources, depending on season, year and water use. For example, many rural dwellers carry water home (often from good quality groundwater sources) for cooking and drinking; they bathe and wash clothes at convenient surface water sources (seasonal and perennial streams) or shallow wells; and they grow crops and water livestock in valley lowlands and natural swamps.

Moreover, some programmes actively encourage communities to establish productive economic activities such as small gardens, livestock husbandry and brick-making to use water from new wells, and these can put additional stress on limited groundwater resources, in terms of both quantity and quality.

Siting may need to take account of this complexity of multiple uses and multiple water sources.

2.6 Industrial uses

Industrial water supplies nearly always need to be located close to the enterprise in question, unless very large quantities of water are needed. In that case, similar considerations exist as with urban water supply. Too often, water-consuming industries are established without sufficient prior thought as to the likely source of water and waste water treatment. Ideally, entrepreneurs should consult well-siting specialists prior to building breweries, food-processing plants or other water-consuming industries.

2.7 Abstraction Requirements

Table 1 gives some very rough estimates of the daily water abstraction depending on the type of settlement to be served.

Table 1: Water supply and water demand

Water use	Scale	Approximate demand [m^3/day]	Average pump rate [l/sec]*
Rural water supply	Single well for 100-300 persons	2 - 6	0.1 – 0.3
Small town water Supply	Single well for 2,000 – 10,000 persons	500 – 2,000	2 -10
Irrigation scheme	100 ha	5,000	140
Assumptions for consumption: Rural water supply – 20 litres/person/day Small town water supply - 40 litres/person/day Irrigation scheme – 50m^3/ha *Assumes that water is pumped for ten hours a day.			

3 How to Determine the Most Suitable Site?

Determining the best site for the water well requires consideration of technical, environmental, social, financial and institutional issues. The siting process should show which groundwater conditions are dominant in the project area and enable the well design to be specified. Professional siting involves desk and field reconnaissance, and makes full use of existing data.

The actual process of well siting requires (i) consideration of key factors and adequate use of sensible combinations of (ii) information sources and (iii) siting techniques. This section examines these three aspects in turn and provides a logical approach to well siting.

3.1 Key Factors for Consideration

In order to determine the best location for a well, 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 (see section 2 for more details). This information is sometimes available from existing documents or maps (see *Information Sources* below) or can be derived by performing a pumping test on an existing borehole[3] (see RWSN 2010, Annex 5).
- **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 calculated water balance of an area.
- **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 should be checked. Well siting must therefore take account of knowledge of the occurrence of such undesirable substances. The quality of the water from the completed and developed well should be compared to national standards. Where these are not available, the WHO guidelines for drinking water (WHO 2008) may be used.
- **Avoidance of potential sources of contamination**. It is essential to avoid point contamination sources such as pit latrines, septic tanks, livestock pens, burial grounds and solid waste dumps. There may be national guidelines on separation distances or groundwater protection zones.
- **Community preferences, women's needs and land ownership**. Engagement with the community to agree on the well location is essential. It 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 to avoid subsequent disputes between the land owner and water users. Formal agreements regarding land ownership and access to the supply may be required.
- **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[3] in existing sources.

[3] See Glossary.

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 and risks of derogation should 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.

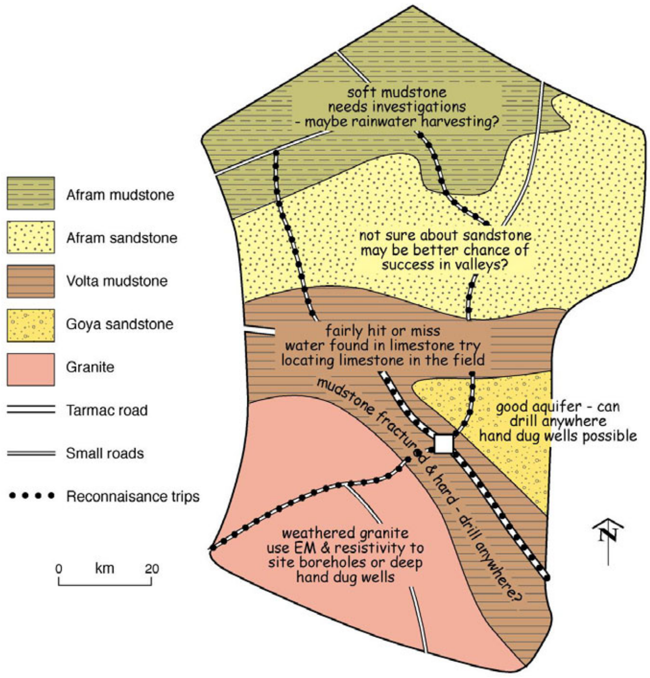
- **Avoidance of interference with natural groundwater discharges**. In a similar way, construction of a well too near to natural springs, watercourses or wetlands can lead to a reduction of water levels, potentially drying up these important water sources and ecosystems and affecting uses and users dependent upon them. The intrusion of saltwater due to too high abstraction of groundwater near the coast could lead to irreversible decline of water quality.
- **Risk**. As part of water-well siting, the risk of drilling a dry borehole should be categorised (e.g. high, medium and low risk). In the case of wells 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 of 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.

3.2 Information Sources

It is essential to use the information sources described below to support the siting techniques described in the following section, and in conjunction with the considerations of different water uses and user group requirements as mentioned in section 2 of this field note.

Maps: Topographic maps provide the most basic information for undertaking a well-siting programme. While community names and locations may not always be correct, the terrain and the rivers are likely to be accurate and provide general indications of the situation of the land and accessibility. Geological and hydrogeological maps present and summarise a great deal of complex information in a succinct visual form. Fortunately, geological maps at usable scales for projects are widely available. Hydrogeological maps at similar scales are much more rarely found. The map legend is as important as the map itself, as it contains much descriptive information which is necessary to get the most from the map itself. Geological maps are often accompanied by bulletins produced by the national Geological Survey, which add further detail to that summarised on the map.

Figure 6: Example Survey Map



More recently there have been useful approaches to the production of maps of groundwater development potential, often at a more local scale. On these, existing hydrogeological information and borehole data are depicted and interpreted to indicate where there is good potential for using groundwater and where there are likely to be significant constraints in terms of both quantity and quality to provision of water supplies.

In the case of remote regions, satellite-based images are also available, e.g. from <http://www.earth.google.com>.

Documents: A wide variety of documents, including project reports, masterplans, geological survey bulletins, consultants' and drillers' reports, NGO project documents and academic studies and meteorological data (i.e. rainfall), can provide useful information about the areas where groundwater development is proposed. These can be found in Ministries of Water Resources, national Geological Survey offices, consultants' and NGO offices, and universities and research institutions. They are not, however, always formally archived in libraries and are likely to require considerable persistence and determination to find them.

Field visits and interviews can provide considerable information from the community on groundwater resources, including seasonal fluctuations. In addition, relevant information on source preferences, water uses, gender issues and economic interests can be collected. These will all influence the selection of a suitable location for the well.

Drilling records, databases and data exchange: Often, the most reliable information on local geology and hydrogeology comes from the field experience of previous drilling and well-digging activities. Ideally, such experience is encapsulated in drilling logs and geologists' logs which are held in national databases. In reality, however, such records are often not kept (especially if the well is unsuccessful), not submitted (especially in the case of NGOs and individuals), or not collated (especially when Government resources are limited, and higher priority is placed on new construction than on record-keeping). In the best cases, such logs, records and databases can be extremely useful sources of information.

The extra cost in a well construction programme of collecting such data is relatively small, and the incremental benefits for siting from the cumulative knowledge, improved interpretation and enhanced conceptual model of local groundwater occurrence are very large. It would be even more beneficial if drilling results were subsequently compared to the specific well-siting techniques used in a systematic, site by site and overall project evaluation. Such an assessment of siting "success" of course reflects on the operator as well as the technique, and this is very rarely done and almost never published. It is also made difficult because siting and construction are often undertaken by different organisations. If these are private contractors or consultants, they may treat the siting data as commercially confidential information which they are unwilling to share.

3.3 Techniques for Siting

Many techniques are available for siting drilled water wells, and the most commonly used ones are summarised in this section. There is no ideal single technique that fits best to every condition. Instead, the use of different techniques should always be tailored to the local conditions and rock types, and in particular to the three situations of increasing hydrogeological complexity set out in section 4.4. Some of the techniques may look simple, but considerable skill and experience is required to understand and interpret the results correctly. Therefore, it is strongly recommended that the techniques always be used by a trained hydrogeologist or technician and carried out under the supervision of one. The most often applied techniques are summarised below.

Remote sensing: The use of aerial photography, side-looking airborne radar (SLAR) and satellite imagery has a powerful role in identifying geological boundaries and hydrologically significant features (such as deep fractures) which may not be visible on the ground. Such remote techniques always require an independent check at the ground surface by field reconnaissance, by geophysical survey or by drilling (known as ground truth) to have confidence in the findings obtained remotely. Remote sensing can be very useful, but its use should always be determined by realistic expectations of what it might or might not indicate.

The most likely applications are firstly in the planning and reconnaissance stage and secondly for narrowing down target areas or locating specific features for geophysical survey, for locating and delineating communities requiring water supplies and identifying existing supply sources. For this second application, conventional black and white aerial photographs have proved extremely useful.

Hydrogeological field surveys: If indications of the potential for using groundwater have been obtained from maps, documents, aerial photographs or satellite images, hydrogeological field reconnaissance provides the opportunity to check this. Thus, the mapped geological formations should be confirmed from rock exposures (for example in river beds and road cuttings). Local topography and geomorphology can influence groundwater occurrence, storage and flow and enhance groundwater recharge and help to produce favourable sites. These should be observed and noted. Vegetation cover can reflect geological conditions and indicate the presence of shallow groundwater.

The field reconnaissance should locate and examine existing dug and drilled wells to verify the information about yields and water levels already collected from secondary sources. Their operating status and condition should be noted, together with any visual evidence of water quality constraints such as iron staining or fluoride impacts, and any likely sources of pollution. These observations should be supplemented by information from local communities who are likely to be very knowledgeable about their local environment and their water sources. Older members of the community, for example, may be able to indicate scoop holes that have dried up, or they may recall vegetation patterns prior to deforestation.

Such information should include the normal seasonal variations and more severe drought impacts on yields and groundwater levels in both traditional and improved sources as well as information about water quality constraints. All of the information collected in the field reconnaissance should be carefully recorded (using a logbook, drawings, photographs, GIS, other field equipment). To collect such information effectively, field surveys need the participation of trained community workers who can converse in the local language.

If the survey finds sound evidence of groundwater potential, then sites can be selected without the need for additional investigations using geophysics. This is likely to the case for most of the areas with simple hydrogeological conditions of unconsolidated sedimentary materials and shallow groundwater (Figure 7 - Scenario 1) and for those weathered crystalline basement rock areas in which granites and gneisses are overlain by an extensive and reasonably consistent weathered regolith aquifer (Figure 7 – Scenario 2). The survey should also enable a choice to be made on the hydrogeological suitability of areas or locations for dug wells or drilled wells where both are envisaged within a programme.

Establishing a siting approach based on a combination of existing information, remote sensing and field survey can be highly cost-effective for these conditions, but will only be successful if it is led by an experienced hydrogeologist. Moreover, qualified personnel with hydrogeological knowledge are needed to decide when such an approach cannot be applied with confidence and additional investment in geophysical surveys is needed, and then to plan, implement and interpret the surveys.

Geophysical surveys: Geophysical surveys are by far the most commonly used techniques in well siting. These techniques measure the physical properties of rocks, such as their resistivity and conductivity, magnetic fields and sonic properties. Most cannot directly detect the presence of water. Instead, the contrasts in sub-surface (rock and water) properties are interpreted in relation to geological features that are expected to facilitate groundwater storage and movement. In favourable circumstances, these techniques can detect vertical fractures in hard rock, layering in horizontal formations, and contrasts between dry and wet rock and between fresh and saline water. As with remote sensing, ground truth is needed, and use of geophysics should always be determined by realistic expectations of what can be achieved.

Although geophysical surveys can assist in locating productive sites, they are often included automatically in a tender in the hope that they will produce something useful. This approach rarely rewards the effort put in, and there are many cases of geophysics having added nothing to the reliability of well siting.

While there are many geophysical techniques, those most commonly used for well siting are the **electrical resistivity** and **electromagnetic** (EM) methods, with seismic refraction and magnetic techniques also having some applications. The main features and suitability of these techniques for use in different hydrogeological environments are summarised in Table 2.

The resistivity method has been used for many years and can be employed in two distinct ways. The first is a **vertical electrical depth sounding (VES)** in which depth variations in subsurface resistivity at a fixed point can be interpreted in terms of a sequence of geological layers. The electrodes are expanded in an array about this central point. The second is a **constant separation traverse** in which the electrode array is moved across the ground to provide qualitative information about lateral changes in subsurface rock types and structures.

Resistivity profiling has largely been replaced by the electromagnetic (EM) methods, which provide better information about lateral changes in resistivity much more quickly and cheaply.

Electrical resistivity and electromagnetic methods are the two most widely used geophysical survey methods. The equipment is relatively inexpensive, robust and not difficult to operate in the field. A widespread consequence of this is the routine use of such equipment by field technicians who do not have geological training.

However, in order to obtain the best results, the interpretation of data from these (or any other) geophysical methods requires experience and triangulation with local hydrogeological knowledge. In fact, siting which is carried out by inexperienced operators and analysts can actually reduce the likelihood of finding water. If the interpretation is poor, it may be better to drill at random.

Table 2: Geophysical techniques for well siting and suitability in different hydrogeological environments

Technique	Measured properties	Approximate maximum depth of penetration	Outputs and Applications	Suitability for hydrogeological environments
Resistivity: vertical electric soundings (VES)	Vertical contrasts in apparent resistivity of the ground	100m	1D geo-electric sounding. Depth to bedrock and thickness/ variation of superficial deposits, depth to water table, depth of weathering, locate saline water interfaces. Calibrate surveys.	Sands in alluvial formations, regolith of weathered crystalline basement rocks, less useful in consolidated sedimentary and volcanic formations.
Resistivity: traversing - using constant electrode separation	Lateral variations in apparent resistivity	100m (but used for less in practice)	Traverses. Location of buried valleys and vertical fracture zones. Determine variations in depth of weathering.	Weathered and fractured crystalline basement rocks, less useful in other environments. Largely replaced by EM.
Electro-magnetic: frequency domain (FEM)	Apparent electrical conductivity of ground	50m	Traverses or 2D contoured surfaces. Variation in thickness and nature of weathered zone and superficial deposits, locate fracture zones.	Weathered and fractured crystalline basement rocks; less useful in others. Quick and easy survey method.
Electro-magnetic: transient or time-domain (TEM)	Apparent electrical resistance of the ground, usually at a single point.	150m	Vertical soundings similar to VES. Better at locating contrasts through conductive overburden than FEM.	Weathered and fractured crystalline basement, less useful in others. Expensive and more difficult to operate than FEM.
Very low frequency (VLF)	Secondary magnetic fields induced by communications transmitters	40m	Traverses or contoured surfaces to locate fracture zones and dykes, also depth to bedrock and water table.	Weathered and fractured crystalline basement rocks, volcanic formations.
Seismic refraction	Seismic wave velocity through the ground	30m	2D vertical sections. Locate fracture zones and determine thickness of superficial deposits. Less useful for variations in superficial deposits. Slow and difficult to interpret.	Weathered and fractured crystalline basement. Not suitable for volcanic formations, alluvium and consolidated sedimentary rocks.
Magnetic	Intensity of earth's magnetic field	100m	Traverses or contoured grids. Location of dykes and sills.	Fractured bedrock and volcanic formations.
Ground penetrating radar	Reflections from boundaries of different dielectric constant	10m	2D sections. Determine thickness of sand and gravel, depth to bedrock, possibly depth to water table, locate horizontal fractures or cavities in karst.	Alluvial formations, karstic limestones, Cannot penetrate clays. Little used in well siting.
Gravity	Density contrasts between geological materials	300m	Sections and contoured surfaces. Geometry of sedimentary basins, location of buried valleys, cavities in karstic formations.	Large alluvial formations and consolidated sedimentary aquifers, karstic limestones. Little used in well siting.

Compiled from: Van Dongen and Woodhouse (1994), Macdonald et al (2005) and Misstear et al (2006).

Test drilling: Where the higher yields of Table 1 are required and the hydrogeological conditions are complex or difficult, then exploratory drilling to assist in siting may be justified. Simple hand drilling is the technique of choice for millions of wells in South East Asia and is growing in popularity in some parts of Africa (RWSN 2009). It has, however, been used to confirm whether subsurface conditions are suitable for well digging and for the construction of shallow drilled wells. Drilling with motorised rigs is likely to be needed in consolidated formations. Whichever approach is used, drilling should come after and draw on the cumulative results of the methods described above to select the most promising exploration sites to avoid 'wildcat' random drilling. Test drilling should be properly planned and supervised by experienced hydrogeological staff to ensure the best possible information is obtained on the geological sequence and water levels and the potential yield of the groundwater and its quality.

3.4 A logical approach to well siting

Siting is not solely about applying the science of groundwater, but also encompasses social, economic and institutional aspects as well as consideration of the management of the water supply. The user aspects highlighted in section 3.1 (i.e. community preferences, women's needs and proximity to the point of use) are important. However, this needs to be balanced with the need to select sites using hydrogeological criteria which ensure the best chance of obtaining adequate and sustained yields of good quality water. These can limit what is possible.

Many investigation techniques are available and often well proven to assist in well siting. However, none are consistently useful at all times, and their success or failure depends on them being used correctly and applied in appropriate situations. The challenge is to match the effort, intensity and costs for investigation to the complexity and uncertainty of the hydrogeological conditions and the scale of user requirements.

A logical and systematic approach to well siting is recommended which:

- Identifies the physical expression of the favourable hydrogeological target zones to be surveyed;
- Selects the geophysical method or methods most suited to the task of locating them;
- Plans the survey fieldwork and interpretation accordingly;
- Provides adequately qualified and experienced staff to undertake the fieldwork and interpretation;
- Provides adequate funding and resources for the work.

Three situations shown in Figure 7 are discussed to illustrate this logical approach:

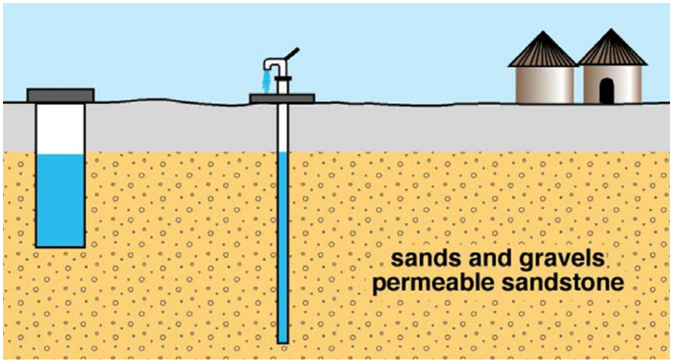
- **Scenario 1**: the hydrogeology is well-known and not difficult; groundwater is relatively easy to find, and wells can be sited almost anywhere;
- **Scenario 2**: the local hydrogeology is largely understood and reasonably consistent but challenging; it needs some effort to find reliable groundwater resources;
- **Scenario 3**: the local hydrogeology is less known and understood; it is complex and uncertain; there is a high risk of failure to get boreholes with enough water.

Figure 7: Three complexity scenarios for siting

Source: MacDonald et al 2005

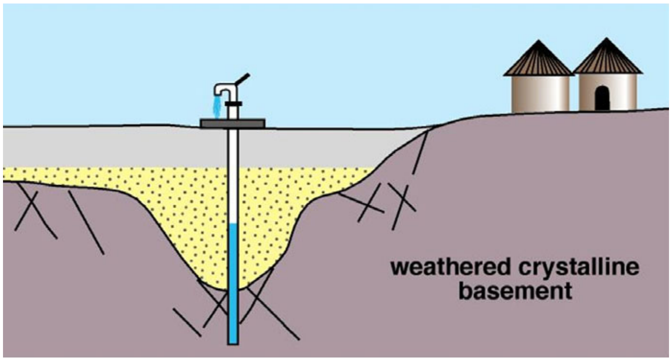
Scenario 1: Easy to find groundwater:

boreholes and wells can be sited anywhere



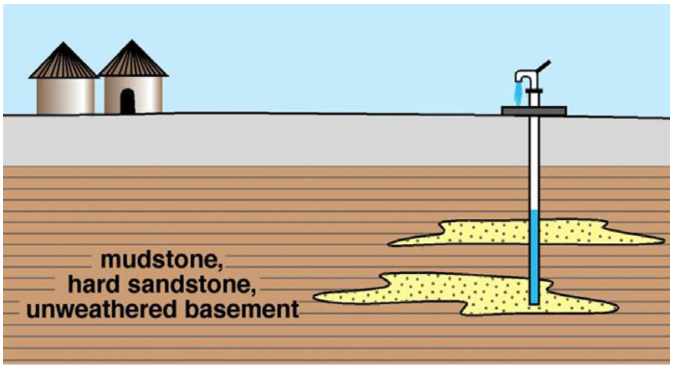
Scenario 2: Hydrology generally understood:

geophysics interpreted using simple rules can be used to site borehole



Scenario 3: Hydrogeology complex:

successful boreholes and wells difficult to locate using simple rules. Detailed investigations required



In these three scenarios, successful siting requires increasing levels of technical capability, manpower resources and costs, as set out in Table 3.

Table 3: Siting scenarios and resources needed

Scenario / Resources	Scenario 1	Scenario 2	Scenario 3
Technical –organisational issue			
Hydrogeological Desk Study	✓	✓	✓
Field visit	✓	✓	✓
Risk analysis	✓	✓	✓
Geophysical survey	-	?	✓
Social issues			
Social structure and community preferences	✓	✓	✓
Time and Costs			
Time needed	**low**	**medium**	**high**
Costs	**low**	**medium**	**high**

Key: ✓ to be undertaken
? depends on level of risk
- not necessary

The case study in Box 2 provides an example of the siting procedure and techniques used in Uganda by an enterprise operating in the conditions of scenario 2.

It is worth mentioning water divining or dowsing techniques in which a person walks along holding a piece of wood or metal or another object to locate groundwater. Usually, the person "feels" the presence of water underground, or the wood or metal object bends at a particular location. Despite claims of its success, there is no scientific basis for divining. The authors of this report thus recommend that the judgements of a water diviner should not be used to overrule the judgement of an experienced hydrogeologist.

4 Preparing Tender and Contract Documents

A siting assignment will most probably form the basis for the subsequent procurement of a drilling enterprise to undertake water-well construction. Ideally, the siting and drilling are undertaken as two separate assignments, with the water-well drilling undertaken after the siting. In some cases, the siting consultant will subsequently be responsible for supervision of the drilling assignment.

There are cases where siting and drilling are undertaken as one combined contract. In fact, some contracts place the full risk of drilling a non-productive well with one contractor who is responsible for siting and drilling. However, such practice should only be undertaken in circumstances where the risk of drilling a dry borehole is fairly low (i.e. scenario 1 in section 3.4). Prior to preparing tender documents, it needs to be decided if siting will be undertaken under separate contract or if it should be combined with the drilling.

In order to prepare tender and contract documents for well siting it is essential to:

- Establish the number of wells that are to be sited and ultimately drilled and their geographic distribution;
- Have an understanding of a conceptual model of the way groundwater occurs (section 1);
- Consider the requirements of the water well (section 2) as well as key social, technical and environmental factors (section 3.1);
- Make full use of all available information sources (section 3.2) and;
- Undertake a pre-selection of suitable siting techniques (section 3.3). Note that the *logical approach to well siting* set out in section 3.4 provides guidance as to the selection of siting techniques.

Box 2: Case Study of Siting by Aquatech Enterprises (U) Ltd

Aquatech Enterprises (U) Ltd, in Uganda follows the following siting procedures:

Phase 1 is a planning and reconnaissance study which includes mobilisation of equipment and personnel, collection and interpretation of existing data and preliminary selection of target areas for detailed investigations. It normally also includes field data collection, site-specific data analysis and verification of results of desk studies and preliminary site selection.

Activities to be carried out during this phase are as follows:

- Liaise with client;
- Collect and review hydrogeological reports and literature for the areas of interest;
- Collect and study maps – (topographic, geological and hydrogeological);
- Collect and study drilling information and records;
- Visit field to determine field conditions, accessibility to preferred sites and community readiness to participate;
- Use a GPS to locate sites on a topographic map.

This will provide information on where to expect to find water and whether the quality is expected to be good.

Phase 2 comprises the hydrogeological investigations, including topographic map analysis and detailed geophysical surveys of the areas of interest. These mainly use the resistivity technique to characterise the different formations. Since most of Uganda is underlain by hard rocks, the approach uses an ABEM Terrameter 300C or SAS 1000 for traversing and vertical electrical soundings. These methods provide a) an estimation of the thickness of the regolith, b) an indication of horizontal changes in aquifer properties and c) the locations of any vertical geological boundaries.

Existing data for nearby water sources are collected and used for calibration. Where data are not available, calibration resistivity soundings are made at existing drilled water wells to characterise the underlying geology in terms of resistivity and groundwater potential. The results of the calibration measurements guide final interpretation of the data. Traversing is carried out to assess lateral variation whenever this is found to be necessary based on the local hydrogeological environment. The anomalies identified from the profiling are further investigated by soundings to ascertain hydrogeological variation with depth. Initial resistivity profiles are always run perpendicular to the inferred fracture zone.

If the client does not have sufficient expertise in the above, specialist advice should be sought. It is unrealistic to expect a non-expert client to properly manage siting consultants and drilling contractors, although this does often happen.

The tender document should include the following:

- **Objective** of the siting.
- A general **description** of the hydrogeological conditions in the siting areas and the challenges to be expected.
- Information about the **techniques** that are considered suitable for investigation and siting.
- A clear explanation of the **deliverables**, including a definition of the specific set of geological and hydrogeological data that should be investigated and verified during the siting (such as depth of water bearing layers, depth to water table, transmissivity).
- The number and approximate **location** of the sites expected, **water use**, **yield** and **water quality** requirements.
- Overall **timeframe** of the work, deadlines and milestones.
- Clear definition of **roles and responsibilities**.
- An assumption of the number of meetings with clients. Siting assignments can lead to an iterative process of interpretation, investigation and detailed assessments. Meetings with the clients are necessary.
- An assessment of the **risks** associated with the assignment. The work could be disturbed by weather conditions, difficult road access or social unrest. These may prevent the siting team from performing the contract as planned. The tender documents should define a clear procedure to be followed in such circumstances. There are also risks of failure to find a suitable drilling site due to the complexity of the geological and hydrogeological conditions. Three categories can be distinguished to describe the risk level and efforts needed to cope with the challenges as discussed in section 3.4 and Annex 1.
- Clarification of the **payment scheme**. Very often, payment for a siting assignment takes place after a debriefing meeting with the client, including presentation of the results, and after submission of the final documentation. Alternatively, some part of the payment could be withheld until the driller has finished work. If unsuccessful drilling occurred because of wrong siting, some of the payment for the siting assignment could be permanently withheld. Such procedures have to be clearly and explicitly defined in advance in the tender documents for the siting.

A rough cost estimate should be generated for the siting work based on this information. This can subsequently be used to compare with the prices quoted in the tender offers submitted.

The quality of the siting directly influences the quality and cost of work of the drillers. Therefore, the Terms of Reference (TOR) in the tender document need to be precise, complete and clearly written. The TOR should define at least the objectives of the assignment, the services executed by the consultant or organisation which undertakes the siting, the tasks of the client, the deliverables including the format of the data, the timeframe and quality standards.

It is recommended to append a draft contract to the tender documents.

5 Procurement and Contract Award

Enterprises interested in undertaking the work **submit tenders** based on the information and requirements of the tender documents. The tender offers should:

- Specify the composition of the team.
- Provide details of equipment and methods that will be used (even including alternatives to those proposed in the tender)
- Set out the experience of the enterprise,
- Provide a rough risk analysis with mitigation measures and
- Set out a draft time schedule with tasks to be completed.

Enterprises should **prepare offers** for their work based on realistic prices. In order to prepare a financially reasonable offer, the consultant or company bidding for the work should be aware of all formal deadlines, eligibility and selection criteria, the Terms of Reference and other contract issues. Any areas which are unclear in the tender documents should be clarified prior to submission of the tender

Figure 8: VES Measurement in Nigeria

The **procurement procedure** should allow the client to select the best eligible offer according to specific eligibility and selection criteria defined by the client. In order to make sure that the process is fair, a clear procedure, as defined by the client or donor organisation, should be followed. The specific eligibility, selection criteria and procedure to be followed should be transparent. These should also be set out in the tender documents. Formal standards and procedures for evaluation for public procurement exist in most countries.

For the evaluation of the bids, the client will first check whether the bidder has fulfilled the eligibility criteria (e.g. licence, registration or other pre-qualification requirements). If these are fulfilled, the offer will be evaluated according to pre-defined selection criteria and price.

The **tender evaluation** should focus on the experience and expertise of the key personnel of the team and their presentation of their methods rather than on analysis of the price alone. Very rarely is the cheapest offer the best offer. Generally, the best offer is the one with the best quality/price relationship.

In cases of complex siting assignments, it is recommended to involve **experienced advice** for the tender evaluation process.

Following the tender evaluation, the siting contract is awarded, and the work can commence.

6 Field Work and Contract Management

After the signing of the contract, both the client and the siting enterprise will plan how the assignment is to be undertaken, including communication between the two parties and field visits to the community.

The siting enterprise will subsequently commence the assignment. The client will introduce a project manager who is also responsible for quality assurance. The siting enterprise/team in particular will collect and analyse available information, contact subcontractors (e.g. for geophysics) and organise staff and logistics. During the entire siting assignment, there should be an organised exchange of information, decisions and documents between the client and siting enterprise. The process of siting often follows an iterative working process which includes:

- Critical analysis of data (deskwork);
- Compilation of a first conceptual hydrogeological model of the area(s) (deskwork);
- Field visits, local knowhow, test drilling;
- Optional: refined conceptual model, verification including water quality data;
- Geophysical field measurements, interviews with water users, land owners, other actors/stakeholders;
- Verification, refined conceptual model, risk analysis;
- Recommendation of sites;
- Documentation (including face to face debriefing).

Depending on the complexity of an assignment, some of these steps could be combined.

In case of questions, constraints and problems, it is advisable to contact the client as soon as possible.

Comprehensive documentation of the preparatory phase and the executed field work is a very import part of the assignment. Both siting enterprise and client should build up sufficient capacities (knowhow, Information Technology [IT] resources) to manage an efficient and comprehensive data exchange process.

Figure 9: VES Sounding in Nigeria

7 Payment, Follow-up and Documentation

Payment for siting services has to adhere to the signed contract. Often, payments will be released after milestones have been passed and the results have been approved by the client. In the case of non compliance, an arbitrator may be required.

The client should build up internal capacities and resources to manage relevant data from the siting assignment and submit it to the relevant authority, e.g. the National Geological Survey or the authority in charge of groundwater resources.

The results of the siting assignment form the basis for the procurement of a drilling contractor.

8 Conclusions and Recommendations

Siting is concerned with the exploration for and identification of water resources for specific uses. The planned use of the groundwater will have an effect on the water resources and may interfere with other water uses in the vicinity. The planning and implementation of siting activities therefore has to take this into consideration.

Siting is much more than a technical procedure and includes very important social aspects as discussed in this field note. Siting is part of a chain of activities that start with the selection of communities and continue right through to the operation and maintenance of a successfully constructed water supply.

The complexity of the hydrogeology has a significant influence on the combination of siting techniques that need to be deployed. In order to achieve a sound basis for further exploration of water resources for water supply, we recommend the stepwise approach as shown in this field note, which starts with a basic understanding of the groundwater in the form of a simple model.

The Code of Practice for Cost-Effective Boreholes (RWSN 2010) sets out nine relevant principles that are related to the planning and realisation of water-well construction. Siting is one of these nine principles. Efforts to strengthen the performance of siting activities should thus consider the wider framework of the Code of Practice to ensure the sustainable use of groundwater for water supply and for other uses.

Some countries have made a considerable effort to build up the human resource base, establish clear working procedures and develop tools on groundwater resources (such as groundwater maps). However, much remains to be done. Unfortunately, many countries lack the skills and human resources to manage or even undertake proper siting of water wells. This is an area where considerable capacity building is required. In addition, there is scope for improvements with respect to the management of groundwater data, with systematic processes for updating information.

Annex 1 Model to Categorise Risk and Payment Structures

The table below provides a model to categorise the 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 water well. 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 water well drilling, namely 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 below.

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 the costs of 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 hydro-geological 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 maps, remote sensing and 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.			

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