OXFAM OPERATIONAL GUIDELINES

WELL DESIGN IN EMERGECNIES: PRACTICAL GUIDELINES

CONTENTS

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GLOSSARY

Aquifer Layers of rock porous enough and sufficiently permeable to allow water to flow through in enough quantity.
Borehole log A recorded description of the characteristics of a borehole, its depth, rock types at different depths, hardness of rock and its water bearing characteristics. Can be pictorial or descriptive.
Drawdown The distance between the pumped (dynamic) water level (PWL) and the static water level (SWL). It is sometimes called the head loss.
Formation stabiliser A material, usually gravels, put between the side of the drilled hole and the casing, which helps support the casing/screen and keep it vertical.
Geophysics A variety of techniques used for measuring physical properties of the ground. It can be used above ground and also down a borehole for logging.
Gravel pack Material around the well screen, used to stop fine particles entering the annulus, which can be natural (occurring insitu) or artificial (installed).
Hydrogeologist Specialist in the water bearing characteristics of rocks.
Overburden The soil/rock above an aquifer.
Pumped water level The level to which water settles on pumping.
Pump testing Method used for measuring aquifer properties.
Recharge The amount of water from the atmosphere reaching the water table.
Static water level The natural water level of the water in an aquifer, this does change and fluctuate with the seasons and atmospheric pressure.
Transmissivity The rate at which water can pass through the thickness of saturated aquifer width under a unit hydraulic gradient.
Well development The process of cleaning a borehole once it has been drilled, to try and allow it to reach maximum yield.
Well discharge The amount of water that a well can sustainably supply. This must be greater than demand.

1.0 Methodology

1.1 The Timeline

1.1.1 The guidelines are based around a chronological sequence of activities to utilise groundwater for water supply (shown in the Table 1 on next page).

1.1.2. The first three activities are stages in data gathering. The data is then interpreted. A description of the activities follow below:

- A pre-visit desk study should aim to obtain as much relevant data as possible. This will come from academic institutions, British Geological Survey, personal contacts, the Internet, and Consultancy firms. Two or three days should be sufficient to get some good background information about the area. (Useful addresses are listed in appendix 6).
- The initial in country desk survey is to gain additional data sources. It is likely to involve visits to Ministries responsible for water, talking to drilling contractors and university departments related to geology/mining/agriculture/water. This data should add to and validate the information from the pre visit desk study. This in country desk study could take up to a week. (At the end of the second activity a greater understanding will have been gained of the conditions on the ground.)
- The third element, the field study, seeks out local, site-specific, information. It is also used to corroborate the information already gained. This may involve interviewing local people and collecting data from previous groundwater development activities.

1.1.3 Developing drill contract specification. The well design is carried out at this point. It should be straightforward if all the information inputs are available. If a third party is undertaking the drilling, the contract for this work becomes a very important document. The document should contain design specifications and responsibilities of the contractor.

1.1.4 Criteria and techniques for siting of a well should have been established from the information feeding into the well design. If the geological conditions change (hard rock geology) geophysical techniques may be needed to site the well.

1.1.5 Construction supervision involves checking the specifications (as determined by the design), confirming that the terms of the drilling contract are adhered to. After construction, the well will need to be developed to ensure the best yield is obtained. Well development is very important. . Water quality should be checked.

1.1.6 Once developed and completed a monitoring programme should be set up. This will monitor water levels and water quality changes with time, initially every 3 months, then yearly seasonally.

Table 1:The timeline

PRE-VISIT	INITIAL IN-COUNTRY SECONDARY SOURCES	FIELD STUDY	DRILLING CONTRACTS	SITING	CONSTRUCTION SUPERVISION	MONITORING
Reports, geological maps, topographic maps, interpretation	Governments, consultants, universities, research institutions	Villages, wells boreholes: location, depths, water levels, pumps, pump testing, quality	Well design: discharge, diameter, depth, drilling method, screen/casing, pumps	Remote sensing	Test pumping	Water quality
Internet	Personal contacts	Geology		Geophysics	Logging	Water level
People & organisations	Climate data/recharge estimations	Water level monitoring		Divining!	CCTV	Discharge
Remote sensing		Vegetation		None	Casing, screen, gravel pack, grout	Climate, rainfall data
Climate/recharge estimations		Anecdotal evidence			Well development	
Cost/time limitations		Demand				
		Climate				
		Exploratory drilling				

1.2 Design as the Centrepiece

1.2.1 The time line has to be followed chronologically from start to finish. It is the well design in the design process that is the most important part. Everything feeds into or out of the design process.

1.2.2 All the activities before design revolve around information that will be needed to allow design to take place. Many of the information inputs can be gained from more than one data source. It is the information that the design process needs which is important and not where it came from. The well design process determines the information needed and the activities that occur before it.

1.2.3 For water to be obtained efficiently a well has to be designed properly. The well can only be designed properly if all the information needed is collected from the earlier activities. It is the focus on the design of boreholes that is at the core of this approach. The reason for this is that the design process is the only element that links all the others together. It is this linkage that gives it importance and the centrality it occupies.

1.2.4 This approach differs from others in the literature, as it is in the form of a set of guidelines specifically oriented around well design. The guidelines allow a user to design wells and make better decisions.

1.3 Structure of the Guidelines

1.3.1 The sequence starts with the data sources. These data sources are gathered from the first three activity columns in the time-line. The data sources have been divided into two categories, high priority and low priority data sources. These categories of priority are for the benefit of a non-groundwater specialist and do not indicate the potential value of the interpreted data. These data sources after being gathered need to be interpreted. For each of the data sources there is a description regarding the interpretation and the information that can be gained from that source. This interpretation of the data sources reveals the information inputs for the well design process. The information inputs are:

Inputs	**Brief Explanation**
• Demand required discharge from the well(s).	You need to know how many people and their daily requirement to determine the discharge needed.
• Geology, hard/soft.	This will determine whether the formation needs support or not and will help determine the drilling method to be used.
• Aquifer, confined or unconfined.	This is of importance for the drawdown characteristics and thus the positioning of the pump. May have implications on recharge/sustainability.
• Thickness of aquifer, depth and rock type.	Indicates the depth you will have to drill. Helps determine how much water is available.
• Rest water level, RWL.	The RWL together with aquifer information will help give the expected pumped (dynamic) water level PWL. This in turn gives the position of the pump.
• Recharge.	This is important for determining the longer-term sustainability of the borehole at the design discharge.

1.3.2 Once the information necessary for design has been collated, the process of well design can take place. The design process is a sequence of steps, which leads the user through the different questions that need to be answered to arrive at the optimum well design. The well design has been separated into three options, based upon following common ground conditions. hard, weak and soft. For each of the ground conditions there is an example of how the design process works. For each ground condition it is then possible to determine the design "outputs" for a particular well.

Outputs	**Brief Description**
• Drilled diameter.	The larger the diameter, the bigger the drilling rig capacity needed.
• Drilled depth.	Important as it will determine how powerful the drilling rig needs to be.
• Screen.	The length and diameter is important as well as the availability. Often this will need to be imported.
• Casing.	The length and diameter is important as well as the availability. . Often this will need to be imported.
• Gravel pack and formation stabiliser.	The sub-surface conditions will determine what pack and support are needed. This may need to be ordered and imported.

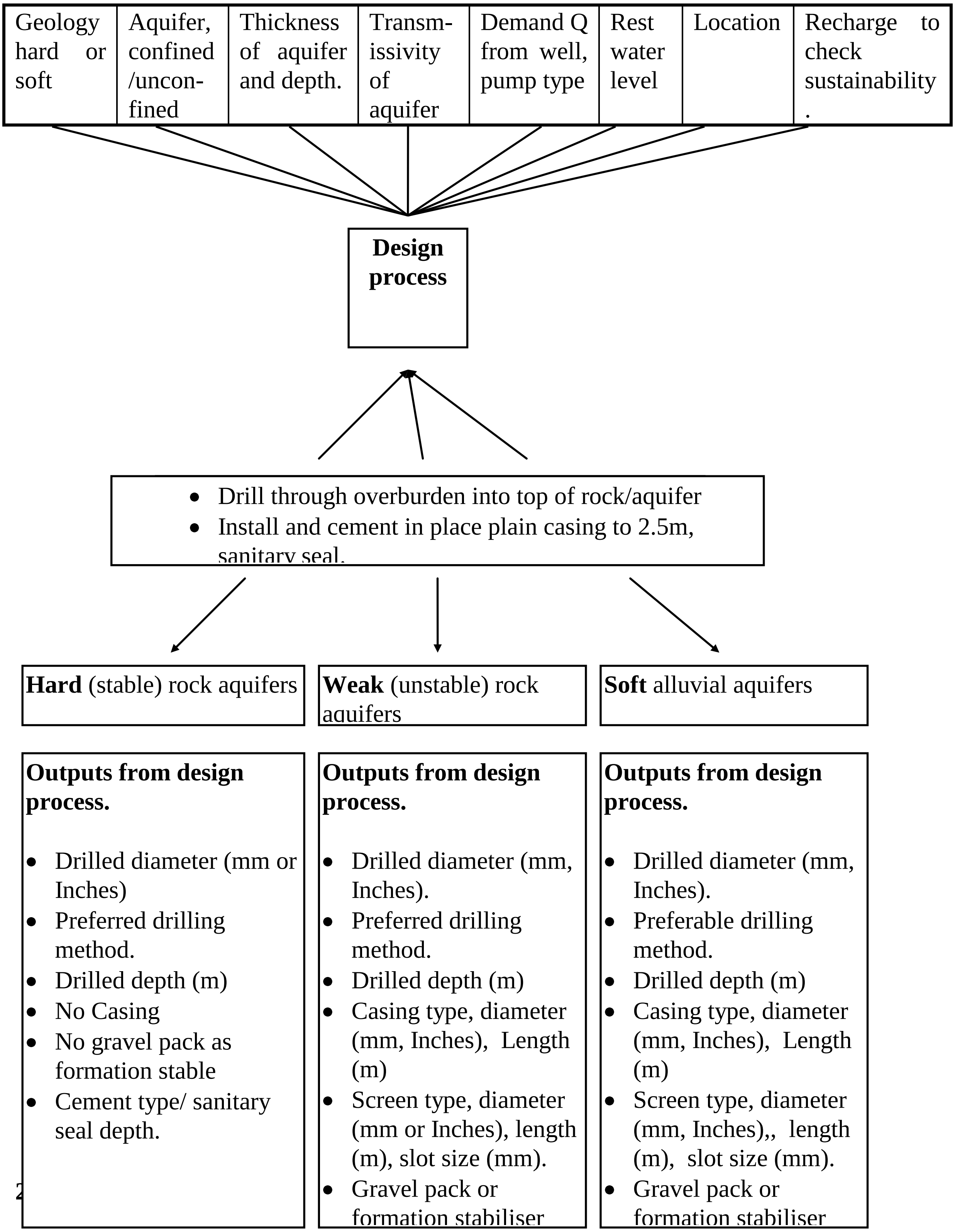
From the design information the likely drilling method will be determined (see Appendix 4). The capacity of the rig is determined by the depth and drilled diameter.

1.3.3 These outputs become the design specification for a particular well. They will determine the materials needed and the detail of a drilling contract.

2 Well design procedure

2.1 Design procedure outline

Before a well can be designed and constructed the information in the list below needs to be gathered from the data sources. The figure below outlines the design procedure. It illustrates the inputs, the inference system and the output for the three common ground conditions.



2.2.1 The demand (Qd) or the maximum yield (Qy) dictates the well design. For a discharge (Q) a certain size pump will be required. The pump has to fit within the pump casing with adequate clearance. It is standard practice to take the required casing internal diameter (ID) as pump outside diameter (OD) + 2” (50mm). The well casing has to fit inside the drilled hole leaving an adequate annulus to facilitate grouting or addition of formation stabiliser. In shallow wells to about 30m, the required hole diameter as casing (OD) + 2” (50mm) min. For deeper wells the required hole diameter is casing (OD) + 4”- 6”. If a gravel pack is being used the drilled diameter will increase again.

2.2.2 Yield estimation and well design

Using Logan’s approximation $T=1.22Q/s$

Where	T	(Transmissivity of aquifer) = k.d	(m^2/d)
	k =	permeability of aquifer formation	(m/d)
	d =	saturated thickness of aquifer prior to pumping	(m)
and	Q =	discharge (demand, pumping or abstraction rate)	(m^3/d)
	s =	drawdown in the well due to pumping a discharge Q	(m)
	Q/s =	specific capacity	(m^2/d)

1. From the drilling log, identify the position of the aquifer.
2. If we know the aquifer formation lithology, estimate aquifer permeability (k).
3. From drilling logs/geological maps/geophysics, identify saturated aquifer thickness.
4. Knowing both k and d we can estimate T.
5. Knowing T for a given discharge (Q), estimate drawdown (s) from Logan equation.
6. From drilling log, dipping of other wells, identify the groundwater level (SWL).
7. Knowing both SWL and s, predict pumping water level (PWL).
8. Knowing PWL, decide on pump setting depth and therefore pump casing depth (if needed).
9. Screen length will be determined by pump casing and aquifer thickness.

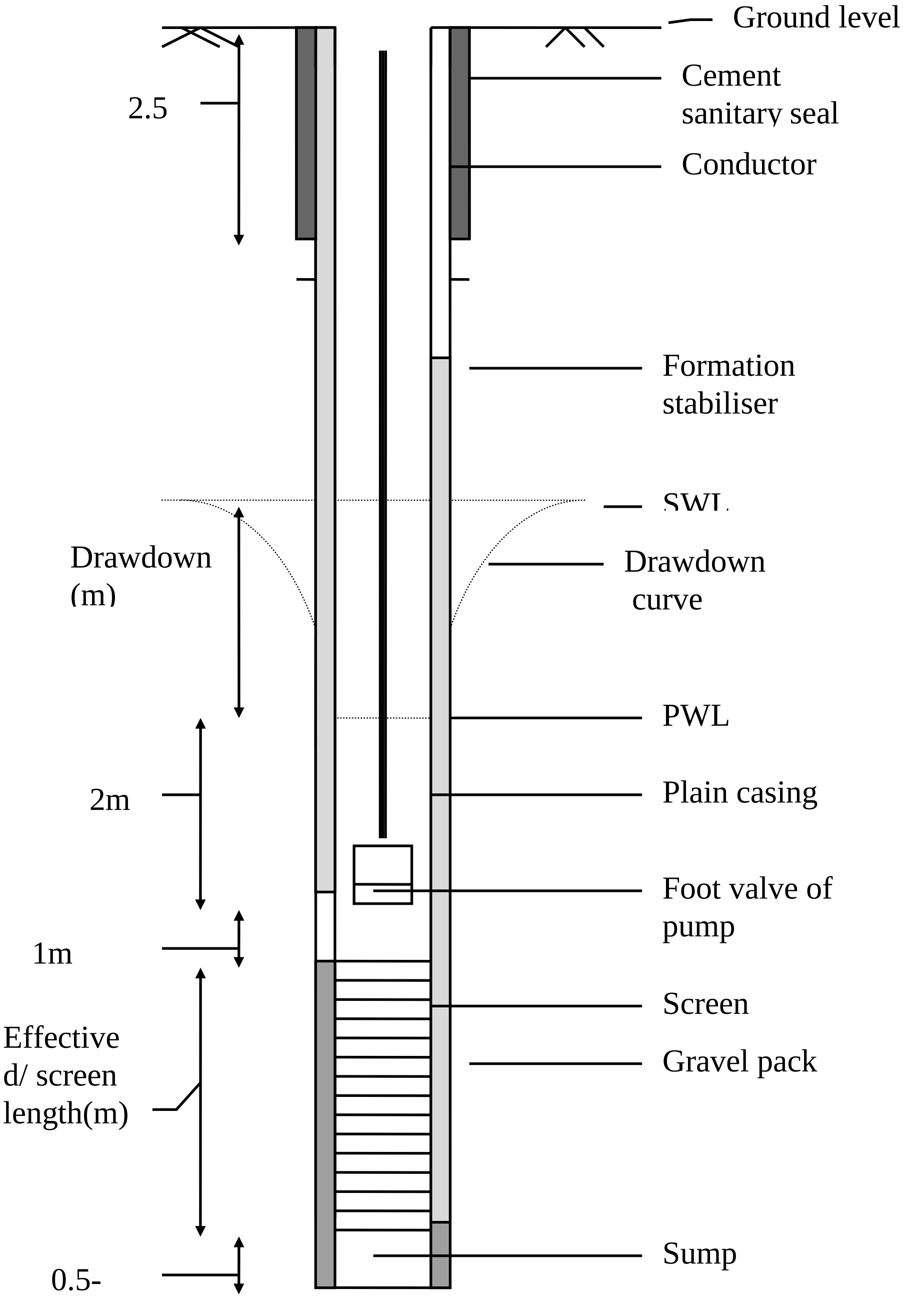
2.3 Design rules of thumb

(1)	Casing for handpumps is usually 4”, pump dia + 2” = internal diameter (ID) of casing.
(2)	Drilled diameter = 2”- 6” + outer diameter (OD) of casing.
(3)	Rules on gravel pack (see Appendix 3).
(4)	The foot valve or pump intake should be at least 2m (min.1m) below the lowest expected PWL and 1m above screen.
(5)	If the water-bearing layer is significantly lower than SWL, the aquifer is confined.
(6)	Slot size determined by grain size of aquifer (see Appendix 3).
(7)	Sanitary seal to be 2.5m deep with cement plus and conductor casing.
(8)	Choosing a GP (see Appendix 3).
(9)	Values of k for different rock types (see Appendix 2.3).
(10)	Cement ratio water: cement, 28 litres to 50kg (by weight). Does the groundwater quality make special cements necessary e.g. sulphate resistance.
(11)	In hard rock lining casing or screen needed except at the sanitary top seal.
(12)	Sanitary seal very important to avoid contamination of the well from the surface.

Summary of components which may make up a well design

For drilled hole

Depth effected by:-	Diameter effected by:-
Q Demand may require large length of effective d. (may not be possible more wells?)	**Pump size** diameter (OD) of pump + 2" (50mm) = casing diameter (ID)
K The aquifer may be deep.	
S If s is high it will reduce the effective d and the hole will be deeper.	**Casing size** (OD) diameter + 2" (50mm) = Hole diameter except **Artificial GP, add 2" to diameter of casing with GP attached.
PWL + 3m for foot valve position + effective d (screen length) + 0.5 -1m for sump = depth from surface needed to be drilled.	**Q / T** If required discharge cannot be met then multiple boreholes may be needed. The diameter of the well can be increased but may not have significant impact.



Sanitary seal [12] very important to avoid contamination of the well from the surface and [7] to be 2.5m deep (in the least impermeable layer) with cement plug and **conductor casing**.
Cement [10] usually ratio water: cement, 28:50 (by weight) Does the groundwater quality make special cements /casing necessary e.g. sulphate resistant.
Formation stabiliser see GP
Drawdown (s) use Logan to find s.

PWL pump water level determined by drawdown (s) using Jacob or Logan equation.
Casing [1] Casing for handpumps is usually 4", pump dia. + 2" = internal diameter (ID) of casing.
Foot valve position [4] The foot valve should be at least 2m (min. 1m) below PWL and 1m above screen.
Screen [6] Slot size determined by grain size of aquifer (see Clark)
GP gravel pack, [8] Choosing a GP (see Clark)

2.4 Well design examples

There are three examples, one for each of the common ground conditions. For each example there is a table containing the data sources and the information gained from those data sources. This information then inputs into the design process. The design rules of thumb combine with the well design process to give the design outputs.

2.4.1 **Southern Ethiopia** (Confined aquifer in hard rock with soft layers)

Table showing information gathered before design attempted.

Information source	**Information obtained**
Geological map	Name of basement complex Undulating terrain
From existing boreholes	Yield 2l/s Ave. depth 80m Ave. SWL 40m Occasionally dry up (pumping stops) Problems with recharge (T low) D.T.H drilling used Log, hard rock with soft layers of ash Main water bearing horizon @ 65m
Demand, Q for handpumps	0.2l/s

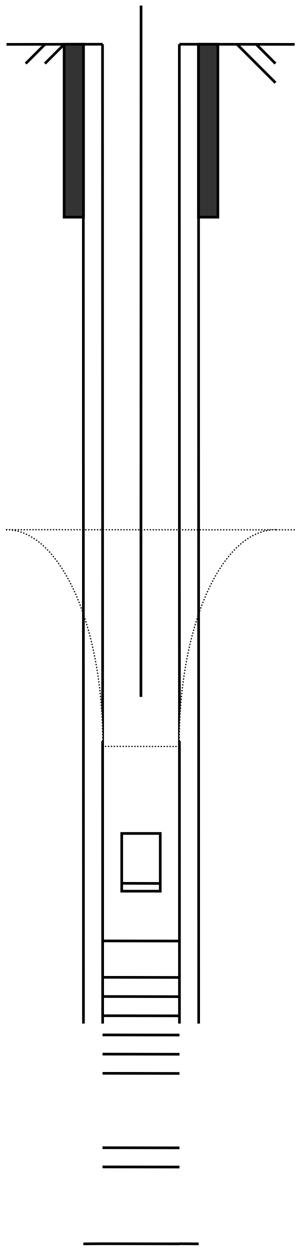


Table showing the design outputs from the information obtained.

Inputs	**Design**	**Outputs**
Hand-pump	HP→ 4" casing and screen (1) 4" c/s → 6" hole (2) Footvalve location (4)	4" casing / screen 6" hole drilled
Geology	No gravel pack (3) Formation stabilizer	FS → x tonnes
Other boreholes	Depth 80m SWL 40m	Drill to about 80m
illers log	Water bearing horizon at 65m, screen from 65m down to 80 with 1m sump.	15m screen 65m casing
RWL 40m	Confined aquifer (5) pump footvalve must be between PWL and 63m, need to know drawdown.	Pump at 63m
	Cemented sanitary seal(7)	2.5m of 5"dia. Conductor casing cemented
	Slot size and entrance velocity(6).	Plastic sawn slot

(1) Casing for handpumps is usually 4", pump dia. + 2" = internal diameter (ID) of casing.

(2) Drilled diameter = 2” + outer diameter (OD) of casing.
(3) See Clark rules on GP.
(4) The foot valve should be at least 2m (min. 1m) below PWL and 1m above screen.
(5) If the water-bearing layer is significantly lower than SWL, the aquifer is confined.
(6) Slot size determined by grain size of aquifer (see Clark)
(7) Sanitary seal to be 2.5m deep with cement plug and conductor casing.

2.4.2 Silsoe Greensand (unconfined in soft rock)

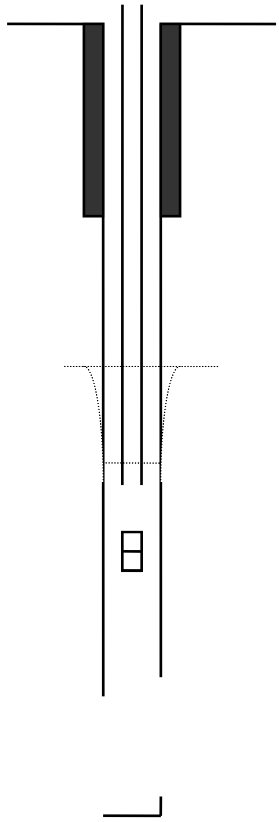
Information source	Information obtained
Geological map	Gault clay 0-4m Lower greensand 4-30m
From existing boreholes	SWL 7.5m Rotary and percussion used water bearing layer found @ 7.5m Geotextile sock use- GP needed.
Demand, Q for handpumps	0.2l/s

Inputs	Design	Outputs
Handpump	HP→ 4” casing and screen	4” diameter casing and screen
Geology	Artificial gravel pack[(8)] and formation stabiliser. Type slot size of screen?	8” dia. Hole drilled FS x tonnes 14m hole depth 3m screen 11m casing Plastic sawn slots.
K from table[(9)]	Transmissivity→PWL	Pump at 9m depth
		2.5m length of conductor casing dia. 6”, sealed with cement[(10)].

(8) Choosing a GP (see Clark)
(9) Values of k for different rock types appear in appendix …
(10) Mortar ratio water: cement, 28:50 (by weight) Does the groundwater quality make special cements/casing necessary e.g. sulphate resistance.

2.4.3 Pure hard rock (unconfined/hard)

Information source	Information obtained
Geological map	Rock type, Limestone.
From existing borehole	Most 30m D.T H. drilling used. SWL 20m
Demand, Q for pump.	20l/s (never any problems)



Inputs	Design	Outputs
Hard rock	Unlined[11]	Unlined
Large discharge	Drill 6" hole	6" hole Drill to 30m
K from table[9]	drawdown low.	Pump at 23m
	no gravel pack	
	sanitary protection at surface and through superficial sediment.[12]	2.5 m length conductor casing dia.5" with mortar seal

[11] In hard rock no lining casing or screen needed.
[12] Sanitary seal very important to avoid contamination of the well from the surface.

3. Information needs and sources

3.1 Introduction

3.1.1 The purpose of this chapter is to identify the essential information needed for completion of a well design. A list of where to find each data source is included. A practical description of how to interpret specific information from each data source is given. The interpretation of the data sources is not exhaustive but will form the basis of the minimum knowledge needed to undertake a groundwater investigation. More information can be obtained but will need specialist groundwater knowledge. A brief outline of the other information that can be gained will be included in each section. Using specialist knowledge will be examined in more detail in chapter 4.

3.2 High priority data sources: Test pumping

3.2.1 From an existing borehole or well a constant flow-pumping test can be undertaken. A constant flow-pumping test measures the drawdown at a constant discharge of water from the well.

3.2.2	Equipment needed
•	A pump (this must have capacity to achieve the required pumping).
•	A flow-measuring device, a weir tank if possible.
•	A borehole dipper or device to measure the pumped water level.
3.2.3	Procedure
1.	Measure the height (in metres) from the static water level to ground level (a temporary benchmark at the top of the well or borehole).
2.	Connect the pump to the flow-measuring device and start the pump.
3.	Measure the discharge when it is constant (m^3/day), simultaneously measure the water level. These two measurements should be recorded every five minutes over the next three hours.
4.	Calculate an average of the pumped water level and then deduct from the static water level to give the drawdown.
5.	It is now possible from the measured discharge and the drawdown using Logan's equation (2.2.3) to work out an estimation of the Transmissivity for that aquifer.
3.2.4	Important notes
•	Make sure permission has been granted from those who are in charge of water well.
•	Pump rate must be constant.
•	Pumped water must not get back to aquifer, need measures to avoid direct recharge.
3.2.6	Outputs from this pump test
	Static water level Pumped water level Drawdown Specific capacity Transmissivity (from Logan)

3.2.7 A specialist can gain much more information from pumping tests. A step drawdown test could measure the well performance and the well efficiency. More accurate constant pump tests could be carried out to measure aquifer characteristics of storativity, hydraulic conductivity and transmissivity. A specialist may also set up a well monitoring programme; this would use pumping test data to work out well efficiencies and well yields. Any existing pump test data would need to be interpreted by a groundwater specialist.

3.2.8 <u>Further reading</u> Brassington (1997) chapter 8, Clark (1988) chapter 9
BS6316:1992. Code of practise for test pumping water wells.

3.3 High priority data sources: Geological maps

3.3.1 Geological maps can be very useful in giving information about the structure of the subsurface rocks. To understand them, a basic knowledge of the principles of geology needs to be understood (Listed in table below). A description of how to interpret the information from the map follows.

Sources
• British Geological Survey (BGS)

• University geology departments • Mining petroleum companies • Ordnance survey • The Internet

3.3.2 Rocks can be categorised into three main groups, a description of them and their hydrogeology is listed in the table below.

Rock type	Description	Hydrogeology (see appendices 2.1, 2.2, 2.3)
Igneous	Crystalline and normally made up of tightly interlocking crystals of a variety of minerals. They are volcanic rocks formed from liquid magna.	Poor primary k Poor to moderate aquifers with jointing/fissures
Sedimentary	Formed from weathered and eroded material, typically occurring in layers. E.g. Sandstone, Mudstone, Limestone.	Primary k Poor to very good aquifers
Metamorphic	Rocks that have been altered by high pressure and/or temperature e.g. Slate, Marble.	Nil – low porosity Poor aquifers

Sedimentary rocks normally provide the best aquifers. Also Igneous rocks with jointing/fractures; have secondary porosity with a better likelihood of good aquifers being found. Generally the younger the formation the better the hydrological properties.

3.3.3 Geological maps can be very complicated. They often have complex legends with many colours and long unpronounceable words. It is important to keep focused on what you want the map for, i.e. to determine the rock type, thickness of overburden and the aquifer properties. The names of the rock from the map can be used to gain the information (see Appendix 1). A geology reference book may be very useful in helping with this.

3.3.4 A specialist may help to determine whether the rocks shown on the map are hard or soft and indicate aquifer properties.

3.3.5 Further reading Barnes (1995)
Brassington (1997) Chapter 3, section 3.2

3.4 High priority data sources: Borehole dipping

3.4.1 Existing wells and boreholes can be dipped to gather information about the water level and the depth of well.

3.4.2	Equipment needed
	A water level dipper is a measuring tape when lowered down a well, and on touching water makes a sound. It allows accurate water levels to be measured. It is possible to make a basic dipper with a surveyors-tape attached to a bottle filled with sand.
3.4.3	Procedure
•	Determine a temporary benchmark at the top of the well as the point at which readings

	are taken, all future readings should be taken from this point.
•	The dipper is then lowered into the well until it touches the water surface.
•	At this point the reading on the measuring tape is taken at the temporary benchmark and recorded. This should be done three times to verify the reading. The distance from temporary benchmark to the water level is the rest water level (RWL).
3.4.4	Important notes
•	Water levels often fluctuate seasonally, thus it is always important to record when data is collected.
•	Water level also fluctuates with atmospheric pressure.
3.4.5	Outputs from borehole dipping
•	Possible to determine the depth (metres) of the rest water level (RWL)
•	The thickness of overburden is known to be less the depth of the RWL in unconfined aquifers.

3.4.6 A specialist could set up a programme of water level monitoring. The data from this could be input into a recharge-monitoring programme. A groundwater specialist could also interpret existing borehole dipping data. This could help to give a broader understanding of aquifer recharge, seasonal fluctuations in water levels and groundwater movement.

3.4.7 <u>Further reading</u> Brassington (1997) Chapter 6
Todd (1980) Chapter 6

3.5 High priority data sources: Geological logging

3.5.1 When a well borehole is drilled, there is often a record kept of the geological material found at the different depths. This can be very useful in giving accurate information about the subsurface rocks and the aquifer characteristics.

3.5.2 Interpreting driller's logs

Looking at an existing driller's logs can yield valuable information about the sub-surface formation and groundwater presence. A driller's log is a record of the information of the formation drilled, the groundwater encountered and the construction of the well as seen by the driller. They are usually shown pictorially showing the different features at differing depths below ground level. The lithological sequence of samples will be described and ground water levels marked. It must be remembered that geological logging is interpreted data and is specific to a particular location. It will not necessarily represent ground conditions in the surrounding area. The information is only as good as the person who interpreted it. Good driller's logs can determine rock type, RWL and the well design for that well.

3.5.3 A groundwater specialist could take a sample by using a hand auger and then undertake sieve analysis on the samples. Exploratory boreholes could be drilled to gain a new driller's log. Geophysical logging could be used to give a further insight into sub surface characteristics (see Appendix 5).
3.5.4 <u>Further reading</u> Clark (1988) Chapter 7
Fetter (1994) Chapter 13, section 13.4
Todd (1980) Chapter 12

3.6 High priority data sources: **Aerial photographs**

3.6.1 Aerial photographs are very useful in highlighting ground features that indicate the presence of groundwater. The table lists some of the places where aerial photographs may be obtained. This is followed by an explanation of how to interpret some simple feature from the photographs.

Sources

- Central government departments, de-restricted military documents
- University departments
- Mapping agencies
- Companies who sell images via the Internet

3.6.2 Interpretation of features (it is useful to trace features onto a new piece of paper).

Topography – From the photograph try and determine if land is of high and low relief. High relief is usually less successful for groundwater recharge as rainfall runs-off quicker. Low relief often has low speeds of run-off and greater chance of groundwater recharge and high incidences of ponding.
Lineations – Look for linear features and the boundaries between them. This may indicate direction of fractures and strata in rock.
Tone- Changes in colour and tone may indicate between different rock type, wet and dry soils may be differentiated. These strata may indicate sedimentary rocks.
Drainage Patterns- Intense drainage pattern indicates that surface run-off is relatively high and that the permeability of the ground below is relatively low. Closed or sparse patterns indicate that run-off may be low and that recharge or evaporation is high.
Drainage Features – Dark patches in seasonal watercourses may indicate where the water table is near the surface. The alluvial deposits of riverbeds can often for good location for siting of a well.
Vegetation – Generally only indicates the shallow groundwater conditions. Sparse vegetation can indicate groundwater is generally inaccessible to plant roots. Thin soil cover. Water being close to the surface. Moderate vegetation along drainage lines may indicate alluvial aquifers existing. Intense vegetation suggests surface and groundwater sources are abundant.

The outputs from aerial photographs are: possible rock type, indication of recharge and a general idea of the locations where further investigation should be undertaken. It will be essential to go to some of the areas highlighted from the photograph to help determine the credibility of the interpretation.

3.6.3 A specialist will be able to interpret more information from the photograph. He/she may be able to give good potential sites for borehole location. These locations need to be investigated further. Information about recharge and recharge boundaries can also be interpreted.

3.7 Low priority data sources

3.7.1 CCTV

A video camera can be inserted in a well to look at the sub-surface features. It can be used to give information about the kind of aquifer and rock type. The visual images need to be interpreted, this requires experience and good groundwater understanding. CCTV can also be a useful tool in checking the construction of new boreholes.

3.7.2 Satellite Images

A form of remote sensing which is becoming increasing available. The interpretation is similar to that of the aerial photographs. Satellite images are often on a large scale and miss local detail, so it is essential to check interpreted information with the reality on the ground. It is also important to know the spectrum range in which the image was taken as interpretation can change depending on the way the image was created. There are two main sources of satellite images; from Landsat 5 and SPOT satellites.

3.7.3 Topographic Maps

These can give good information about relief, high and low areas and also drainage patterns. They will also help to plan the logistics side of any drilling operation.

3.7.4 Geophysics

This is often thought to be the solution to all groundwater dilemmas. It is certain that it can be a useful tool when incorporated with the other data. The important aspect of a geophysical study is to know what information is required, e.g. specific location (fracture), what depth is the water table etc. Geophysical investigation does not only involve a lot of specialist equipment but also specialist interpretation skills. Before a survey is commissioned it is essential that the specific information required is outlined.

Table 2: Summary of high priority data sources

Data Source	Potential inputs to Well design	Tasks that could be undertaken by non specialist	Interpretation (by non specialist)	Specialist Tasks/Interpretation
Test pumping Data	• Accurately determines transmissivity • RWL and expected pumped water level • Confined or unconfined • Recharge monitoring programme	• Constant flow pumping test	Work out transmissivity from drawdown and discharge using Logan approximation	Step drawdown test Well monitoring programme. Recovery tests. Determine well yield, well efficiency and transmissivity more accurately.
Aerial Photos	• Rock type, hard or soft • Location (general areas, to check) • Recharge (from drainage patterns there will be an idea of the potential)	• Trace lineations, vegetation, drainage patterns and determine areas of high low relief	Vegetation – water present Fractures – more likelihood of water. High relief less likely to have groundwater than low. Changes in rock type, fracturing	Shallow groundwater. Recharge boundaries.
Geological Maps	• Rock type, hard or soft • Thickness or aquifer • Confined or unconfined • Transmissivity • Thickness of overburden • Recharge, general idea	• Identify rock type (to determine whether hard/soft or aquifer)	Requires some basic geology. Look for sedimentary rocks. Find their values of k from appendix.	Better understanding of the more complex geological names and corresponding relationships to hydrogeology.
Borehole Dipping	• Thickness of overburden • RWL • Recharge	• Dip existing wells/boreholes	Find RWL depth of well and overburden thickness.	Dipping programme, seasonal fluctuations. Barometric fluctuations on RWL.
Geological Logs	• Rock type, hard or soft • Type of aquifer • Thickness of aquifer • Thickness of overburden • Transmissivity • RWL	• Look at existing driller's logs	Determine the RWL depth, geological formation, design of well, type of aquifer: hard or soft.	Geophysical logs, take and interpret. Dig hole, hand auger, exploratory borehole. Take sample for visual inspection and sieve analysis.

4. Specialist inputs

4.1 Introduction

A non-specialist can only be expected to have a minimal understanding of groundwater and the techniques that are involved in its investigation. The chapter will explain when to use groundwater experts and how different techniques may gain information for a well to be designed.

4.2 When to use specialist techniques
• If not enough information available to design well. • To save time. • If information sources dispute each other and it is not obvious which to believe. • To add confidence if uncertain.

If a non-specialist has exhausted all the avenues of data collection it may be necessary to use hydrogeologists. It may save time at an early stage of an emergency to contract a specialist to get some good quality information. It is possible that some of the information collected is of poor quality or the interpretation is poor. This may lead to conflicting information, to resolve the dispute it may be necessary for a specialist to examine it. The magnitude of a situation may demand the validation of information to give the confidence to go ahead with developing groundwater sources.

4.3 What information is needed from an expert?

Information specific to the inputs for the well design process, the filling of information gaps. It is important that information already collected is not unnecessarily duplicated. Specialists have better interpreting skills and are able to gain more information from the existing data sources, such as geological maps, borehole logs and pump tests. The user needs to know what information is required (see list of inputs 1.4.1), and which inputs are required for the well design process. These specific information requests must be expressed clearly to the specialist in Terms of Reference.

Table 3: When to use which specialist techniques/experts

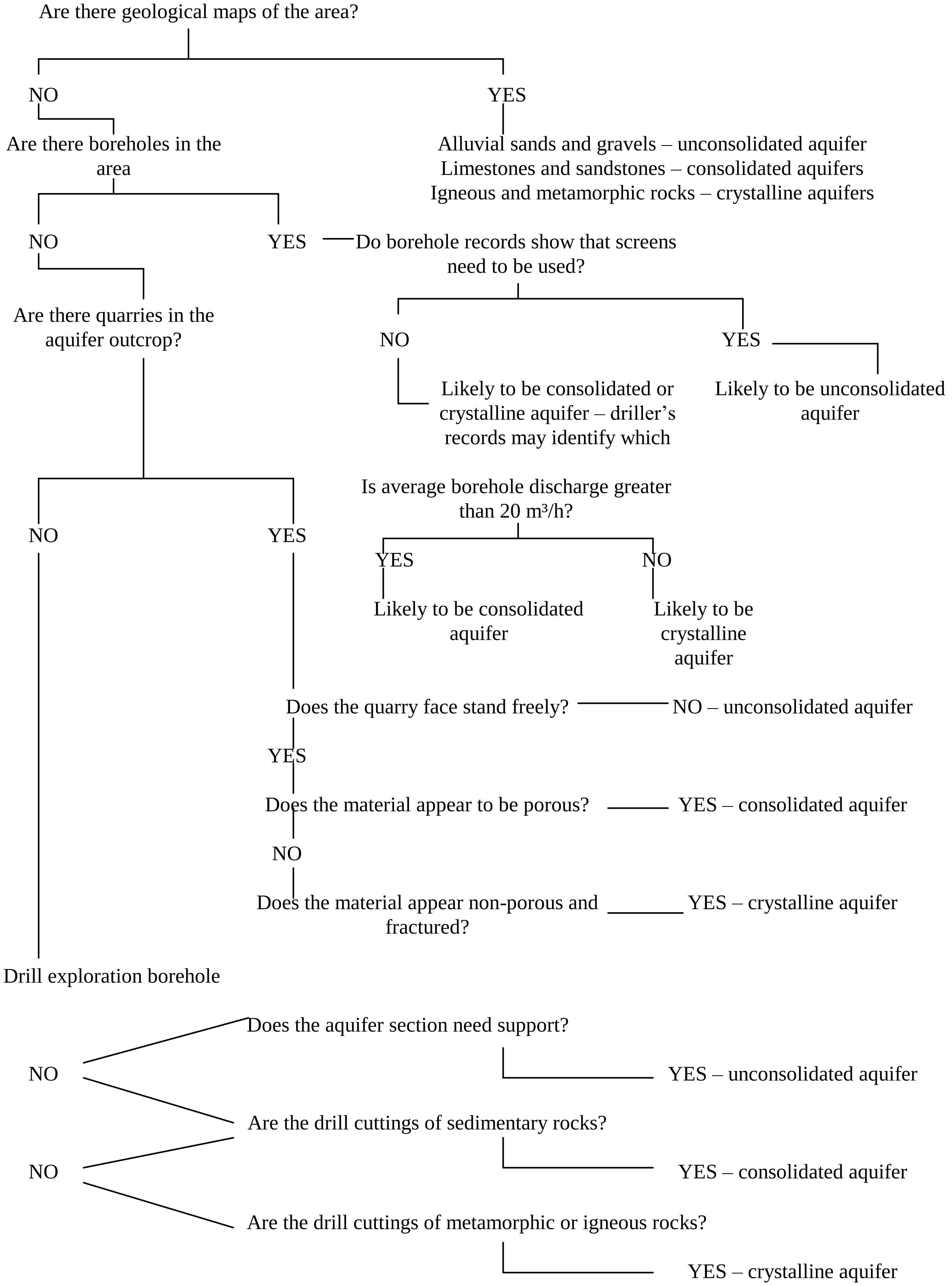
Technique	When Used	To find out what
Geo-physics	Initial field study and siting.	Should be used in conjunction with drilling and to find out something specific to feed into the well design. Could be used for finding the depth of groundwater, giving an idea of the value of k at depth, locating fractures for specific locations.
CCTV	Initial field study, construction and monitoring.	Used on existing or test boreholes to see the kind of material which is below the ground. Can help check the quality of construction and indicate deviations from design specification.
Divining	Initial field study and siting.	This could be a relatively cheap option and may be worth while in locating particular sites, there may even be

		some expectation that a water diviner is involved in the location and siting of a new well. There may be local traditions, specific local vegetation and people who may have proven experience of locating water.
Hydro-geologist	Pre-visit in-country initial field study and siting.	May be used to help in the interpretation of map information and test pumping data. A consultant may be asked in to gather all the information to input into the well design.
Driller	Drilling contracts, well design.	Experienced driller may be needed for quick set-up and training of local team to ensure: drilling contract components are correct, if drilling conditions difficult if a large number of exploratory holes needed.

5. Recommendations

- The guidelines are aimed at Oxfam's emergency support personnel and other field engineers who have training in water engineering but are not groundwater specialists. They will have a basic understanding of the principles of groundwater. The guidelines are for use in the field.
- Appropriate training should be given to those non-specialists who are likely to be responsible for drilling with Oxfam's rigs.
- The information gathering process must be done thoroughly and given enough time to obtain the inputs into the design process.
- Increased internal resources should be provided towards preparing for the use of groundwater by gathering information on potential areas of need prior to an emergency.
- Specialists should only be used when the specific information needed from them is ascertained.

Appendix 1 – Classification of aquifers in the field (Clark 1988)



Finally: geophysically log the borehole to confirm the aquifer classification

Appendix 2.1 – Classification of rock types in terms of permeability (from Brassington, 1997)

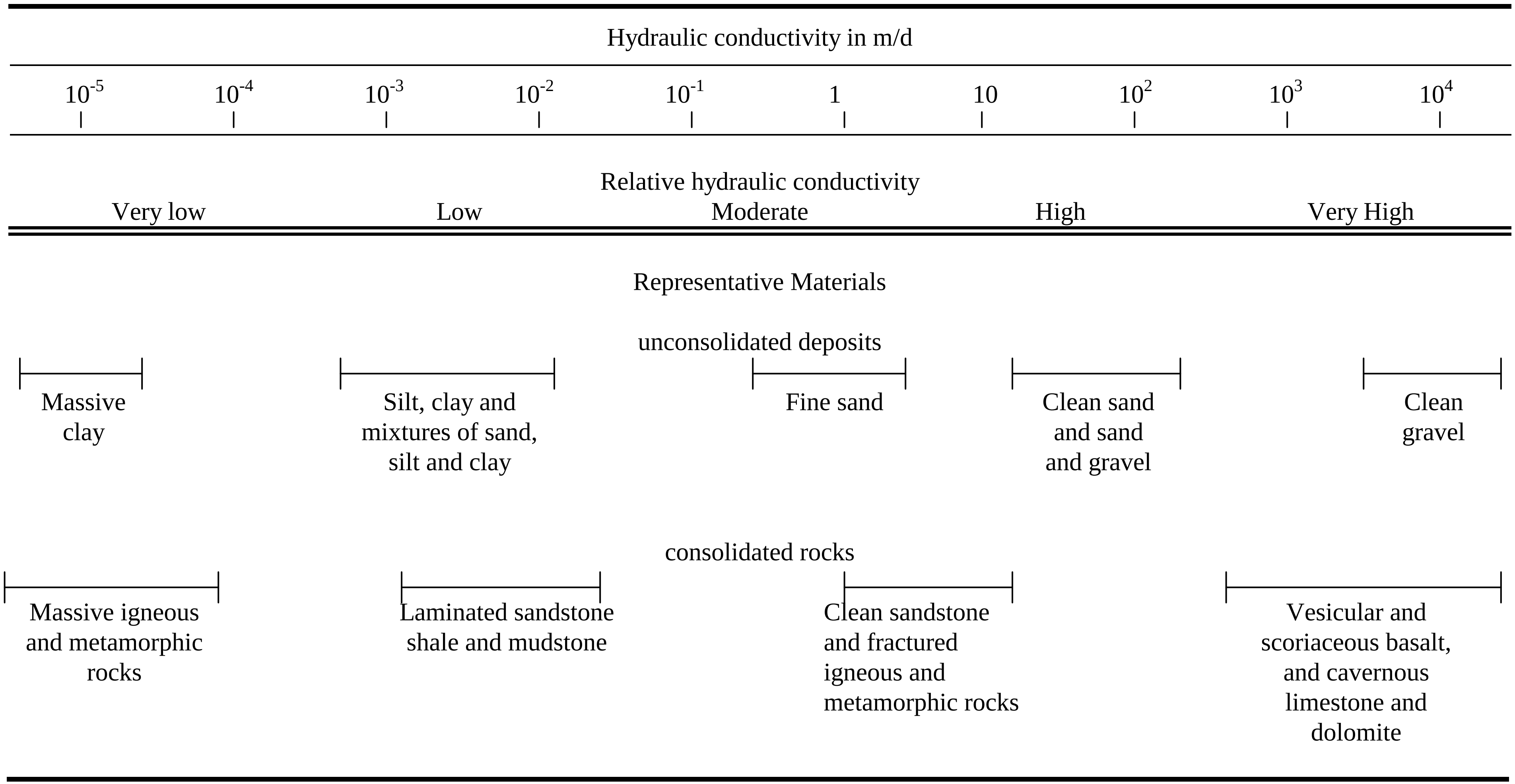
	Sedimentary			Volcanic	
Type of permeability	Unconsolidated	Consolidated	Igneous and metamorphic	Consolidated	Unconsolidated
Intergranular	Gravelly sand, clayey sand, sandy clay		Weathered zone of granite-gneiss	Weathered zone of basalt	
Intergranular and secondary		Breccia, conglomerate, sandstone, slate, zoogenic limestone, oolitic limestone, calcareous grit		Volcanic tuff, volcanic breccia, pumice	
Secondary		Limestone, dolomite, dolomitic limestone	Granite, gneiss, gabbro, quartzite, diorite, schist, mica-schist		

Major rock types, which behave as aquifers, have been classified on the basis of the type of permeability which they exhibit. Intergranular or primary permeability is a feature of unconsolidated deposits and weathered rocks. It also occurs in most sedimentary rocks and those igneous rocks which have a high porosity. Secondary permeability is largely due to fissuring or solution weathering and only affects indurated rocks. Adapted from *Groundwater in the Western Hemisphere* by permission of the United Nations

Appendix 2.2 – List of indicative porosites and hydraulic conductivities for unconsolidated sediments and rocks (from Brassington, 1997)

Geological material	Grain size	Porosity	Hydraulic conductivity, *K* (m/d)
Unconsolidated sediments			
Clay	0.0005-0.002	45-60	$<10^{-2}$
Silt	0.0002-0.06	40-50	$<10^{-2}$-1
Alluvial sands	0.06-2	30-40	1-500
Alluvial gravels	2-64	25-35	500-10000
Consolidated sedimentary rocks			
Shale	Small	5-15	5×10^{-8}-5×10^{-6}
Sandstone	Medium	5-30	10^{-4}-10^{1} (secondary permeability)
Limestone	Variable	0.1-30 (secondary porosity)	10^{-5}-10^{1} (secondary permeability)
Igneous and metamorphic rocks			
Basalt	Small	0.0001-1 (up to 50 if vesicular)	0.0003-3 (secondary permeability)
Granite	Large	0.0001-1 (up to 10 if fractured)	0.0003-0.03 (secondary permeability)
Slate	Small	0.001-1	10^{-8}-10^{-5}
Schist	Medium	0.001-1	10^{-7}-10^{-4}

Appendix 2.3 – Hydraulic conductivities in metres/day for various rock types (from Brassington, 1997)



Appendix 3 – Summary of gravel pack and screen selection (from Clark, 1988)

1. Is the aquifer:

a) Crystalline? Yes – then no screen or pack is required. Formation stabiliser may be needed (p.30).
b) Consolidated? Yes – then screen and pack are usually not required (p.14). If needed for multiple aquifer system (p.18) use formation stabiliser or follow criteria for unconsolidated aquifer.
c) Unconsolidated aquifer? Yes – then screen and gravel pack needed.

Then plot grain-size distribution (GSD) curves for samples of aquifer material (Clarke).

1. Is the aquifer heterogeneous (sorting coefficient >2.5)?
   Yes – then a natural gravel pack can be developed (p.29). The screen slot width should be the average D40 of the aquifer samples (Fig. 3.3).
   No – then an artificial gravel pack is needed (p.30). Design the pack by plotting two curves parallel to the GSD curve of the finest aquifer sample but four and six times coarser than that curve (Fig.3.4). The GSD curve of the gravel pack used should lie between the two new curves. The screen slot width should be between the D10 and D40 of the gravel pack.

2. The screen diameter will have been decided during the structural design (p.17). The choice of screen material and slot design will depend on aquifer:

a) Is the aquifer very thick? Yes – then a long screen with limited (but >10%) open area may be chosen.
b) Is the aquifer thin? Yes – then a screen with a very high open area should be chosen.
c) Is the aquifer over 200m deep? Yes – then a strong screen must be chosen: mild or stainless steel.
d) Is the groundwater corrosive? Yes – then plastic, GRP, stainless steel or coated screens should be used.
   No – then mild steel screens can be used.
e) Is the groundwater encrusting? Yes – then screen with a high open area should be used to reduce entrance velocities (p.33).

Appendix 4 – Comparison of construction methods for wells (from Clark, 1988)

	Advantages	Disadvantages
Manual construction	- Uses low technology, and therefore is cheap where labour is cheap. -	Often restricted to shallow depths, but depths of 40-50m have been achieved. -
Percussion drilling	- Low technology rigs, and therefore cheap mobilisation and operation. - Needs small work area. - Uses little water.	- Can drill only to shallow depths because of temporary casing. - Relatively slow drilling.
Rotary drilling		
Direct circulation	- No limit to depth of drilling. - Fast drilling. - Needs no temporary casing.	- High technology rig so expensive mobilisation and operation. - May need a large working area for rig and mud pits. - Can use a lot of water. - Mud-cake build-up can make development difficult.
DTH and air-flush rotary	- No pollution of aquifer by drilling fluid. - Needs no water. - DTH is very fast in hard formations.	- DTH should not be used in soft, unstable formations. - Drilling depth below the water table is limited by hydraulic pressure.
Reverse circulation	- Leaves no mud cake. - Rapid drilling in coarse unconsolidated aquifers at large diameters.	May use great volumes of water.

Appendix 5 – Applications of borehole geophysics (from Clark, 1988)

Type of log	**Geophysical log**	**Cased/screened borehole**	**Uncased borehole**	**Mud/water-filled borehole**	**Dry borehole**
Formation	Resistivity	No	Yes	Yes	No
	Self-Potential	No	Yes	Yes	No
	Gamma	Yes	Yes	Yes	Yes
	Neutron	Yes	Yes	Yes	Yes
	Gamma-Gamma	Yes	Yes	Yes	Yes
Structural	Caliper	No use	Yes	Yes	Yes
	Casing Collar Locator	Yes	No	Yes	No
	CCTV	Yes	Yes	Only in clean water	Yes
Fluid log	Flow-meter		Yes	Not in mud	No
		Yes, but of limited use			
	Temperature/▲				
	Temperature		Yes	Yes	No
	Conductivity/▲		Yes	Yes	No
	Conductivity				

Appendix 6 - Useful addresses

British Geological Survey (BGS) Keyworth Nottingham NG12 5GG UK 01491 -838800 (Switchboard)	**Hydrogeology Unit (BGS)** MacClean Building Crowmarsh Wallingford Oxfordshire OX10 0RA UK
Ordnance Survey Romsey Road Maybush Southampton SO9 4HD UK	**Spot Image** 16 Bis Avenue Edourd Belin BP 4359 310300 Toulouse Cedex France
Water, Engineering and Development Centre (WEDC) Loughborough University of Technology Leicestershire LE11 3TU UK	**United States Geological Survey (USGS)** Box 25425 Federal Centre Denver Colorado 80225 USA

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