Government of the Republic of Zambia

Professionalising Groundwater Development in Zambia
A five-day Short Course on Drilling Supervision

9th July - 13th July 2018

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Unit 2
Understanding Groundwater – without jargon

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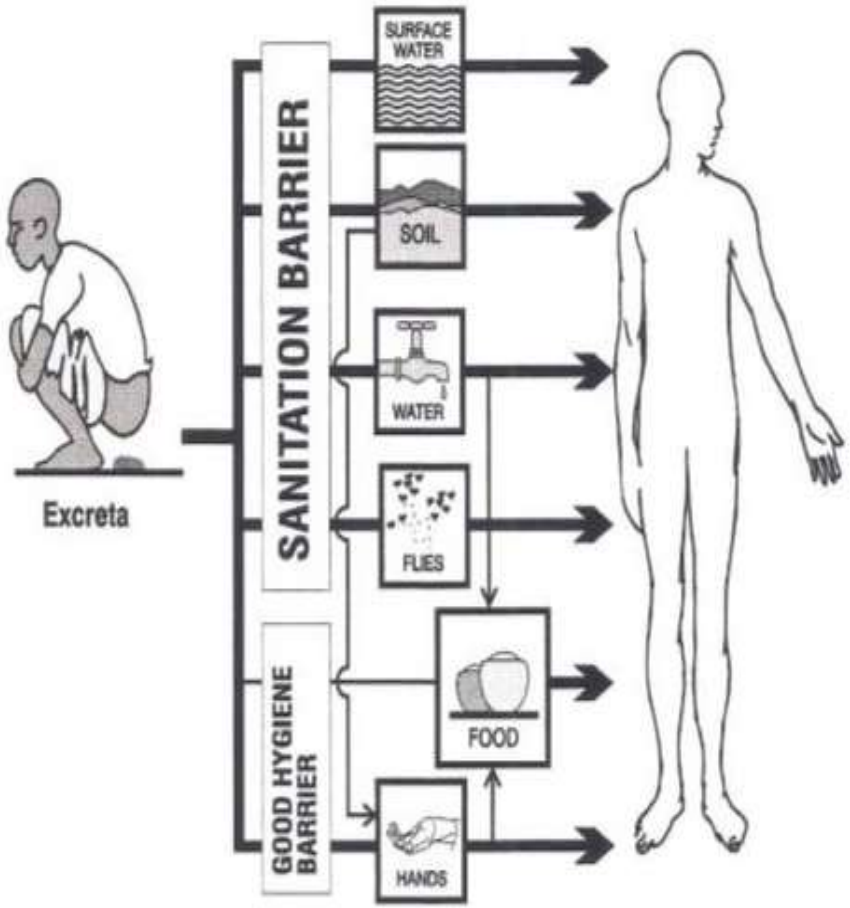
Unit outline

1. The importance of water
2. Groundwater and the water cycle
3. Groundwater abstraction structures
4. Groundwater usage
5. Groundwater occurrence
6. Steps in finding groundwater
7. Borehole design
8. Borehole construction
9. Borehole development and pumping test
10. Groundwater recharge
11. Groundwater quality
12. Data Collection and Management
13. Borehole functionality monitoring
14. The groundwater resources of Zambia

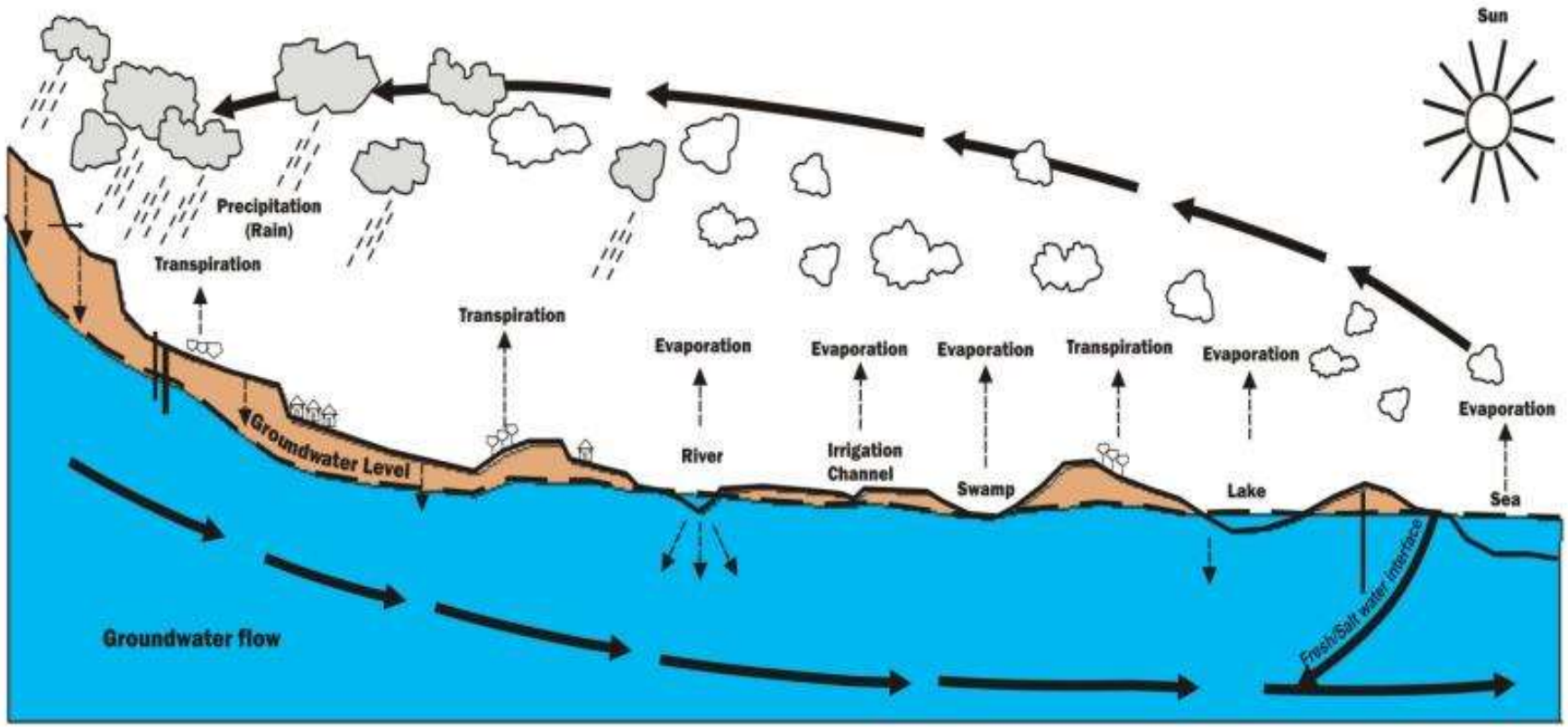
1. The importance of water

- Water is life
- Water Sanitation & Hygiene (WASH)
- Water and agriculture
- Water for livelihoods



The importance of sanitation and hygiene **(Source: Smith, 2003)**

2. Groundwater and the water cycle



2a The water budget

Water balance or water budget equation

$$P = Et + Ro + Q$$

Where

P = Precipitation (Rainfall)

Et = Evapotranspiration

Ro = Runoff

Q = Groundwater recharge

'All the rivers run to the sea and yet the sea is not full. To the place from which the rivers come there they return again'. *King Solomon 1000 B.C.*

3. Groundwater abstraction structures

Dug holes in river channel

Dug wells

Springs

Drilled hole

4. Groundwater usage

- Globally - 4 billion people (estimate based on JMP) depend on groundwater
- Zambia – 65% of the population depend on groundwater
- Zambia - An estimated 3.4 million people rely on boreholes today compared to 1.2 million in 2002

4a. Advantages and disadvantages of groundwater

Advantages

- The abstraction structures are quick to construct if the equipment is available
- Generally free from pathogens
- Generally free from suspended matter
- Not immediately affected by drought

Disadvantages

- The abstraction points can be expensive to construct
- Sometimes expensive exploration methods are necessary to locate the sources
- Sometimes they contain contaminants so their good quality cannot be taken for granted
- If quality deteriorates remedies are costly and difficult to implement

5. Groundwater Occurrence

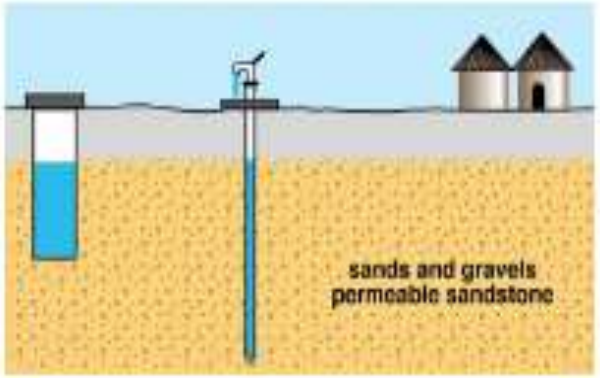
- Groundwater occurrence depends on the nature of the rock underlying the area in which it occurs i.e. whether igneous or sedimentary or metamorphic
- A rock that can yield usable quantities of water usable is called an aquifer
- An aquifer stores water and releases it when needed e.g. sand deposits. It allows water to pass through it and it is said to be permeable
- Aquifers provide storage, filtration and distribution
- A poor groundwater source stores but does not easily release the water e.g. clay deposits. Therefore it is not an aquifer

5a. Groundwater occurrence in different rock types

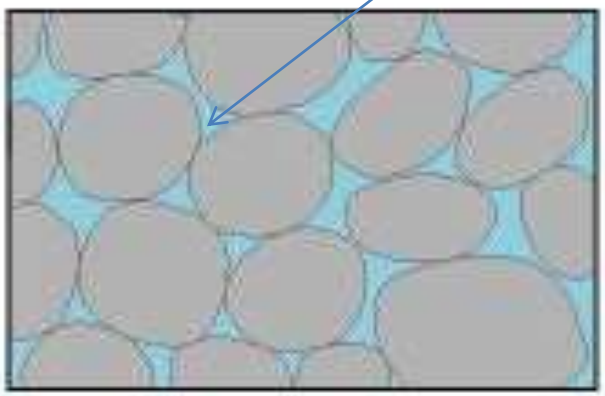
- In sedimentary rocks e.g. sands, gravels, sandstones, as in the Kalahari Group, groundwater occurs in the **spaces** separating individual grains of rock which are called **pore** spaces
- In igneous and metamorphic (crystalline) rocks e.g. granite, groundwater occurs in **joints** and **fractures** in the rocks and the pore spaces **in the loose weathered material overlying** the fresh rock

5b. Groundwater occurrence in loose sediments

- In loose sedimentary rocks e.g. the coarse sands and gravels of the Kalahari system of Zambia, there are many pore spaces for water to occupy, therefore the porosity is said to be high
- Yields can be up to 30 l/s and more and could be adequate for urban water supply.
- But a great part of the Kalahari system is very fine and poorly productive



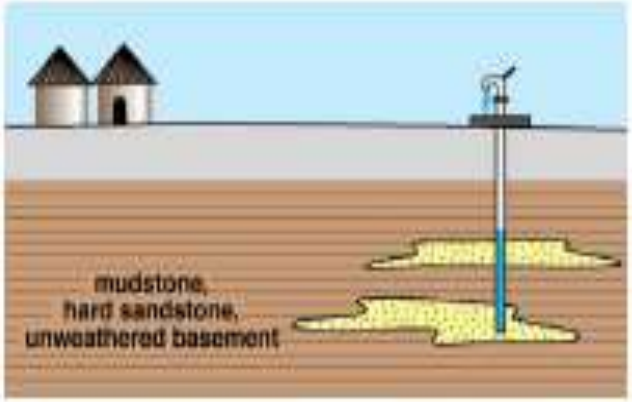
Pore spaces between sand grains holding and releasing water



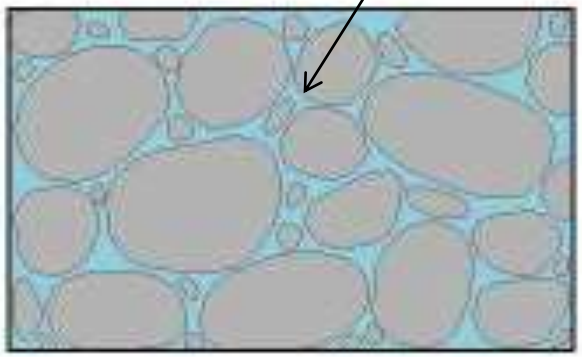
Source: MacDonald et al 2005

5c. Groundwater occurrence in compacted sediments

- Sometimes sediments are compacted and cemented to form sandstones and mudstones
- The pore spaces are reduced by the cementing material
- The yield from the aquifers is low to moderate, about 1-4l/s; adequate for small community supply



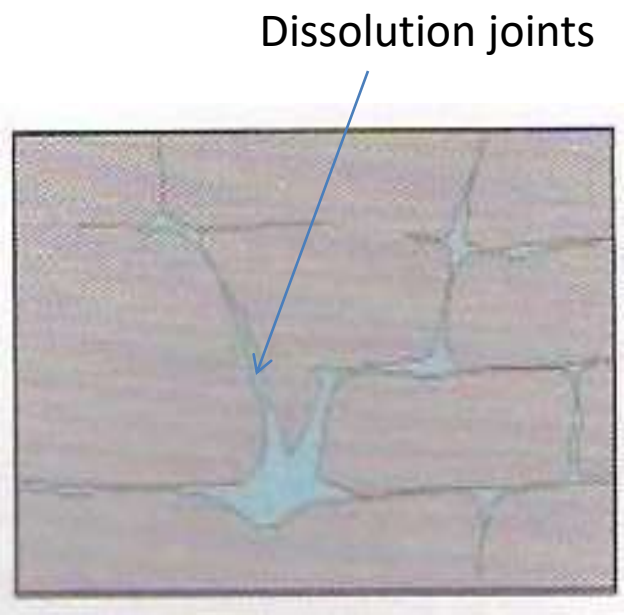
Porosity reduced by the presence of clays and minerals



Source: MacDonald et al 2005

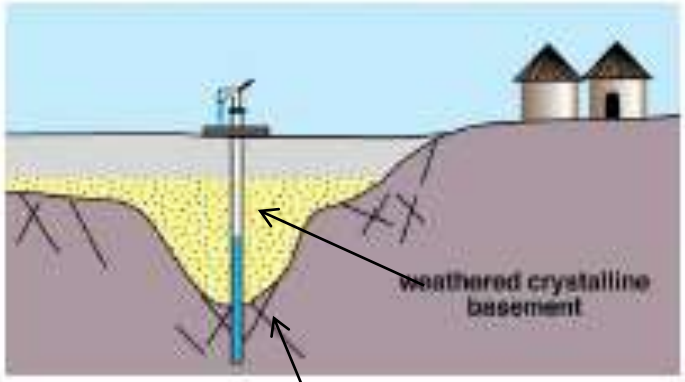
5d. Groundwater occurrence in limestone

- Limestone is a sedimentary rock composed mainly of the skeletons of old sea creatures
- Rain water dissolves some of the rock particles in limestone creating joints
- The joints in limestone deposits of Zambia are very productive
- Yields are between 35 and 50 l/s
- The aquifers provide a significant proportion of the water supply of Lusaka, Kabwe and Ndole municipalities.
- Borehole depths are about 50-90 m below ground level.

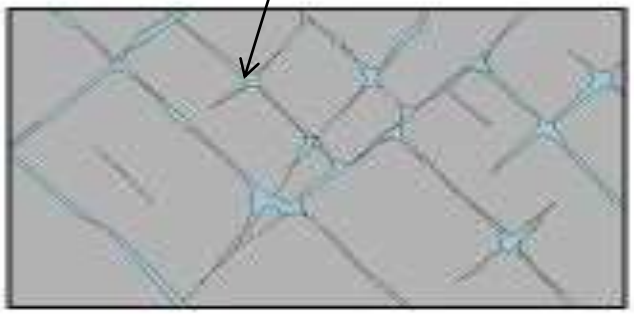


5e. Groundwater occurrence in crystalline rocks

- Crystalline rocks e.g. granites have no pore spaces
- Water occurs in the soft weathered material overlying the hard rocks or in the joints
- Yield from boreholes is about 1-3l/s but if not properly sited could be dry



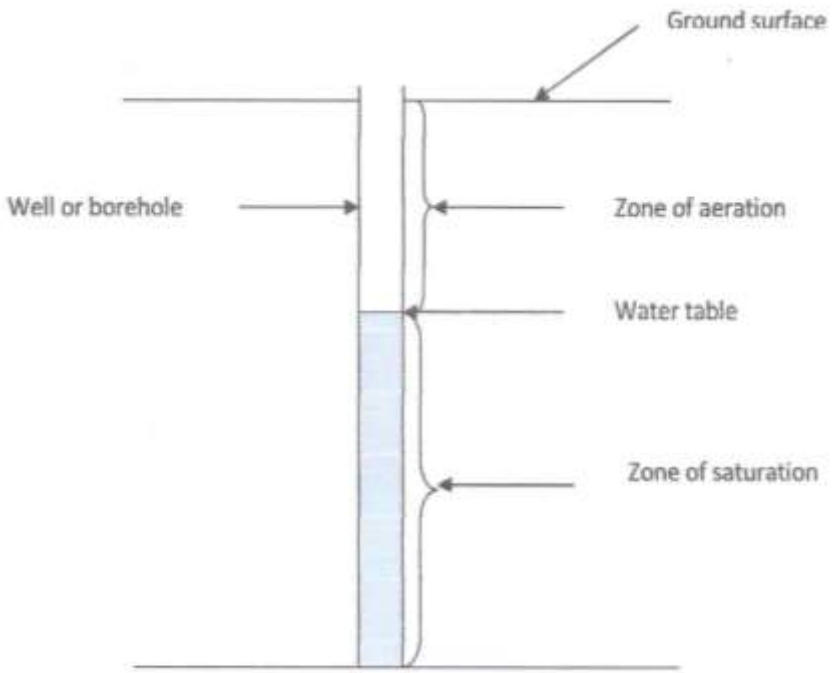
Joints in crystalline rocks



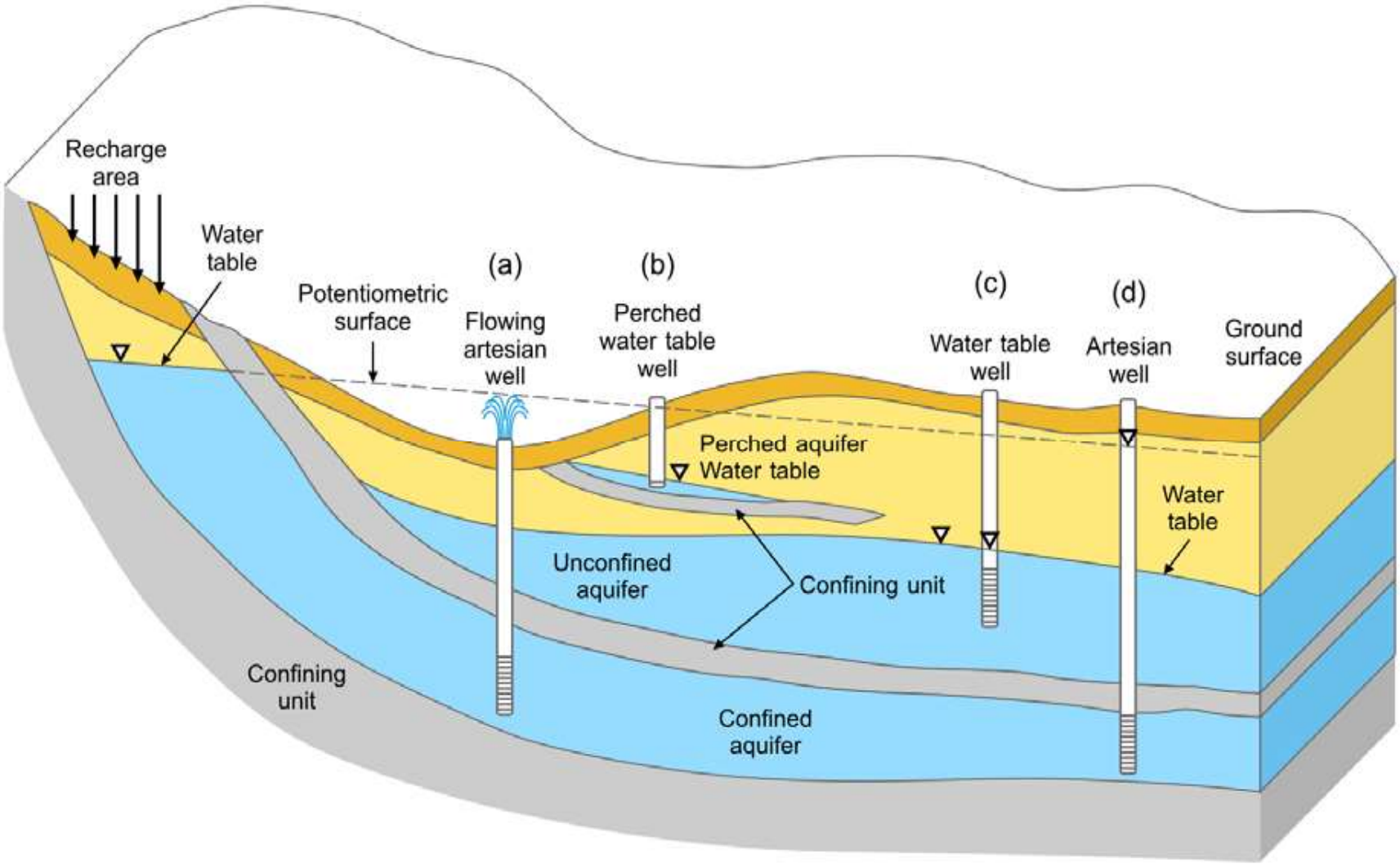
Source: MacDonald et al 2005

5f. The water table

- The water table is the level at which water stands in a well or pond
- The level of the water table is not constant. It fluctuates seasonally and with abstraction
- In the zone of aeration the pore spaces are filled with air; the pore spaces allow the water to pass through them
- In the zone of saturation the pore spaces in a rock are filled with water



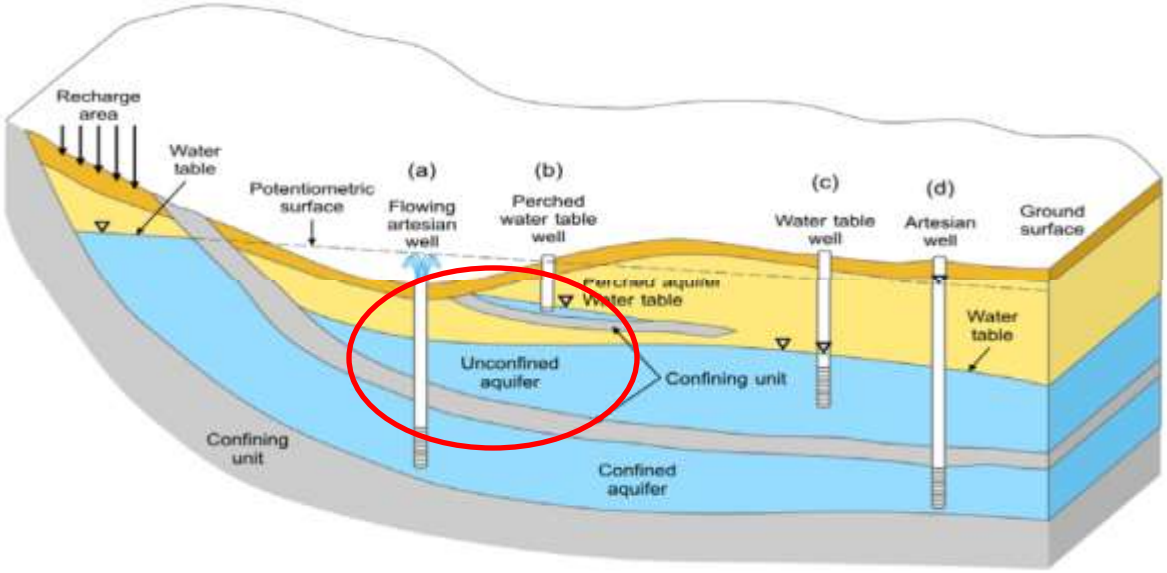
5g. Different aquifer types



Source: Todd et al 2005

5h. Unconfined Aquifers

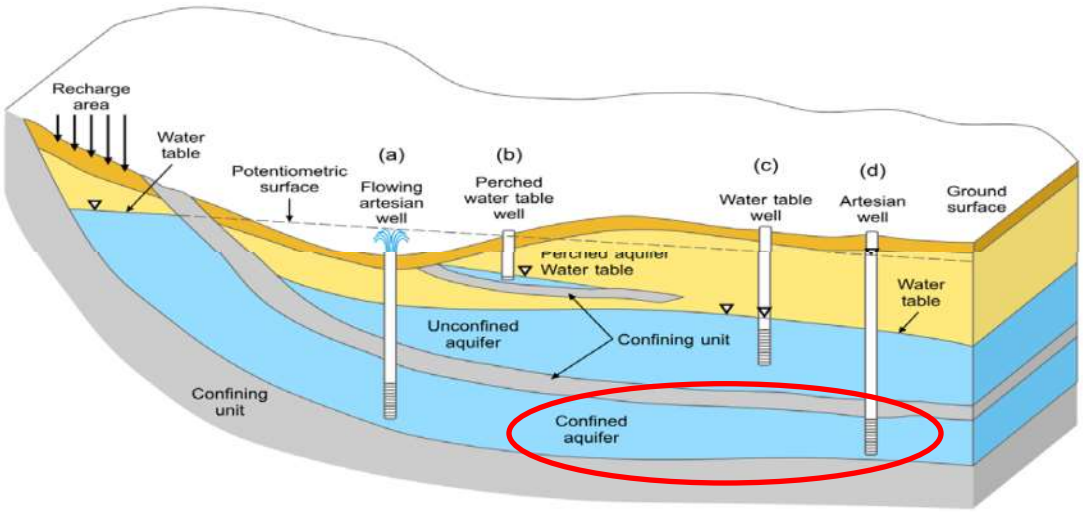
- In unconfined aquifers the water table is in continuity with the atmosphere
- Unconfined aquifers of limited lateral extent and thickness are known as perched aquifers
- Unconfined aquifers are prone to contamination from the surface e.g. from pit latrines, pesticides, fertilisers, urban run-off and industrial waste



Source: Todd et al 2005

5i. Confined aquifers

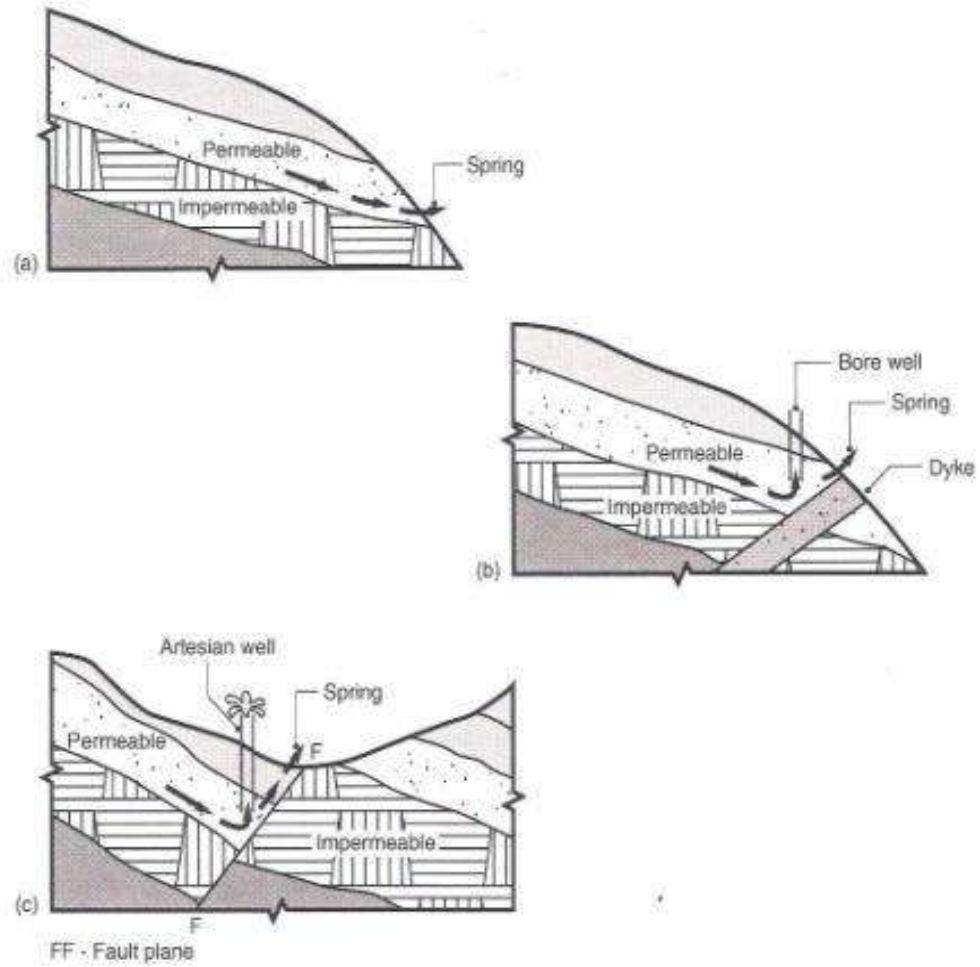
- Confined aquifers (pressure aquifers) are covered by impermeable material such as clays, and hold water under pressure
- In a borehole tapping a confined aquifer the water level rises under this pressure. In some cases where conditions permit, artesian flows may develop
- The level at which water stands in a borehole tapping a confined aquifer, is called the piezometeric level



Source: Todd et al 2005

15j. Groundwater as springs

- Water that flows out of the ground is known as a spring
- Water travels down through soils and rocks until it reaches a harder layer and flows out



5k. Aquifers along river floodplains

Advantages

- The aquifer is usually recharged by the river channel
- Even in the dry season when the river may be dry there is still some storage
- The sands and gravels in the dry channel and floodplain filter the river water and therefore cheaper to treat than the surface water

Limitations

- The sand could be very fine
- The sand may have a high clay percentage, therefore yield little water
- Water may be turbid due to the presence of the clays
- The aquifers are prone to bacterial contamination due to shallow depth

Quick Questions!

- Do you have any questions or comments on what you have heard so far?
- Is there anything new that you have learned?

6. Steps in finding water

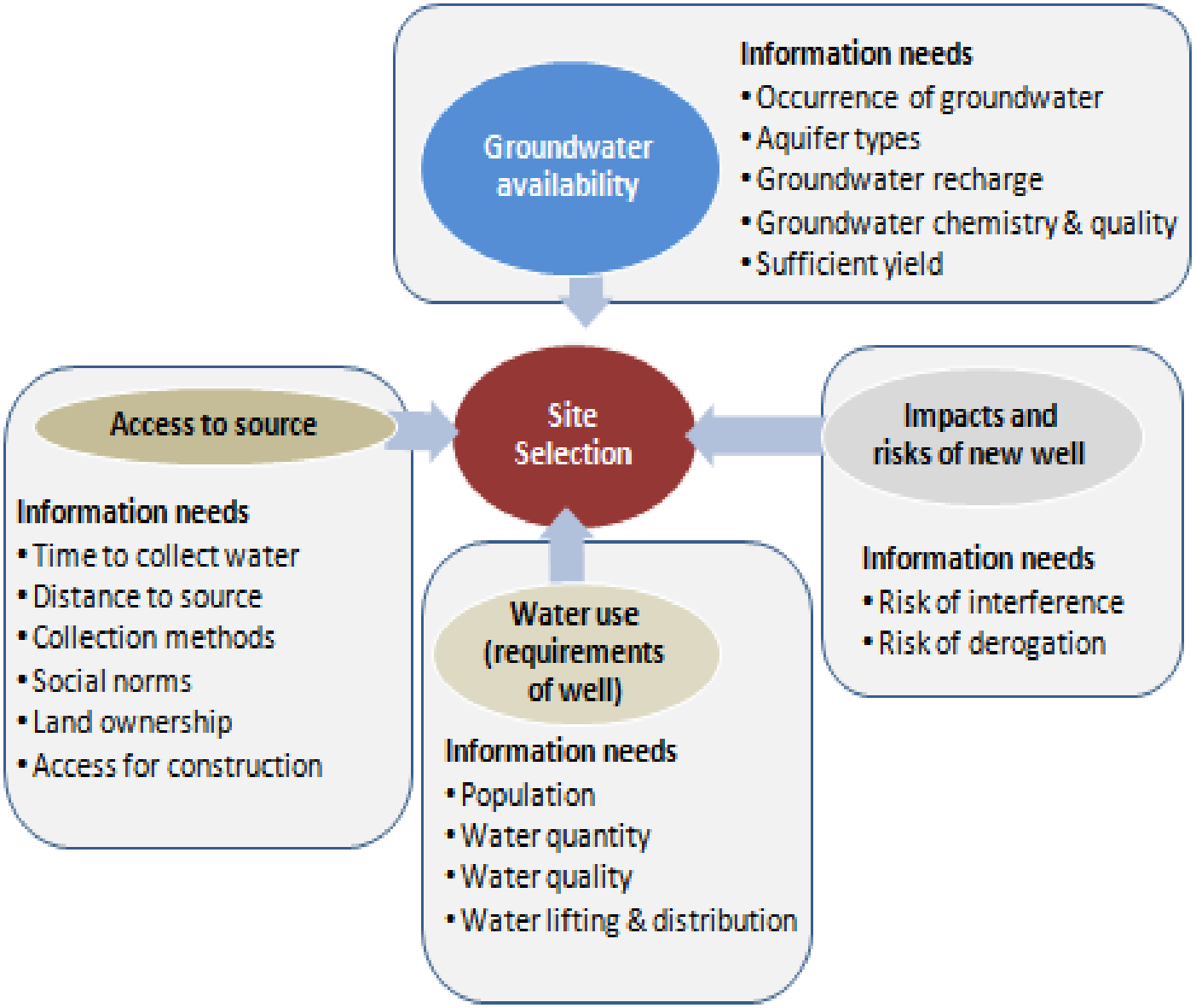
Step 4: Test drilling where existing information is inadequate

Step 3: Field work: Cross check desk study data and gather additional information; geophysical investigation where necessary

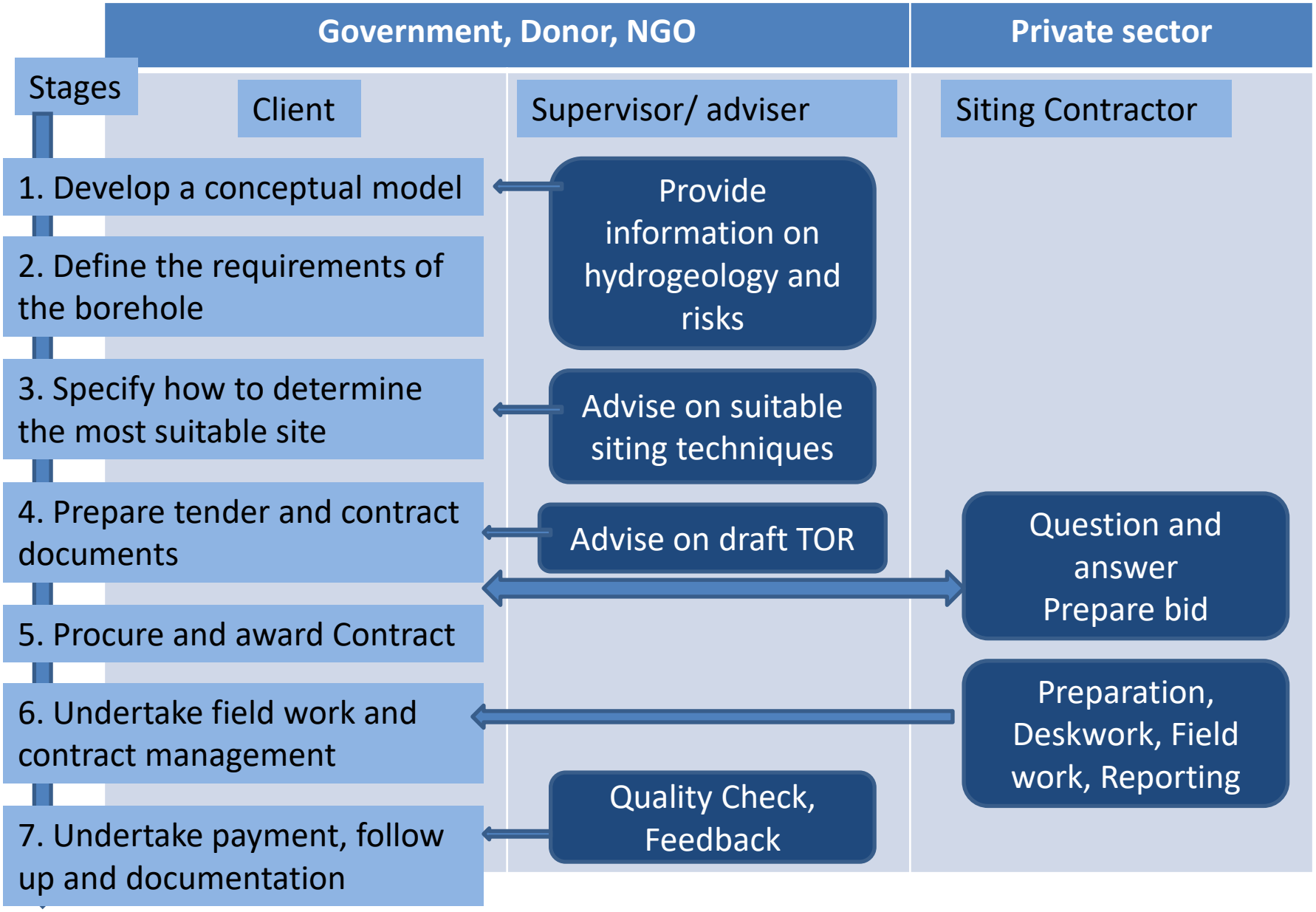
Step 2: Define the requirements of the borehole

Step 1: Develop a conceptual model: Desk study to collate all available information from existing documents, maps etc

6a. Different Aspects of Site Selection



6b Work Flow for borehole siting



6c. Conceptual model

Desk study

- Could be in the form of a map or report containing the required information
- Define the geographical reference
- Check the geology of the area
- Groundwater occurrence i.e. unconsolidated/ consolidated, fractures
- Aquifer types i.e. unconfined/confined
- Likely effects of pumping
- Sources of groundwater recharge
- Groundwater quality

Stage 6d. Determine the borehole requirements

- Rural water supply
- Motorised abstraction with reticulation
- Small town water supply and camps
- Urban centres
- Agricultural uses
- Multiple uses
- Industrial uses
- Abstraction requirements

Stage 6e. Determining the most suitable site

Key factors for consideration

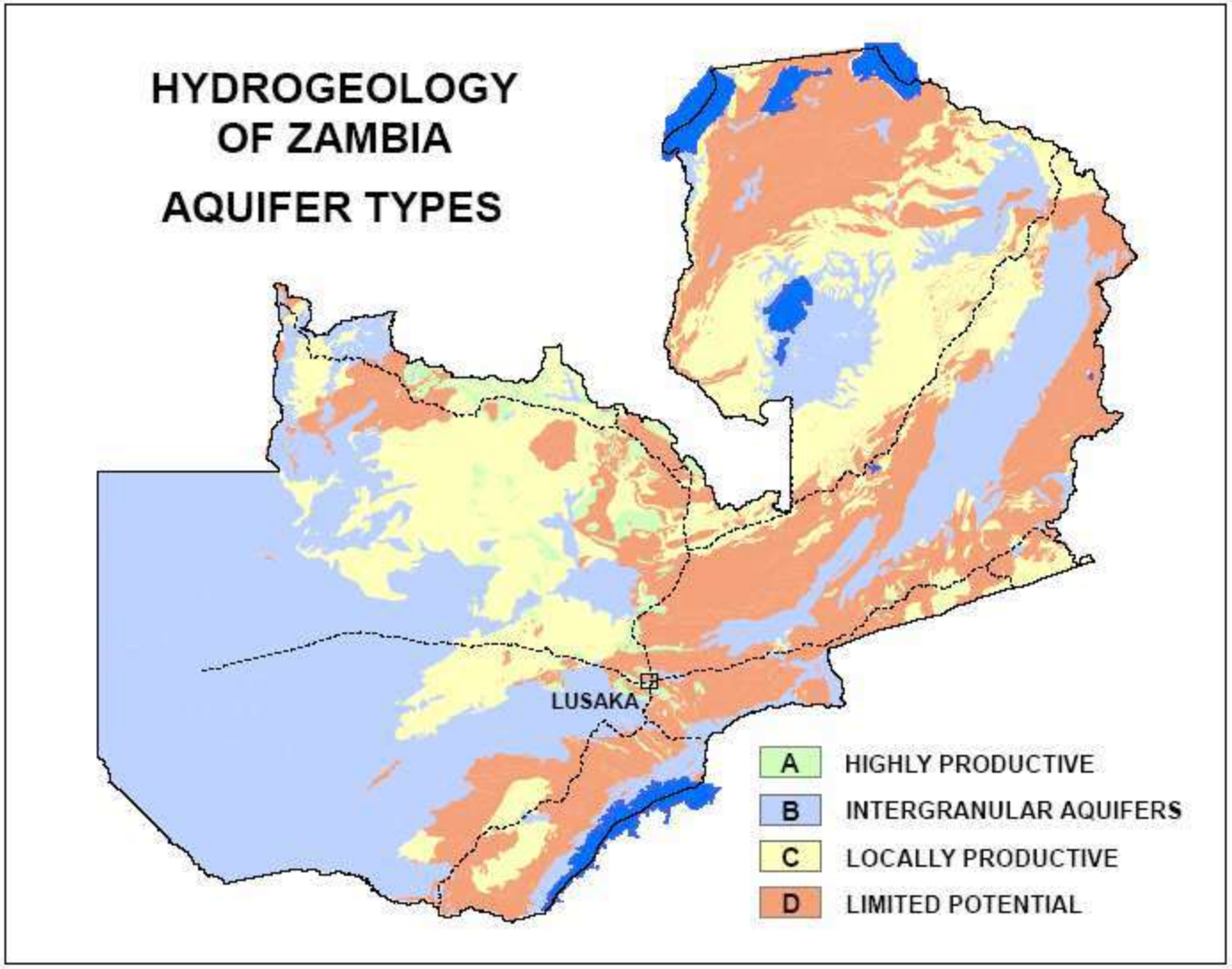
- Sufficient yield for the intended purpose
- Sufficient renewable water resources for the intended purpose
- Appropriate water quality for the intended purpose
- Avoidance of potential sources of contamination
- Proximity to the point of use
- Land ownership
- Access for construction and maintenance teams
- Avoidance of interference with other groundwater sources
- Risk of drilling a dry borehole

Stage 6f. Determining the most suitable site

Sources of information

- Remote sensing – Maps, GIS, Satellite based images e.g. http://www.earth.google.com
- Existing documents
- Field visits and interviews
- Drilling records and databases and data exchange

6g. Developing a conceptual model



6h. Techniques for siting

- Remote sensing
- Hydrogeological field surveys – aquifer correlation
- Geophysical survey
  - Resistivity method
  - Electromagnetic conductivity
- Test drilling

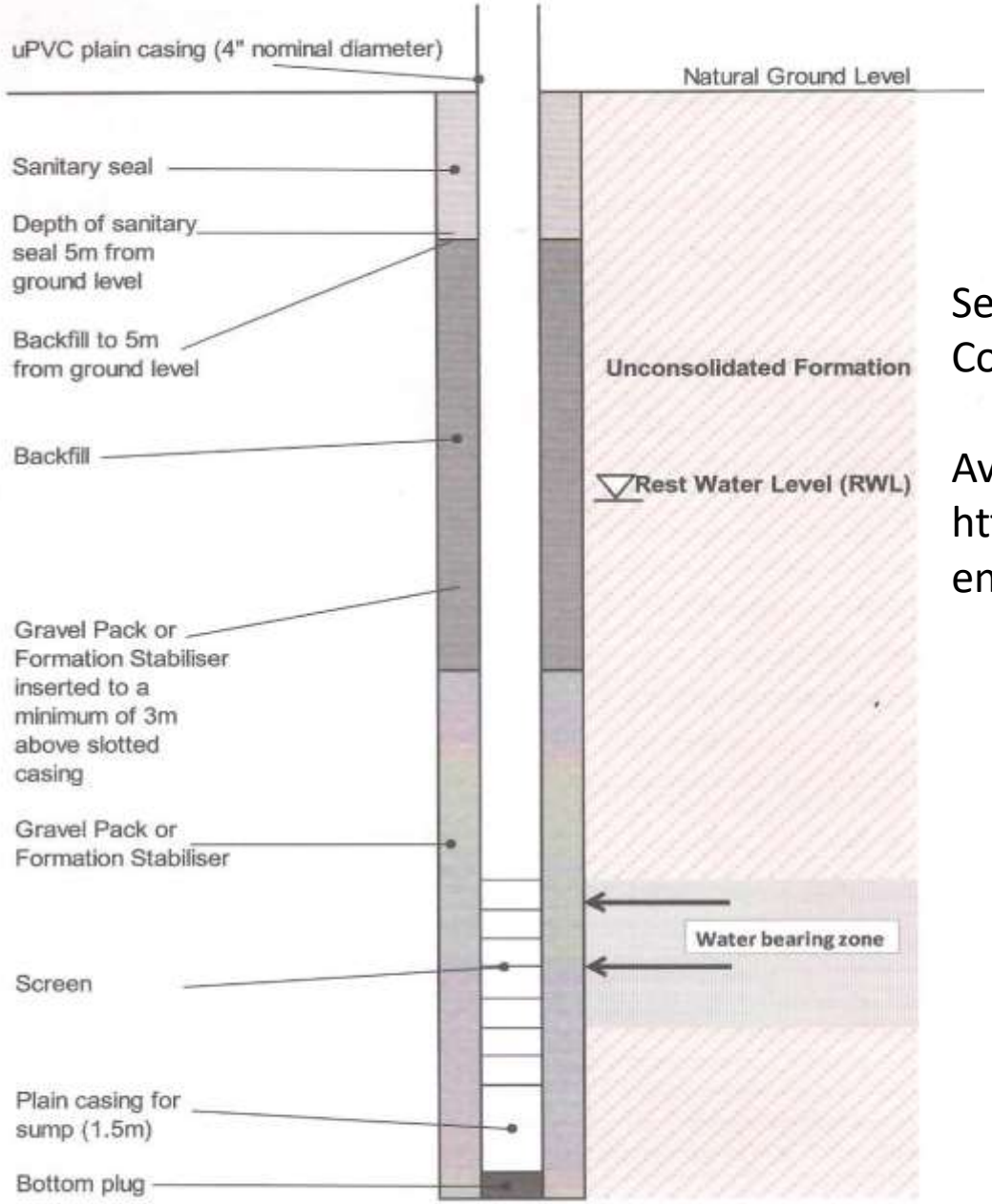
6i. Geophysical methods

Geophysics is not always necessary in borehole siting. It should only be sued where it provides additional useful information in siting

Resistivity method

Electromagnetic method

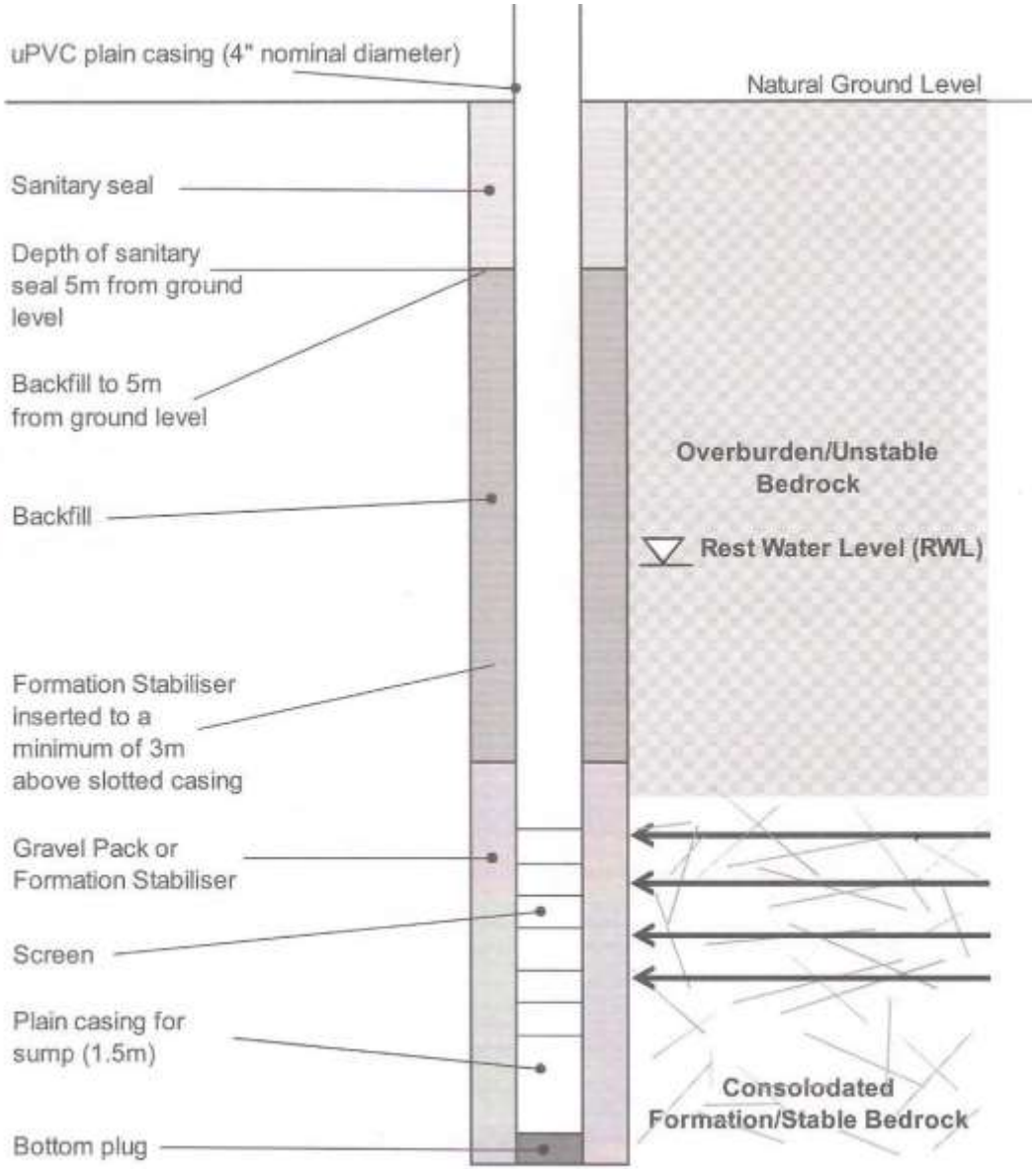
7. Borehole Design 1 (Sands and gravel formation)



See RWSN Code of Practice for Cost Effective Boreholes (Annex)

Available on: http://www.rural-water-supply.net/en/resources/details/128

7a. Borehole design 2 (Sandstone Formation)



See RWSN Code of Practice for Cost Effective Boreholes (Annex)

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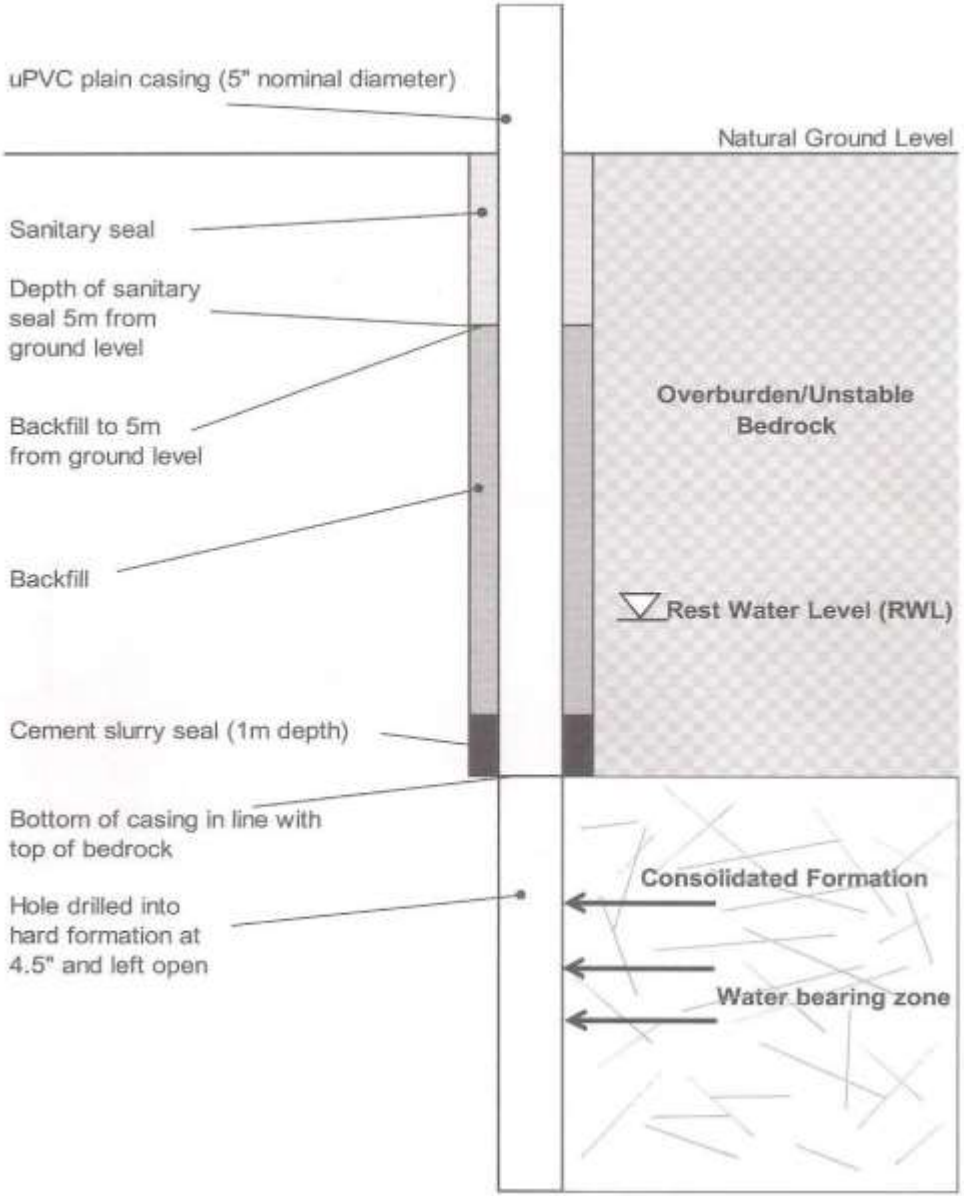
7b. Borehole design 3 (Granite)



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Available on: http://www.rural-water-supply.net/en/resources/details/128

8. Borehole construction

A borehole can be drilled by a machine or manually. All drilling techniques must be able to :

- penetrate, break or cut the formation to be drilled
- remove the loose material from the hole
- support the hole to prevent collapse during, or immediately after drilling

8a.Manual drilling

8b. Machine drilling

Compressor

Drill rig

Drag bit

Drill samples

Down the hole hammer

8c. Manual v. Machine Drilling

Manual	Machine
• Low capital • Low technology • Borehole cost a fraction of machine drilled holes • Portable equipment- easy to manoeuvre into tight spaces	• High capital • Low technology • Borehole cost can be high • Equipment difficult to get into tight places

Quick Questions!

- Which is likely to provide a sustainable borehole, a manually drilled borehole or a machine drilled borehole?

8d. Safety on site

- A security tape in bright colour should be used to demarcate the drilling area and indicate a no-go area for non drilling personnel and on-lookers.
- The drilling crew must all wear protective clothing; hard hats, boots and gloves.
- The drill rig should be level and as much as possible avoid sloping ground.
- There should be no drilling during a thunderstorm.
- The rig should be some distance from overhead power lines.
- Inflammable items such as petrol or chlorine etc should be kept in approved containers, properly marked and stored away from sources of heat.
- Lifting of loads heavier than 30 kilograms by an individual should be avoided.
- The drill equipment should be kept in good working order and the area around the drilling rig kept tidy.

Quick Exercise! Discuss the photographs below in relation to site safety

8e. Lining and gravel packing

Lining with UPVC casing and screen

Gravel packing

Drilling fluid: water, air, biodegradable mud, clay (bentonite)

8f. Borehole Screens

UPVC screen

Special screen for fine sand formation

Stainless steel screen

9. Development and pumping testing

Development

- The borehole is cleaned with water by jetting and airlifting
- Development continues until the water is clean of mud and sand free

Development by jetting and airlifting

9a Pumping test

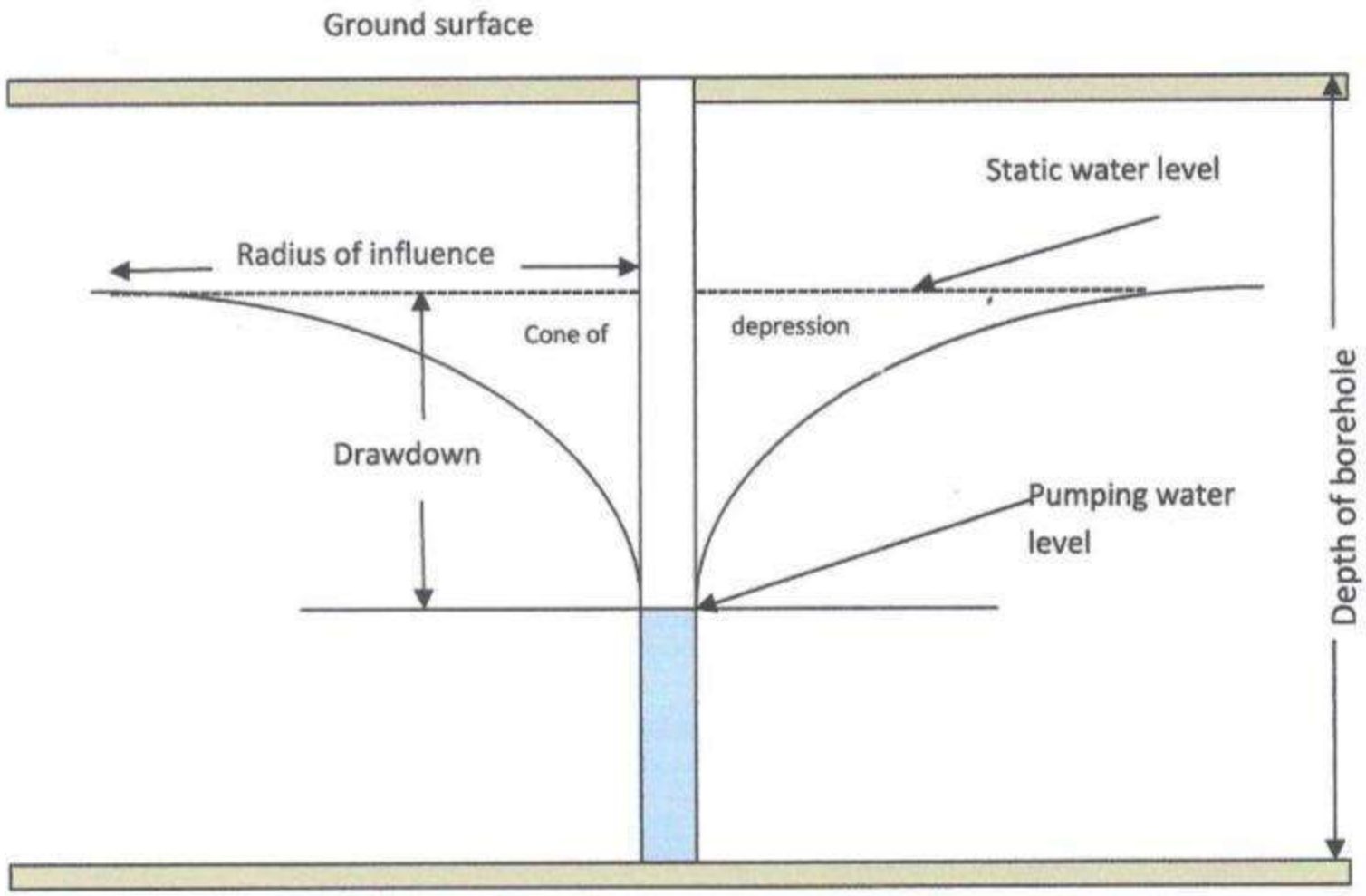
Pumping test is used to determine the borehole's

- Static water level
- Dynamic water level
- Drawdown
- Yield
- Specific capacity
- Safe pump rate
- Pump setting

Also the aquifer properties of

- Transmissivity
- Storativity

9b. Effects of pumping on groundwater



9c. Borehole and aquifer parameters

- Static Water level - the level of the water in the borehole before pumping starts
- Dynamic water level are the levels of water in the borehole as the borehole is being pumped
- Drawdown is the difference betwee the static water level and the final dynamic water level measured
- Borehole yield is volume of water discharged per unit of time in liters per second. It is the maximum pumping rate a borehole can sustain for a reasonable drawdown
- Specific capacity = yield/drawdown l/s/m of drawdown

The pump is usually set above the screen in the borehole and below the last dynamic level measured and allowing for seasonal fluctuation in water level

9d. Borehole and aquifer parameters

- **Transmissivity:** How easily groundwater flows through a rock into a borehole
- **Specific yield**: Volume of water that can be removed from an aquifer for a given lowering of water level over an area
- **Interference** is the increased drawdown experienced in each borehole when two boreholes are pumped close together
- **Derogation** is the adverse effect of the abstraction on the yield of other wells and springs

Quick Question!

- What is the likely yield from a borehole Where the specific capacity =10 l/s/m

  Drawdown = 3 m

10. Groundwater recharge

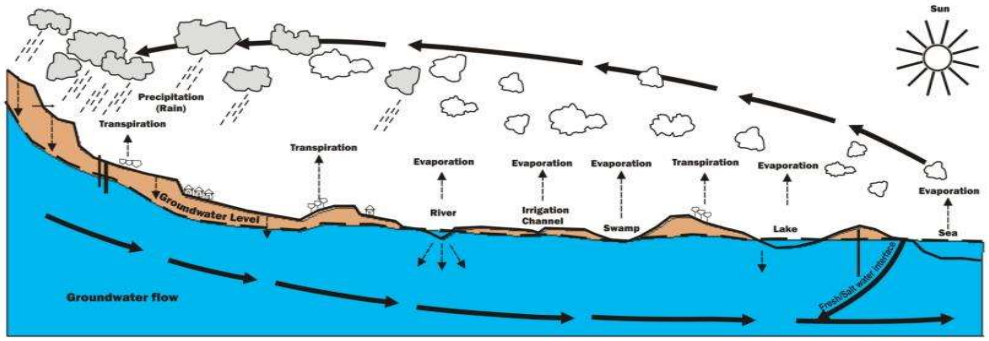
For sustainable development water taken from the ground has to be replaced. The replacement is called recharge.

Recharge takes place through:

- rain water infiltrating into the ground
- water from rivers and lakes infiltrating into the ground

The rate and amount of recharge depends on the

- rock types
- topography
- vegetation
- rainfall intensity
- climate



It is very important to consider recharge as recharge in groundwater development

11. Groundwater quality

The quality of groundwater is usually good but it should not be taken for granted. Some concerns are:

- Bacteriological contamination
- High nitrates from fertilisers and poorly disposed excreta posing danger to babies
- High iron content causing staining and toxicity
- High arsenic causing cancer
- High fluoride causing bone diseases

11. Water quality parameters and reason for concern and probable causes (Smith, 2003)

Parameter	Concern	Probable cause
Turbidity	Rejection by consumer as unsightly; increases treatment cost	Suspended matter e.g. clays, silts organic matter
Odour	Rejection by consumer as offensive; may indicate the presence of other pollutants	Hydrogen sulphide from septic , organic matter, industrial waste
Colour	Rejection by consumer as unsightly; may indicate the presence of other pollutants	Metals, organic matter, industrial waste
Conductivity	Rejection by consumer; corrosion and encrustation	Dissolved solids
pH	Rejection by consumer; affects treatment requirement	Acids or alkalis
E.coli	Possible presence of pathogens	Faecal contamination
Chloride	May be rejected by consumer (salty taste); possible contamination by urine	Sea water intrusion, salt deposit, industrial pollution
Fluoride	Health - mottled teeth, skeletal fluorosis	Runoff from igneous rocks
Iron	May be rejected by the consumer as unsightly;	Rocks and minerals, leachates, sewage
Manganese	May be rejected by consumer due to taste and colour	Rocks and minerals
Nitrates	Health – reports of blue baby, indication of faecal contamination	Fertilizer, sewage, vegetation breakdown
Arsenic	Health- carcinogenic	Naturally occurring, weed killers,

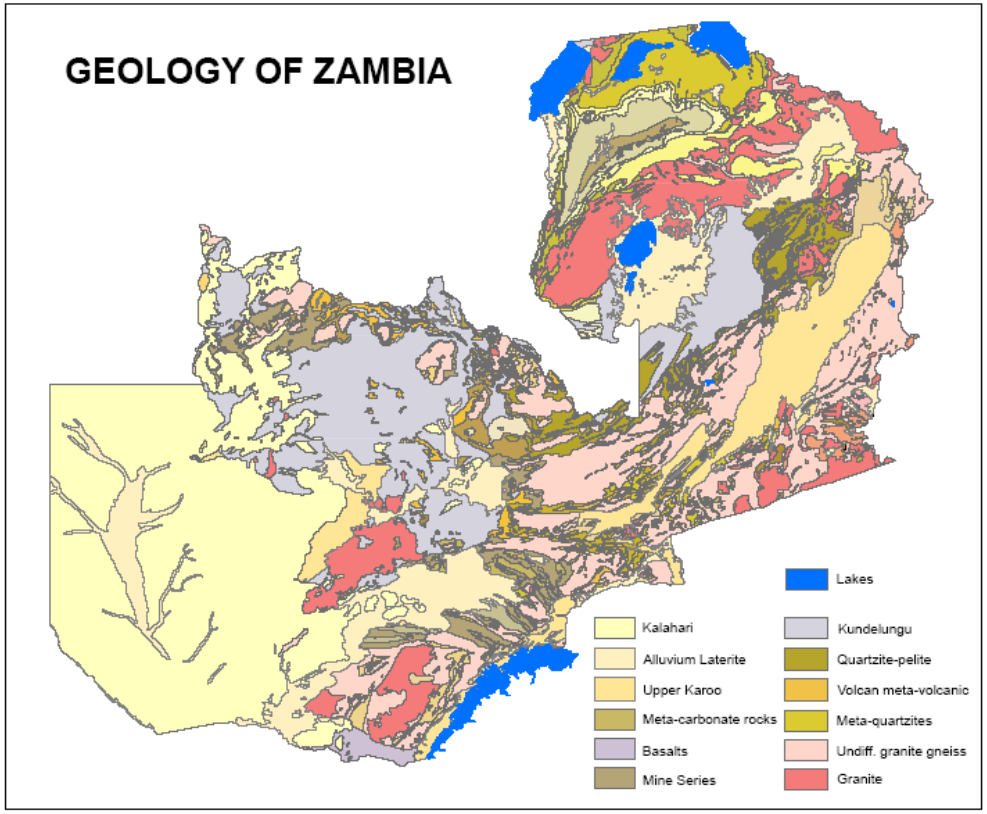
Quick Questions!

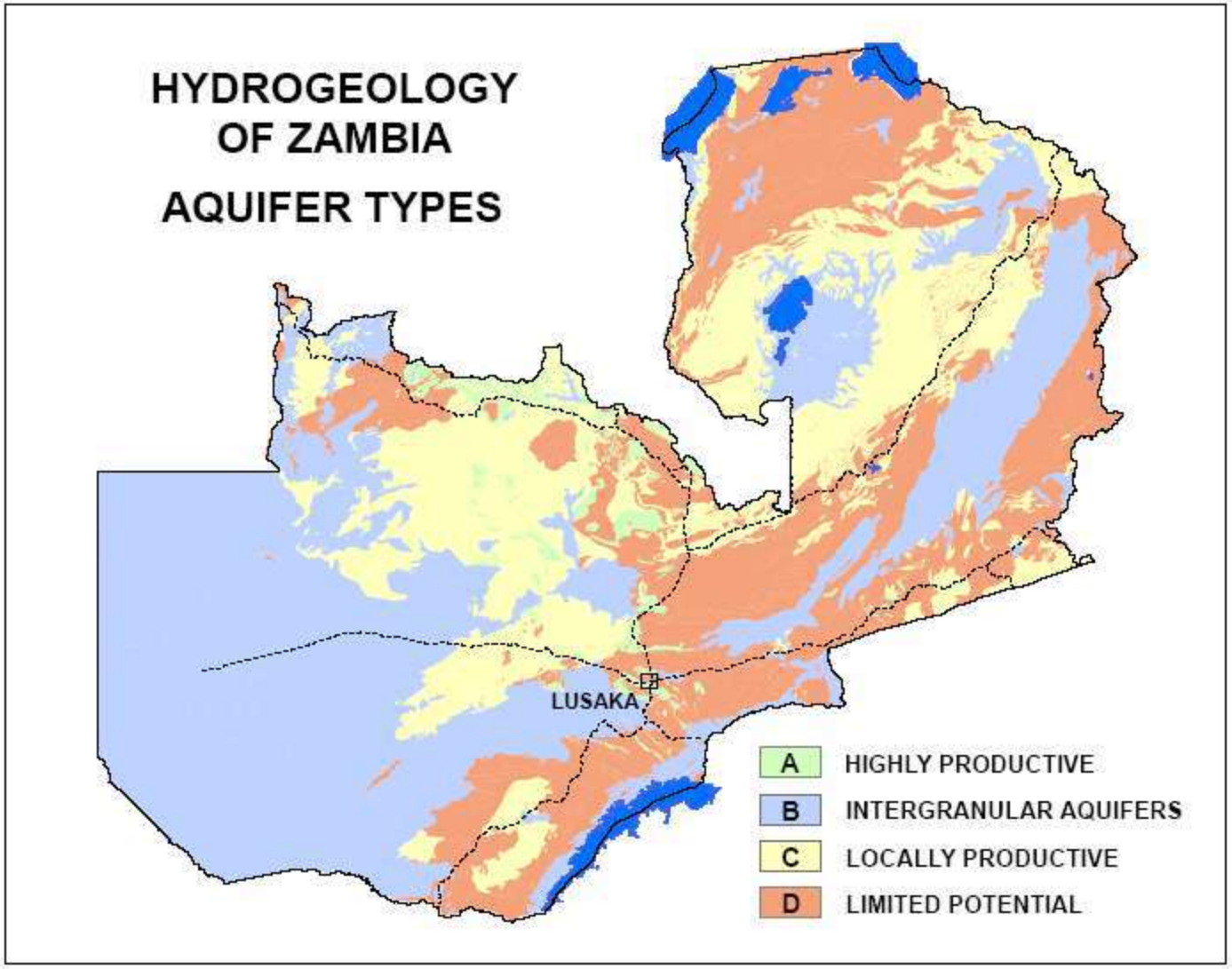
- Do you have any questions or comments on what you have heard so far?
- Is there anything new that you have learned?

12.The groundwater resources of Zambia

The groundwater resources of Zambia can be classified into 4 main units

- **Basement complex rocks**: gneisses, schists, granite. They are dominant. Yield is limited, 0-2 l/s
- **Katanga System** the limestones and, dolomites are very productive – 35 to 50 l/s but the shales and quartzites are poor aquifers
- K**aroo System**: the sandstone and conglomerates and limestone provide good aquifers but the shale, coal seams are poor aquifers. The sandstones are the best aquifers, 10-20l/s
- **Kalahari Formation:** loose sands, gravels. Yields 10-20l/s




HYDROGEOLOGY
OF ZAMBIA
AQUIFER TYPES
LUSAKA
A HIGHLY PRODUCTIVE
B INTERGRANULAR AQUIFERS
C LOCALLY PRODUCTIVE
D LIMITED POTENTIAL

Summary

- Groundwater is water that percolates into the ground when rain falls
- It occurs in the pore spaces and fissures in unconsolidated and partially consolidated rocks; and in the weathered overburden and joints in granitic rocks and in fissures in limestones
- For sustainability of the resources consideration must be given to aquifer recharge in groundwater development.
- Groundwater quality is usually good but it must not be taken for granted as it can be contaminated either by poor sanitation practices or by dissolved minerals in the rock types through which the water has passed.
- The most productive aquifers in Zambia are the fissured dolomites and limestones of the Katanga system

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Thank you!

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