Bharathidasan University

Tiruchirappalli – 620 023, Tamil Nadu

6 Yr. Int. M.Tech. Geological Technology and Geoinformatics

Course code : **MTIGT0604**

GEOINFORMATICS IN WATER RESOURCES MANAGEMENT

Unit-3 : Groundwater Resources

Dr. K. Palanivel
Professor, Department of Remote Sensing

Course Objectives

- To know the potential sources, origin, occurrences of water resources
- To understand the concepts of water resources prospecting, water quality mapping and conservation
- To learn the capabilities of Geoinformatics and its applications for water resources targeting, quantification, budgeting and management
- To learn the Geological Technology and Geoinformatics in understanding the functions of aquifers and groundwater movement
- To learn the basics and applications of hydrogeological models.

MTIGT0604: GEOINFORMATICS IN WATER RESOURCES MANAGEMENT

--- 4 Credits

1. Surface Water Resources: Hydrological Cycle - Global Distribution of Surface water Bodies – Drainage Morphometry – Sources of Surface water – Snow, Rainfall and groundwater table. Modelling assumptions - choice of equation - phenomena and model geometry - choice of variables and parameters - data and knowledge acquisition - model building – calibration and verification, results presentation. **12Hrs.**

2. Geoinformatics in Surface Water Resources: Satellite data based Surface water budgeting and Quantification – Automated drainage Mapping Using DEM – Spectral Response Pattern of Water – Water quality mapping and monitoring using Remote Sensing – Infra Red data based Water Quantity Forecasting – Water quality Mapping and Monitoring using satellite data. **12 Hrs.**

3. Groundwater Resources: Groundwater Origin & Occurrence: Sources of Groundwater – Classification of Groundwater. Aquifer Types**:** Crystalline Aquifer, Sedimentary aquifer, Unconsolidated Sedimentary Aquifer, Geomorphic aquifer. Darcy's Law in homogeneous and heterogeneous media, Groundwater quality, Application of H and O isotopes in groundwater studies; Targeting: General Investigations - Geological mapping- Geological Cross sections - Well inventory – Geophysical Methods – Drilling and Exploration - Pump tests **-** Groundwater Assessment and Budgeting - Issues and conservation Strategies**.** **16 Hrs.**

4. Geoinformatics in Groundwater Resources: Geoinformatics and evaluation of lithologically controlled, Structurally controlled and Geomorphologically controlled aquifers – Concept of Hydro geomorphic mapping. Natural and Artificial recharge site selection - detection of site specific mechanisms – Quantification of allowable recharge. **12 Hrs.**

5. Hydrological Models: Surface Water Hydrological Models: Snow melt Runoff modeling – GIS based Runoff modeling – Various hydrological models using Geoinformatics. Models for Inter watershed water transfer. Groundwater models: Stochastic – MOD Flow- Linear – Finite Element Modeling. **12 Hrs.**

Course outcomes

After the successful completion of this course, the students are able to:

- ✓ Understand the availability, sources and importance of the water resources prospect for both surface and groundwater resources using Geoinformatics technology
- ✓ Determine the types of aquifers, their characteristics and their recuperation ability
- ✓ Delineate suitable sites and mechanisms for natural and artificial recharge
- ✓ Understand the application of Geoinformatics technology for surface and groundwater resources exploration, targeting, quantification, budgeting, conservation and management
- ✓ Learn the application of Geological technology and Geoinformatics tools in developing various hydrological models.

Text Books:

1. David Keith Todd, Groundwater Hydrology, Wiley Student Edition.
2. Raghunath H.M., Ground Water, New Age International (P) Limited Publishers, 1987.
3. Ramakrishnan. S. Groundwater, 1998.

References:

1. Chang, H.H. Fluvial processes in river engineering, John Wiley and Sons, New York. 1988.
2. Bedient, P.B, Hydrology and flood Plain analysis, Addision westery publishing company. 1988.
3. Driscoll, F.S. Groundwater & Wells, 2nd Edition, Scientific Publishers, Joclpur, 1986.
4. Karanth K.R., Groundwater Assessment Development and Management, Tata McGraw Hill Publishing Company Limited, New Delhi, 1987.
5. Clorer. R.C., Groundwater Management.
6. Scalf M.R., Manual of SW Quality Sampling procedure
7. Mutreja, K.N Applied Hydrology, Tata McGraw Hill Publishing Company Limited, New Delhi, 1986.
8. Thomann R.V, Principles of Surface Water Quality Modeling and Control, HIE, Harper & Row, Publishers, New York, 1987.
9. Mohammed Ali, George E Radosevich, Water Resource Policy for Asia, A. A. Balkema/Rotterdam/Boston, 1987.

10. Mc Donald AT, Water Resources: Issues and Strategies, Longman Scientific & Technical, 1988.
11. Pillai, K.M., Water Management and Planning, Himalaya Publishing House, 1987.
12. Gower. A.M., Water Quality in Catchment Ecosystem, John Willey & Sons, 1980.
13. Ramesam. V. Trends in Groundwater Research, The Geological Society of India, Bangalore, 1987.
14. Trivedi, R.N., Shatrunjay Kumar Sing, Water Resources and Quality Management, Commonwealth Publishers, New Delhi, 1990.
15. Fetter C.W. Applied Hydrology, CBS Publishers & Distributors, 1988.
16. Gautam Mahajan. Groundwater Surveys and investigations, Ashish Publishing House, New Delhi, 1995.
17. Chow V.T., maidment, D.R., and Mays, L.W. applied Hydrology, McGraw Hill, New York, pp.530 to 537. 1988.
18. Deman, MCJ. Smith G.S and H.T.Verstappen (eds), Remote Sensing for resources development and environmental management, A.A. Ballkema Publishers, Totterdam, Netherlands. 1986.

Unit-3: Groundwater Resources :

3. Groundwater Resources: Groundwater Origin & Occurrence: Sources of Groundwater – Classification of Groundwater. Aquifer Types**:** Crystalline Aquifer, Sedimentary aquifer, Unconsolidated Sedimentary Aquifer, Geomorphic aquifer. Darcy's Law in homogeneous and heterogeneous media, Groundwater quality, Application of H and O isotopes in groundwater studies; Targeting: General Investigations - Geological mapping - Geological Cross sections - Well inventory – Geophysical Methods – Drilling and Exploration - Pump tests **-** Groundwater Assessment and Budgeting - Issues and conservation Strategies**.** **16 Hrs.**

Groundwater Origin, Occurrence & Sources of Groundwater

- **Juvenile water** – is trapped within the rock mass, which cannot be tapped
- **Connate water** – This can be tapped but has a lot of dissolved solids / salts – that is why they are **not potable** in quality
- These waters though available below the ground surface, they cannot form groundwater source.

- The **Meteoric water**, and the water available on the surface due to glacier melt, condensation/rainfall & irrigated water as flowing rivers/streams or stagnated in reservoirs / lakes / tanks / irrigated lands (wet crop lands) can infiltrate and percolate inside the earth within the aquifers and form groundwater.
- This groundwater is taped because it is potable.

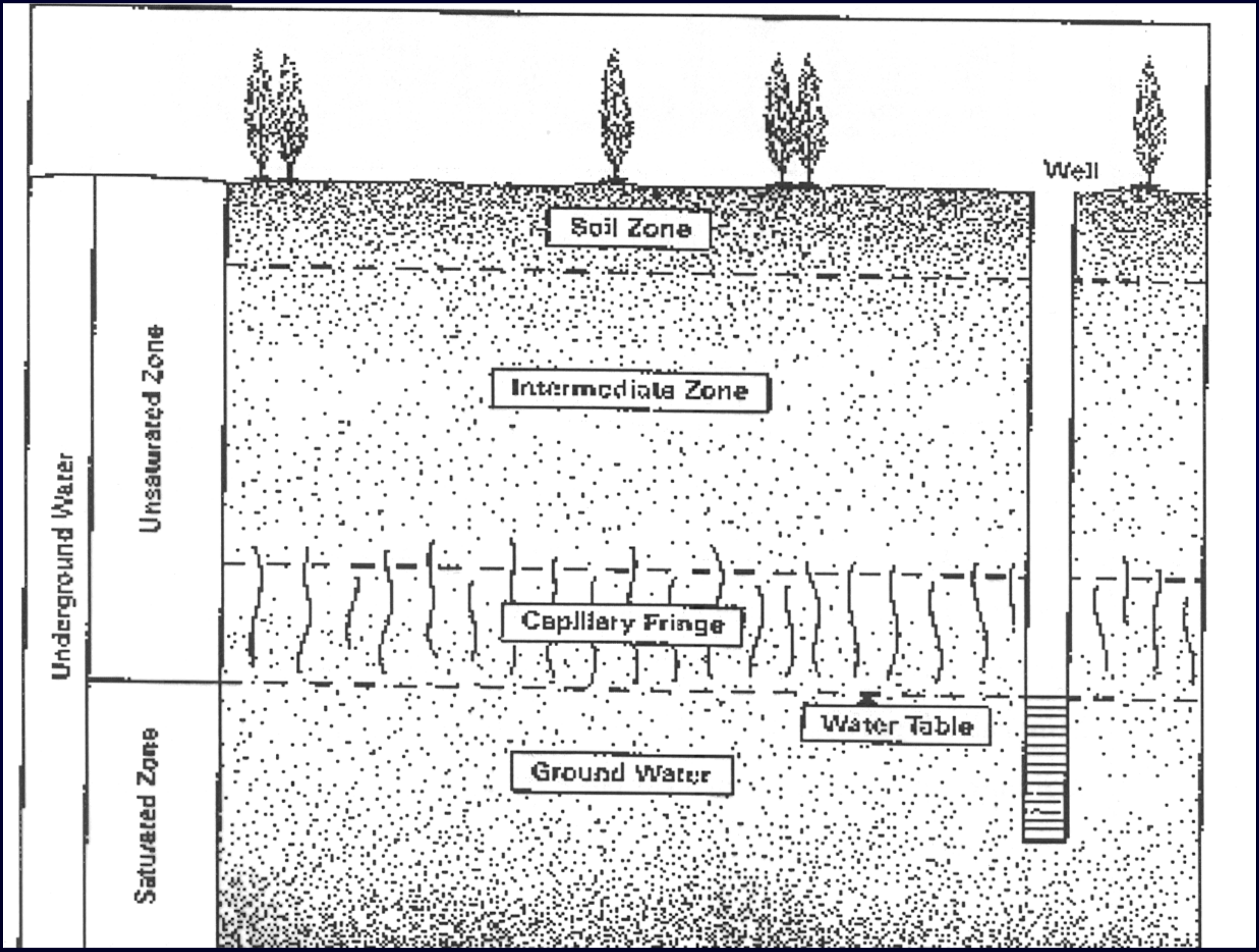
Occurrences of Groundwater in India

- Indo-Gangetic Alluvial plains
- Deccan – Intertrappean Aquifers
- Thar – deep saline / good water aquifers
- Mahanadi alluvial plains
- Narmada-Tapti alluvial aquifers
- Godavari – Krishna Deltaic plains
- Cauvery – Vaigai – Tambraparani deltaic aquifers
- Coastal aquifers
- Crystalline aquifers
- Shallow aquifers in plateaus and slope of Hills / Ghats

Classification of Groundwater

- The groundwater reservoirs are classified broadly in to two types based on the rock types that form the aquifer :
  - **Crystalline / Hard rock / Fractured aquifers** – Weathered and fractured **Igneous & Metamorphic rocks**,
  - **Sedimentary Aquifers** – porous and pervious **sedimentary formations – Consolidated or unconsolidated**.
- These aquifers can be further classified into 3 :
  - **Confined Aquifers,**
  - **Semi-confined aquifers and**
  - **Unconfined aquifers**.
- The Unconfined aquifers sometimes may contain a **Local** or **perched aquifer** when there is a lens type of impermeable layer occurs within pervious formation. E.g. clay lens within sandstone formation.

VERTICAL DISTRIBUTION OF GROUNDWATER



Subsurface water occurs in two different zones.

One zone, located immediately beneath the land surface in most areas, contains both water and air in the voids. This zone is referred to as the **unsaturated zone**.

Other names for the unsaturated zone are **zone of aeration** and **vadose zone**.

The unsaturated zone is almost always underlain by a second zone in which all voids are full of water.

This zone is defined as the **saturated zone**. Water in the saturated zone is referred to as **ground water** and is the only subsurface water available to supply wells and springs.

HYDROLOGICAL CLASSIFICATION OF FORMATIONS

AQUIFER An *aquifer* is a saturated formation of earth material which not only stores water but yields it in sufficient quantity. Thus an aquifer transmits water relatively easily due to its high permeability. Unconsolidated deposits of sand and gravel form good aquifers.

AQUITARD It is a formation through which only seepage is possible and thus the yield is insignificant compared to an aquifer. It is partly permeable. A sandy clay unit is an example of aquitard. Through an aquitard appreciable quantities of water may leak to an aquifer below it.

AQUICLUDE It is a geological formation which is essentially impermeable to the flow of water. It may be considered as closed to water movement even though it may contain large amounts of water due to its high porosity. Clay is an example of an aquiclude.

AQUIFUGE It is a geological formation which is neither porous nor permeable. There are no interconnected openings and hence it cannot transmit water. Massive compact rock without any fractures is an aquifuge.

The definitions of aquifer, aquitard and aquiclude as above are relative. A formation which may be considered as an aquifer at a place where water is at a premium (e.g. arid zones) may be classified as an aquitard or even aquiclude in an area where plenty of water is available.

Some Aquifer Types:

1. **Crystalline Aquifers**

   - Top soil, Weathered zone & Fractured zones together form crystalline / hard rock / fractured aquifers

2. **Fractured Aquifer system**
   - **Aquifers controlled majorly by Fractures / Lineaments / Fault systems or their swarms**
   - **Classification of fractures into water bearing -open, i.e., conducive & water barren -Tight / closed, i.e., non-conducive.**

3. **Sedimentary aquifer : Two types:**
   a. **Consolidated Aquifer**
   b. **Unconsolidated Sedimentary Aquifer,**

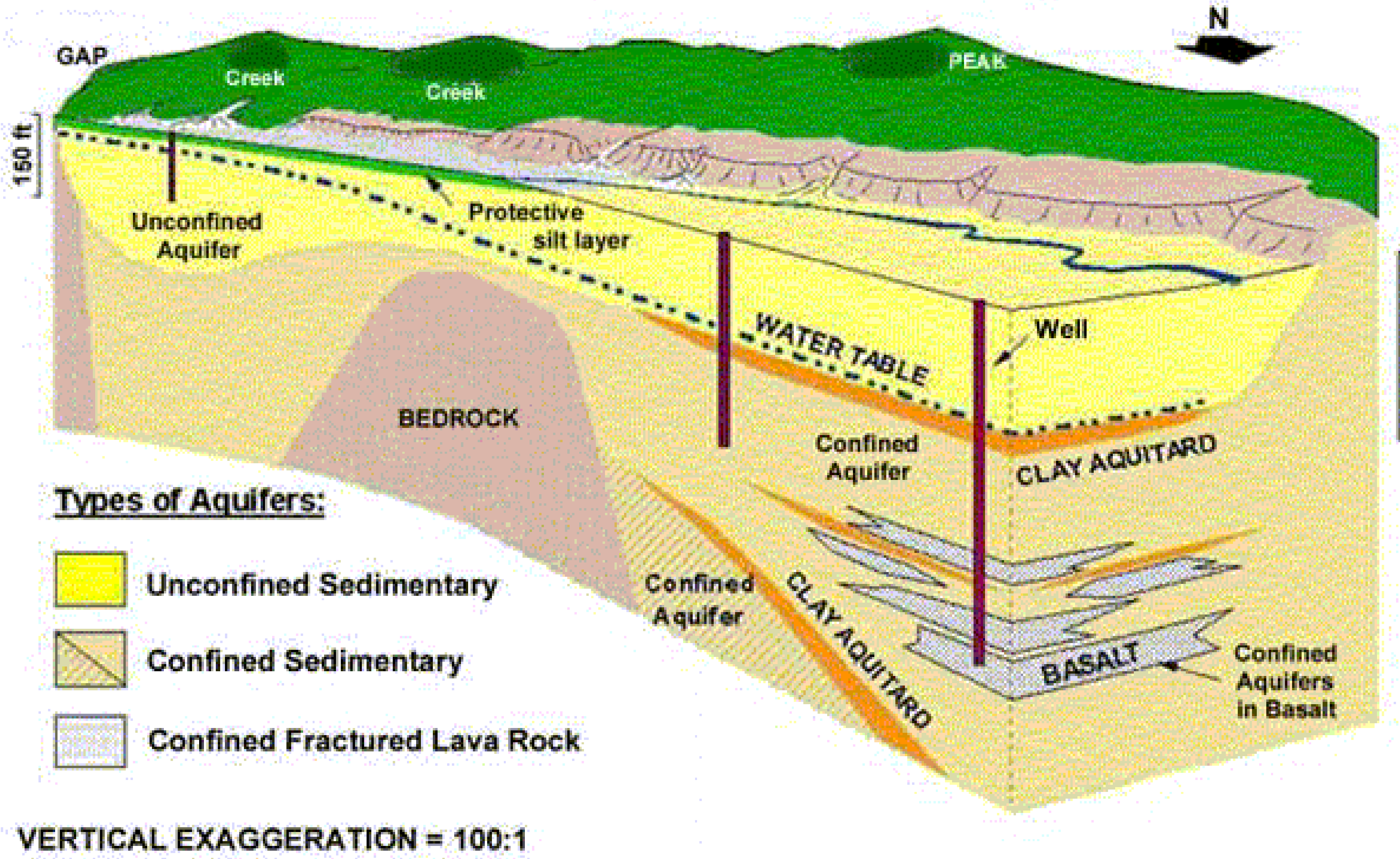
4. **Geomorphic aquifers**
   a. **Glacial aquifer**
   b. **Alluvial aquifer**
   c. **Fluvial aquifer**
   d. **Coastal aquifer, and their intercalated landforms develop**
   e. **Glacio-fluvial, Fluvio-marine, Aeolian aquifers, etc.**

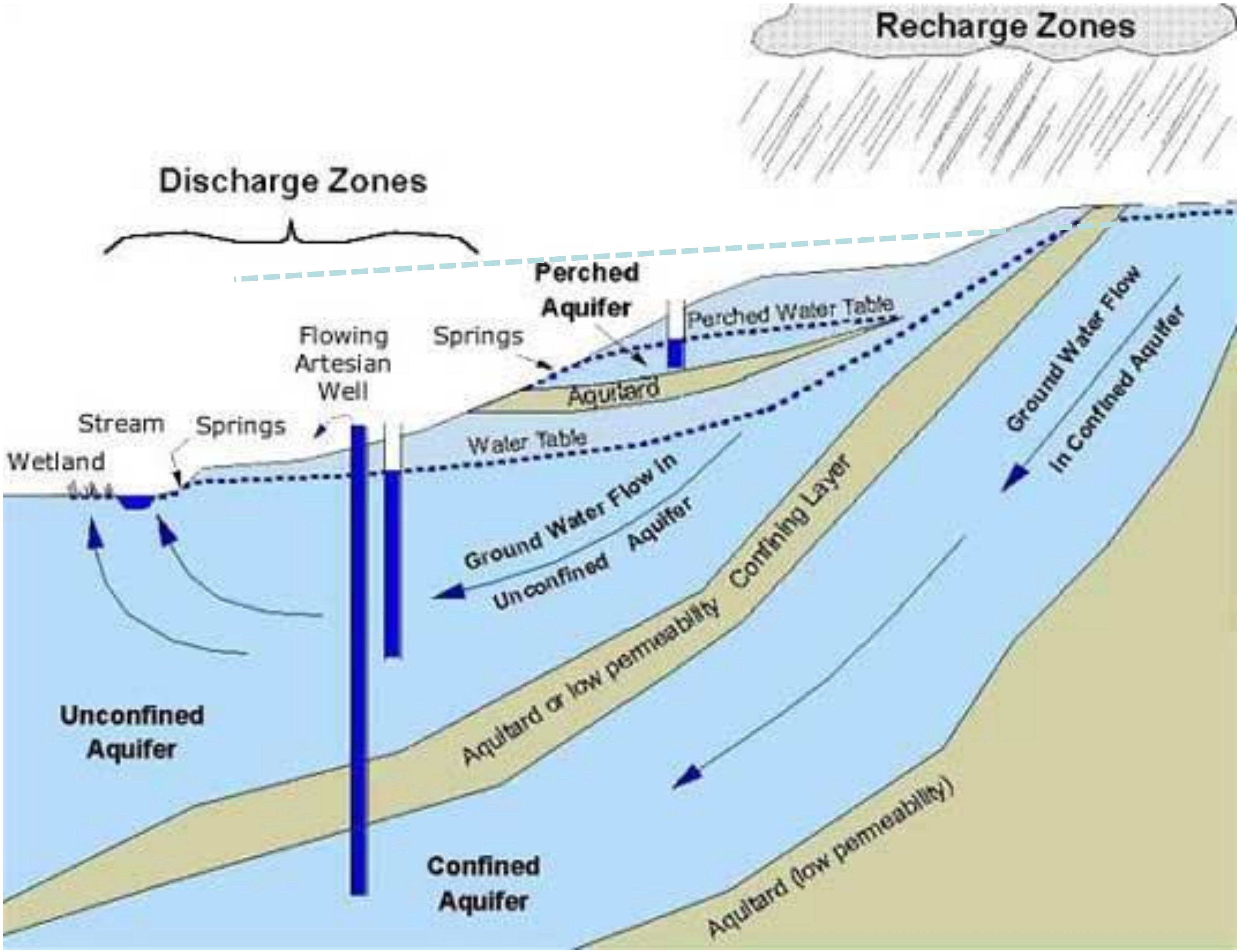
Aquifers can also be classified based on their depth to water table conditions, such as **Shallow** (<30m), **Moderate** (between 30 and 80m) and **Deep aquifers** (> 80m), as the NRSC, RGNDWM national mission project. Or, more generally, it can be classified in to two types of aquifers such as **Shallow** (<80m) and **Deep** aquifers (>80m).

Deep Aquifer

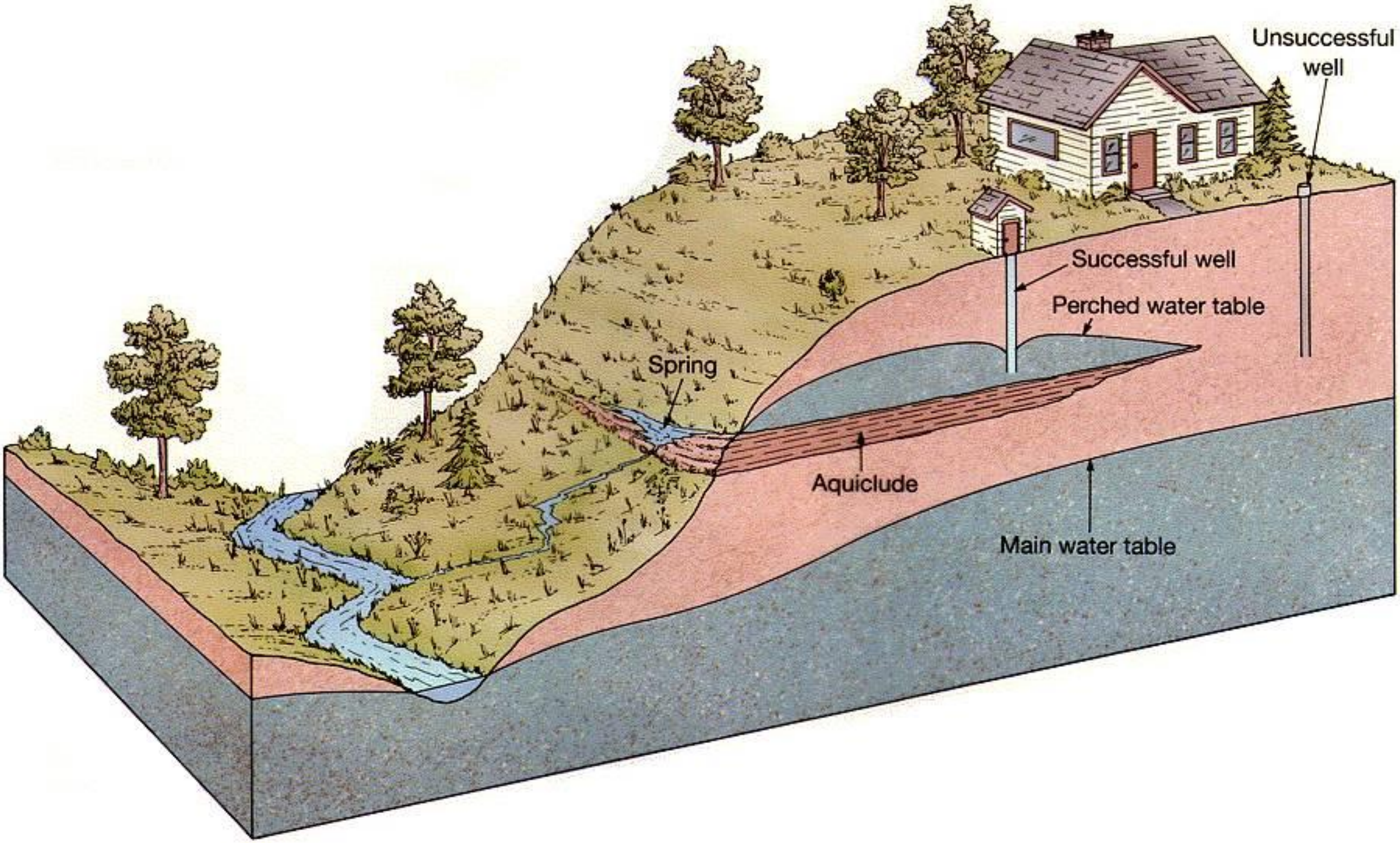
Shallow Aquifer

Anatomy of an Aquifer:

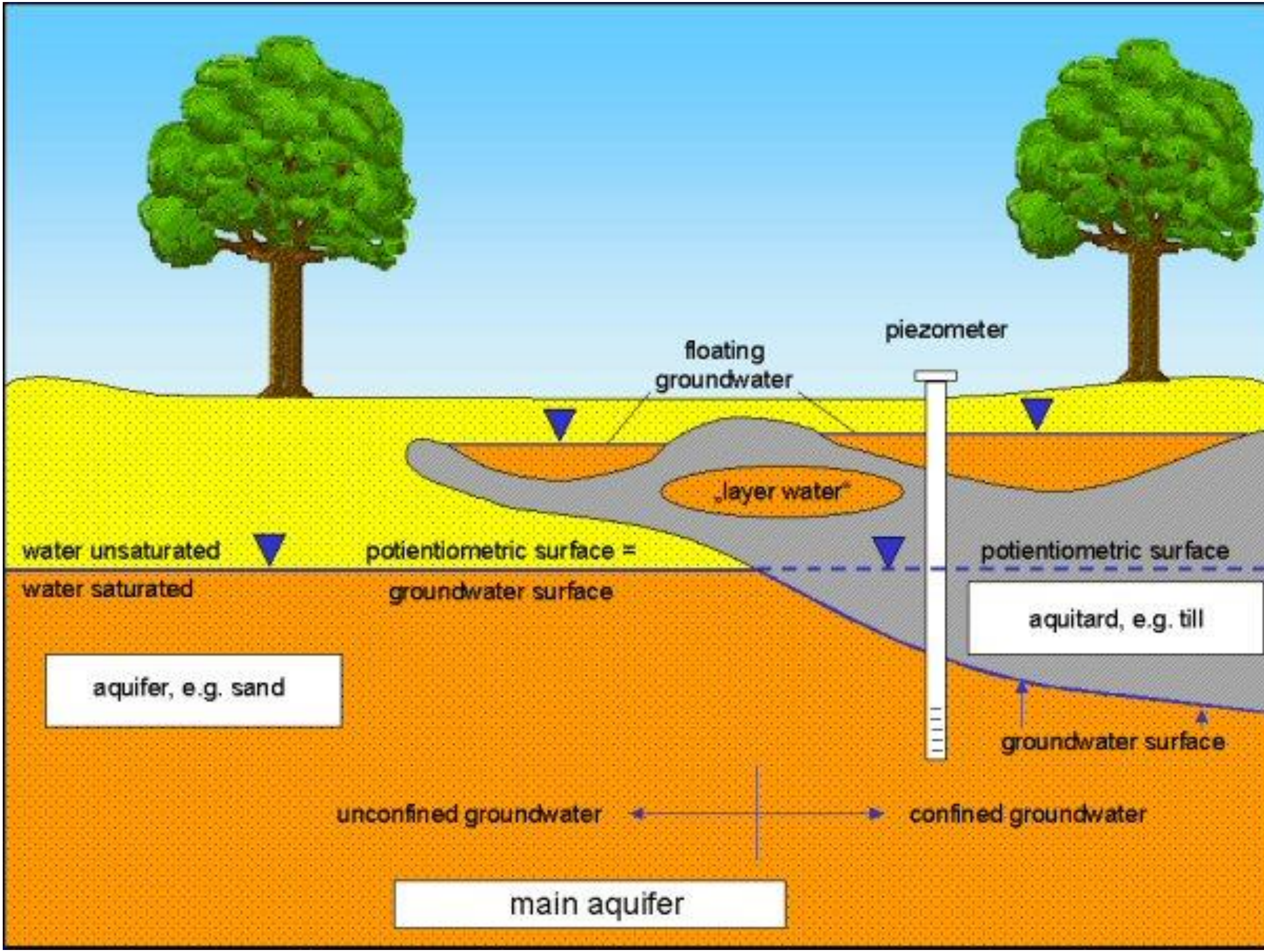


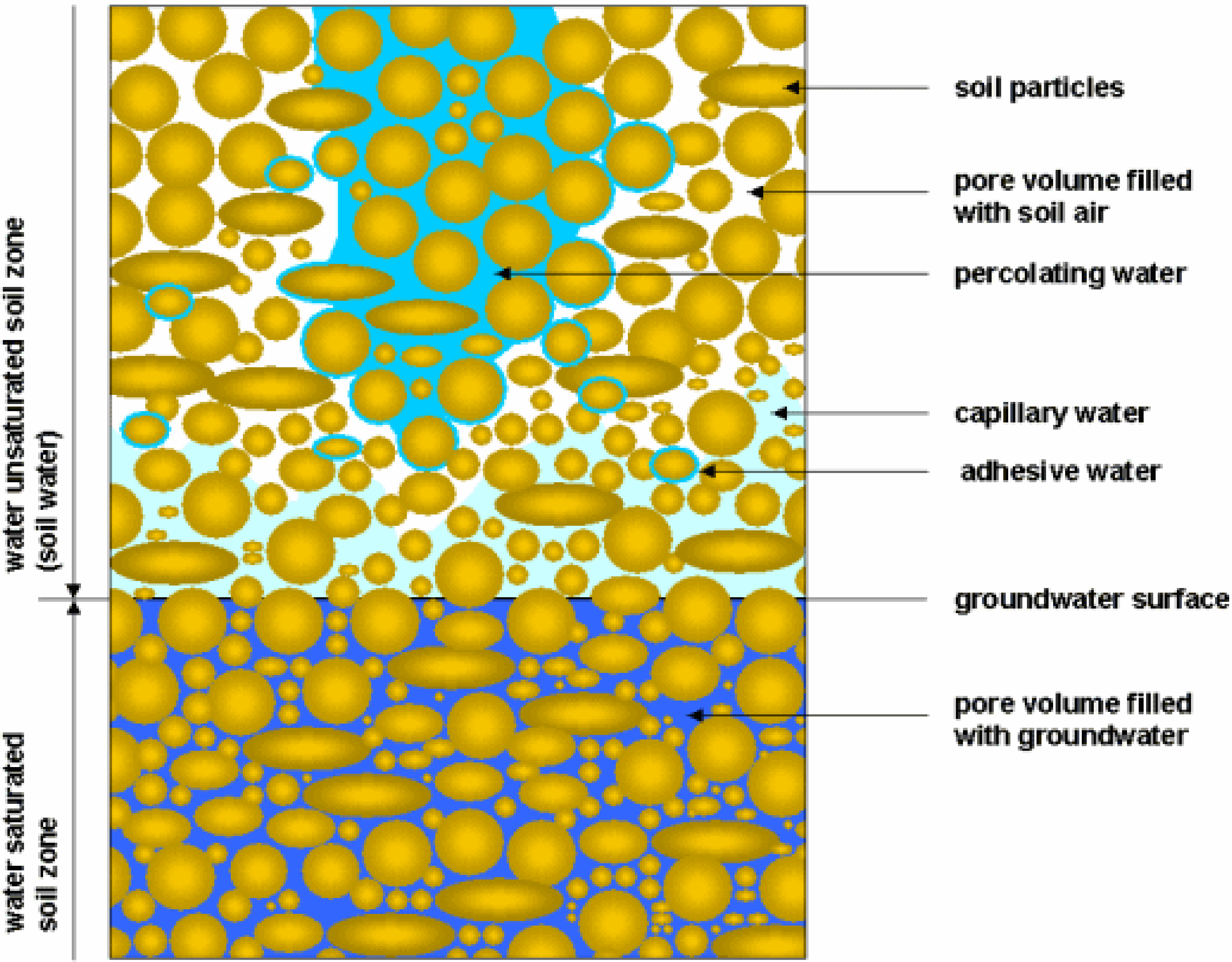


Recharge Zones
Discharge Zones
Perched Aquifer
Perched Water Table
Flowing Artesian Well
Springs
Aquitard
Stream
Springs
Water Table
Wetland
Ground Water Flow in Unconfined Aquifer
Confining Layer
Ground Water Flow in Confined Aquifer
Unconfined Aquifer
Aquitard or low permeability
Confined Aquifer
Aquitard (low permeability)

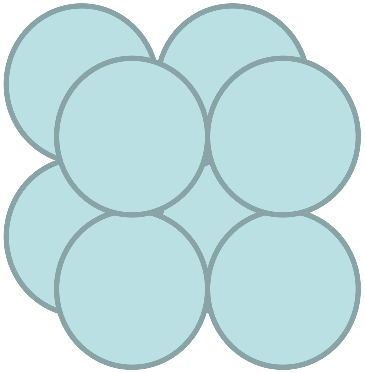


Unsuccessful well
Successful well
Perched water table
Spring
Aquiclude
Main water table

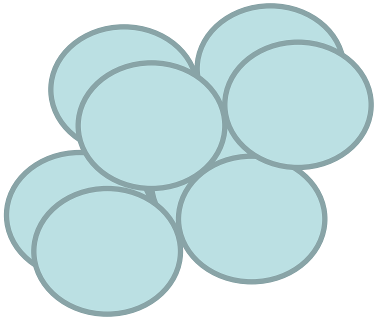

piezometer
floating groundwater
„layer water"
water unsaturated
potientiometric surface =
groundwater surface
water saturated
potientiometric surface
aquitard, e.g. till
aquifer, e.g. sand
groundwater surface
unconfined groundwater
confined groundwater
main aquifer


soil particles
pore volume filled with soil air
percolating water
capillary water
adhesive water
groundwater surface
pore volume filled with groundwater
water unsaturated soil zone (soil water)
water saturated soil zone

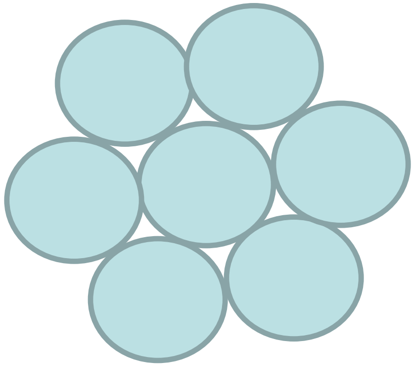
Differences in Pore Volume based on grain characters



Cubic packing of **well sorted, well rounded** and **Sandy grained** formation forms an high yielding aquifer as there is more than **40% of porosity** prevails in this unconsolidated formation



Rhombic packing of **well sorted** and **well rounded** sand grains form an Excellent Aquifer but with **30% of porosity** due to its packing which reduces the pore spaces – three dimensional compression.



Hexagonal packing of **well sorted** and **well rounded** sand grains form an Excellent Aquifer but with **35% of porosity** due to its packing - two dimensional compression.

Thus, the formation with **angular and unsorted grains** comparatively will have **less porosity**.

As a rule, groundwater flows at a low incline into the rivers and lakes (receiving bodies of water) and infiltrates into them (**effluent conditions**; Fig. a – **Effluent Stream**).

In times of flood water water surface is situated above the groundwater. During that time bodies of water infiltrate into groundwater (**influent condition**). This is known as **bank-filtered water** (Fig. b – **Influent Stream).**

If in the neighborhood of these surface waters groundwater is discharged, e.g. through wells, so that the phreatic surface drops below the level of that body of water, the surface water infiltrates into the groundwater as bank-filtered water, too (Fig. c).

The **groundwater velocity of flow** in Berlin is about 10 to 500 m p/a, depending on groundwater incline descent and the permeability of the aquifer. However, near well facilities, these low flow velocities can increase significantly.

Fig. a: Groundwater infiltrates into bodies of water

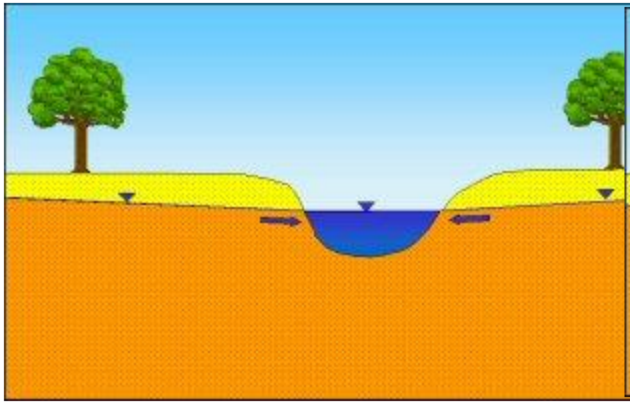


Fig. b: Bank-filtered water caused by flood water: bodies of water infiltrate into groundwater

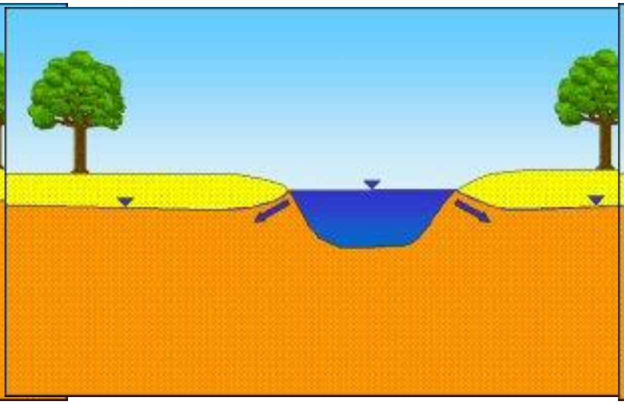
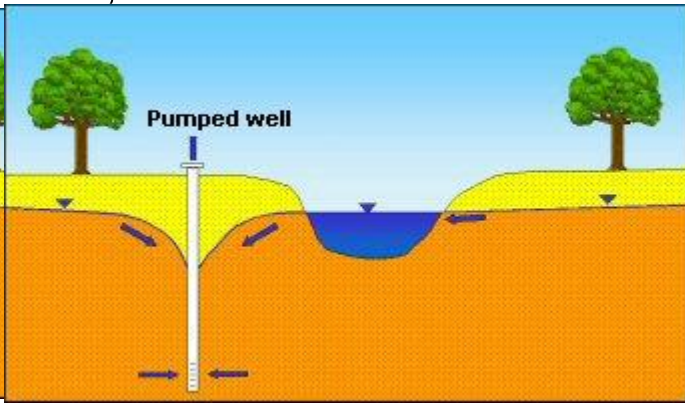


Fig. c: Bank-filtered water caused by discharge of groundwater: caused by the lowering of the groundwater by wells,



NATURAL RECHARGE / DISCHARGE & GROUNDWATER MOVEMENT

- Groundwater Levels are measured from the ground surface where the bore wells or open dug wells or bore cum dug wells are located.
- The groundwater level (GWL) data are collected through out the year periodically (for every month / week / daily)
- It is important to group them into two, like **Pre- monsoon GWL** (for Tamil Nadu in general, it falls during April, May, June & July) and **Post-monsoon GWL** (during December of previous year, January, February & March).
- If, the GWL data are available for several years, then the results for every year will be correctly representing the GWL oscillations. It is best practice to collect past data for several years and then averaged Pre-monsoon GWL values can be differentiated with Post-monsoon values for every sample well locations.
- The results will have **Natural Recharge** (if the resultant values are with positive sign) / **Discharge** (if the resultant values are in negative sign) status of aquifers in an area.
- The **groundwater table** (GWT) can be calculated using GWL with reference to MSL for each sample well locations. The GWT well locations can be plotted and data can be entered and isolines can be prepared to understand and map the Groundwater flow / direction of movement & rate / velocity of movement.

GENERAL INVESTIGATIONS FOR GROUNDWATER

In the field, it is common by a Hydrogeologist / hydrologist to look for :

Biological Indicators

1. Linearly aligned vegetation / trees flourishingly grown following a geological linearity-Shear, lithocontact, pervious formation, lineament, faults, etc. In South India, aligned natural growth of Palm trees are used as a common indicator
2. Living / existence of Ant nests / Termites – i.e., white ants
3. Normally, old cities are located over the recent / paleo flood plains where surface / groundwater resources are plenty

Geological Indicators

1. Lithological controls – Porous, unconsolidated / semi-consolidated Sedimentary formations
2. Structural controls – inter connected sets / swarms of Fractures, Joints, Lineaments, Faults, Unconformities, Gneissic/Schistose planes, Fissile planes / Shear planes
3. Geomorphologic controls – Favourable groundwater holding landforms such as Dissected Plateaux, Fractured and Filled Valleys, Bajadas, Burried Pediment, Alluvial plains, meander / Flood plains, Palaeochannels, Deltaic plains, coastal plains, Beach ridges, etc….

GEOLOGICAL MAPPING FOR GROUNDWATER

1. **Lithological Mapping** – Porous, unconsolidated / semi-consolidated Sedimentary formations
2. **Structural Mapping** – inter connected sets / swarms of Fractures, Joints, Lineaments, Faults, Unconformities, Gneissic/Schistose planes, Fissile planes / Shear planes
3. **Geomorphological Mapping** – Favourable groundwater holding landforms such as Dissected Plateaux, Fractured and Filled Valleys, Bajadas, Burried Pediment, Alluvial plains, meander / Flood plains, Palaeochannels, Deltaic plains, coastal plains, Beach ridges,…
4. **Subsurface Geological Mapping** – By conducting Geophysical / Litholog Surveys, the thickness of Top soil, Weathered Zone & Fractured Zones and Depth to Bed Rock profiles can be mapped
5. **Aquifer Characteristics Mapping** – By conducting Pump test, the aquifer parameters like Transmissivity(K), Permeability (P), Storage Co-efficient (S), Specific Yeid (SY) can be mapped.

Hydrogeological Mapping is performed by integrating the above Geological maps and the **groundwater potential zones** can be delineated.

AQUIFER CHARACTERISTICS - DEFINITIONS

“Transmissivity (**T**) is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient.” Transmissivity is a measure of the ease with which groundwater flows in the subsurface. It is expressed as the product of the average hydraulic conductivity and thickness of the saturated portion of an aquifer. The Unit of T is mentioned as **gallons per day per feet (g/d/ft)**.

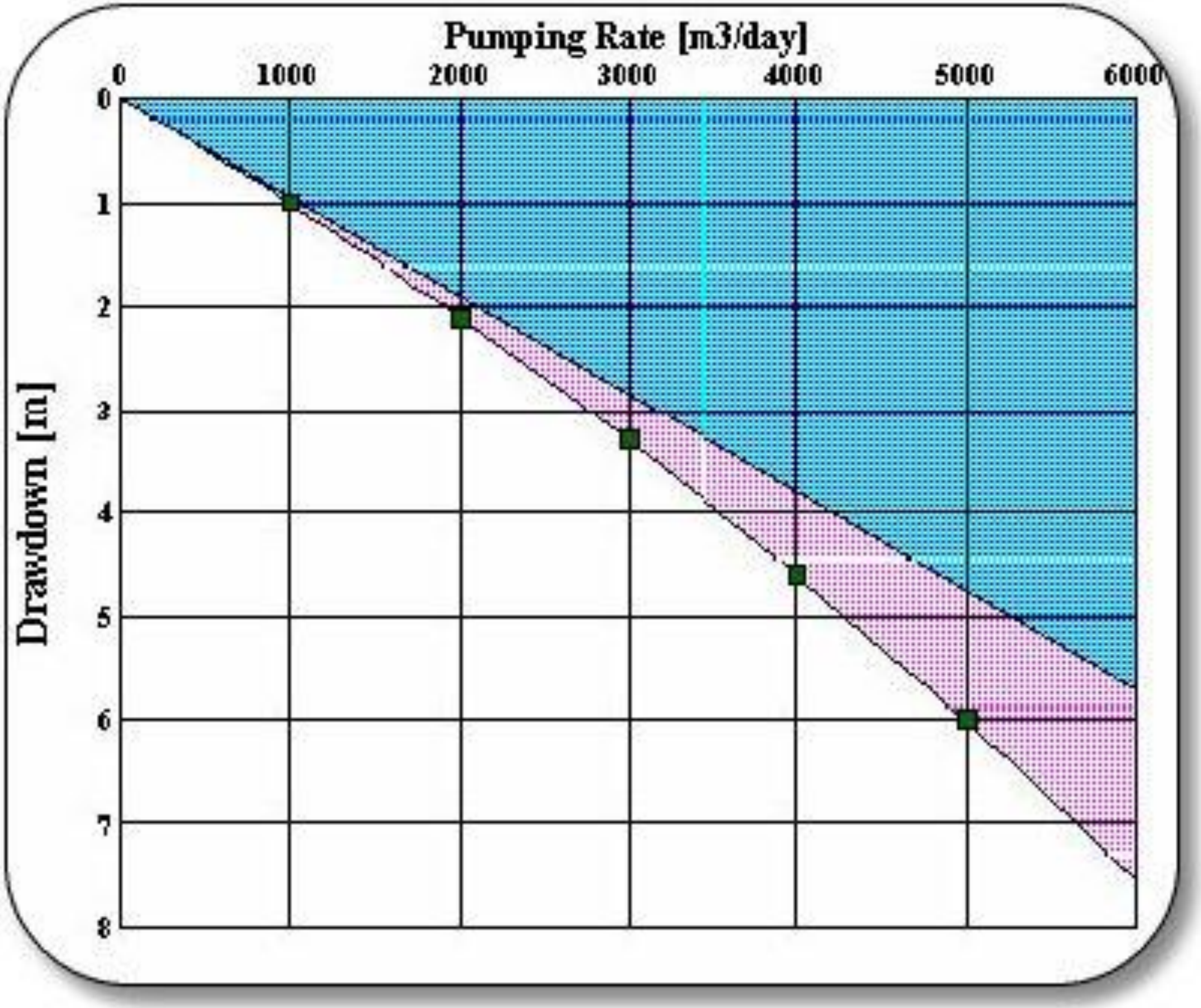
“Permeability (k) is a measure of the interconnectedness of pores.”
The ease with which a fluid can pass through a porous medium and is defined as the volume of fluid discharged from a unit area of an aquifer under unit hydraulic gradient in unit time (expressed as m3/m2/d or m/d); it is an intrinsic property of the porous medium and is dependent of the properties of the saturating fluid.

The connection between pore spaces allows groundwater to flow through the sediment or rock. The combination of water storage (porosity) and flow (permeability) makes a good aquifer—a rock unit or sediment that contains usable groundwater. The Unit of P is mentioned as **gallons per day per feet^2 (g/d/ft^2).**

“Porosity is the ratio of the volume of void space to the total volume of the rock or earth material.” The amount of space there could be to hold water under the ground, and permeability describes how those pores are shaped and interconnected. This determines how easy it is for water to flow from one pore to the next. This can be mentioned in terms of **percentage (%)** of pore space vs mineral / volume of soil particle.

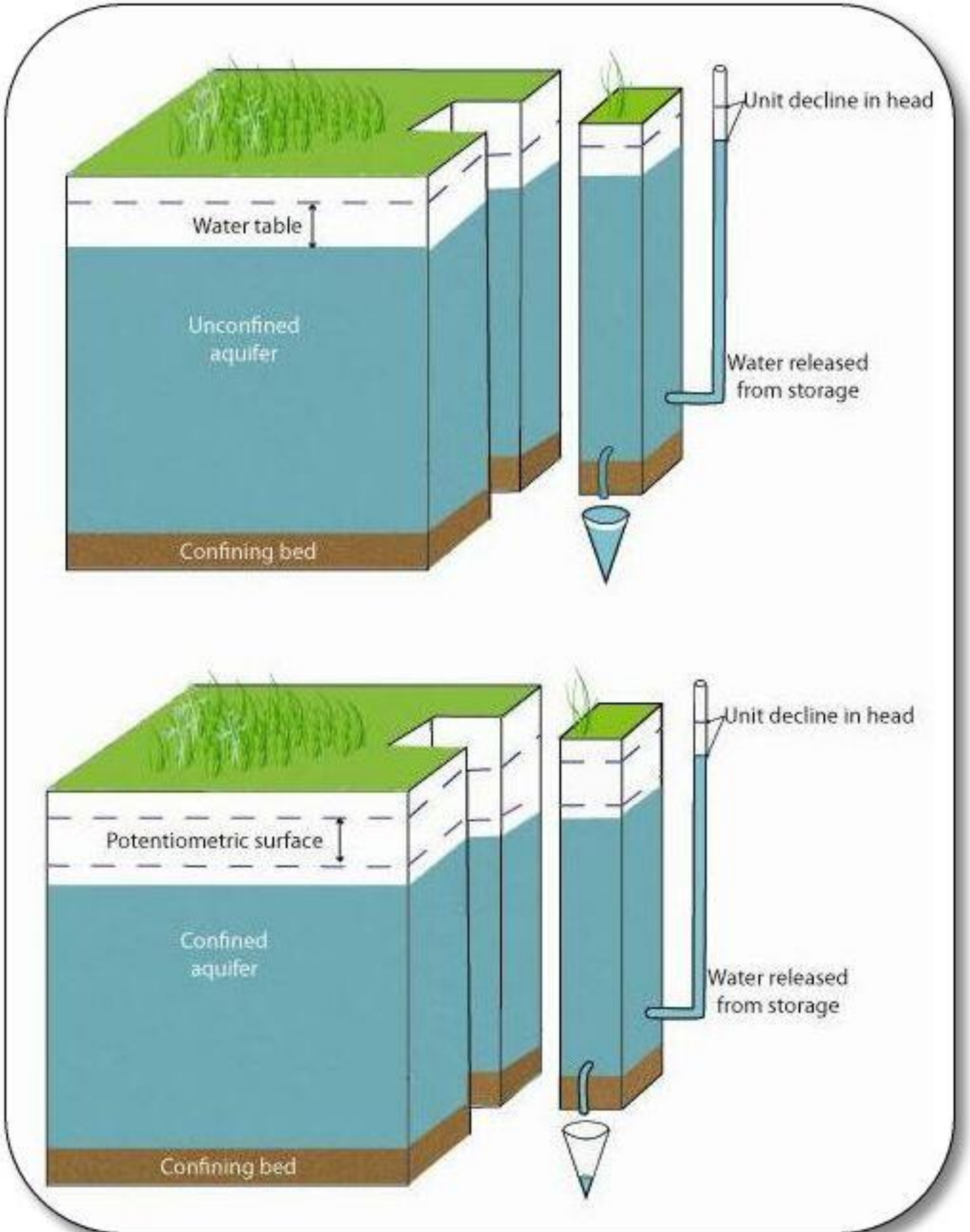
Specific Capacity The rate of discharge from a borehole per unit of drawdown, usually expressed as m3/d·m.

Specific capacity is a measure of borehole performance and is calculated by dividing the yield of the borehole by drawdown induced
by abstraction.

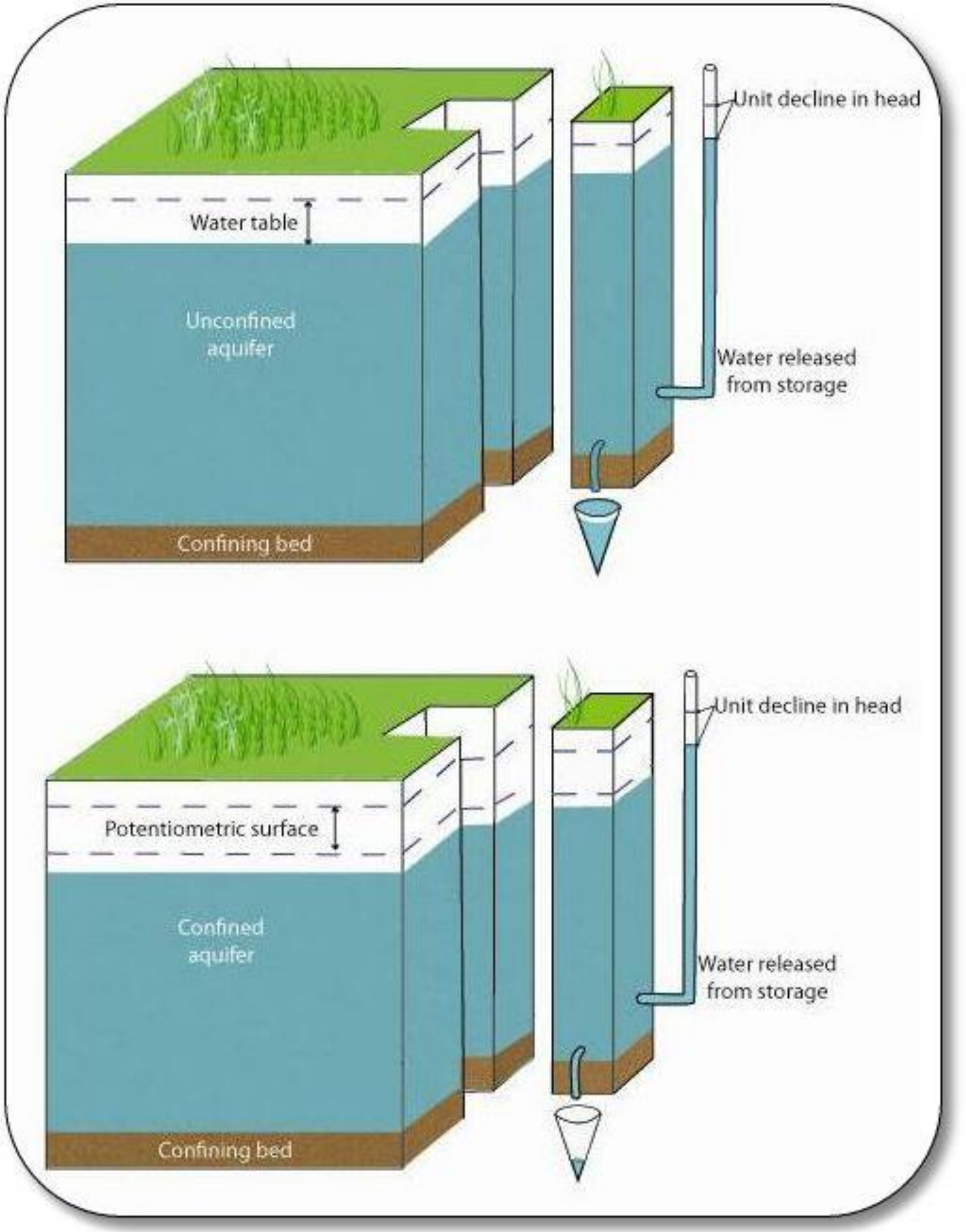


"**Storage coefficient** or **storativity (S)** is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head."

It is a volume of water per volume of aquifer released as a result of a change in head. For a confined aquifer, the storage coefficient is equal to the product of the specific storage and aquifer thickness. In most of the confined aquifers, the value of storage coefficient, **S** ranges between 0.00005 to 0.005**m³**. While mentioned as a sheet, the unit is "**m**".



"**Specific yield (Sy)** is a ratio between 0 and 1 indicating the amount of water released due to drainage, from lowering the water table in an unconfined aquifer." This is a measure of the water released from an unconfined aquifer.



Source: https://www.dws.gov.za/Groundwater/Groundwater_Dictionary/index.html?introduction_specific_yield.htm

GEOPHYSICAL METHODS FOR EXPLORATION OF GROUNDWATER

1. **Electrical Resistivity surveys** can be conducted to delineate the:
   a) surface and subsurface extent of Lithological features– Porous, unconsolidated / semi-consolidated Sedimentary formations;
   b) Structural features like inter connected sets / swarms of Fractures, Joints, Lineaments, Faults, Unconformities, Gneissic/Schistose planes, Fissile planes / Shear planes
   c) Depth up to which the existence of Favourable Geomorphic groundwater holding landforms such as Dissected Plateaux, Fractured and Filled Valleys, Bajadas, Burried Pediment, Alluvial plains, meander / Flood plains, Palaeochannels, Deltaic plains, coastal plains, Beach ridges,… can be established.
   d) Characteristics of aquifers like T, K, S & SY can also be approximated.
2. **Seismic Survey-** The Medium and deep aquifer formations can be mapped.
3. **Self-Potential survey**– By conducting Self-potential survey GW Prospects can be mapped.
4. **Geophysical Logging** – Resistivity log, Litho log, Calipper log, Gamma log, etc. can be conducted to establish the aquifer properties.

MINING METHODS FOR GROUNDWATER

INTRODUCTION

- **A water well is a hole, shaft, or excavation used for the purpose of extracting ground water from the subsurface.**
- Water may flow to the surface naturally after excavation of the hole or shaft.
- Such a well is known as a ***flowing artesian well****.*
- More commonly, water must be pumped out of the well.
- Until recent centuries, all artificial wells were pumpless hand-dug wells with pulleys and they remain a very important source of potable water.

- To install **large production wells**, a test hole will be drilled before well drilling to obtain more detailed information about
  - the depth of water-producing zones,
  - confining beds and their aquifer characters such as, unconsolidated & uncemented, well sorted, well rounded, etc.
  - well production capabilities,
  - water levels, and
  - groundwater quality.
- The final design is subject to site-specific observations made in the test hole or during the well drilling.

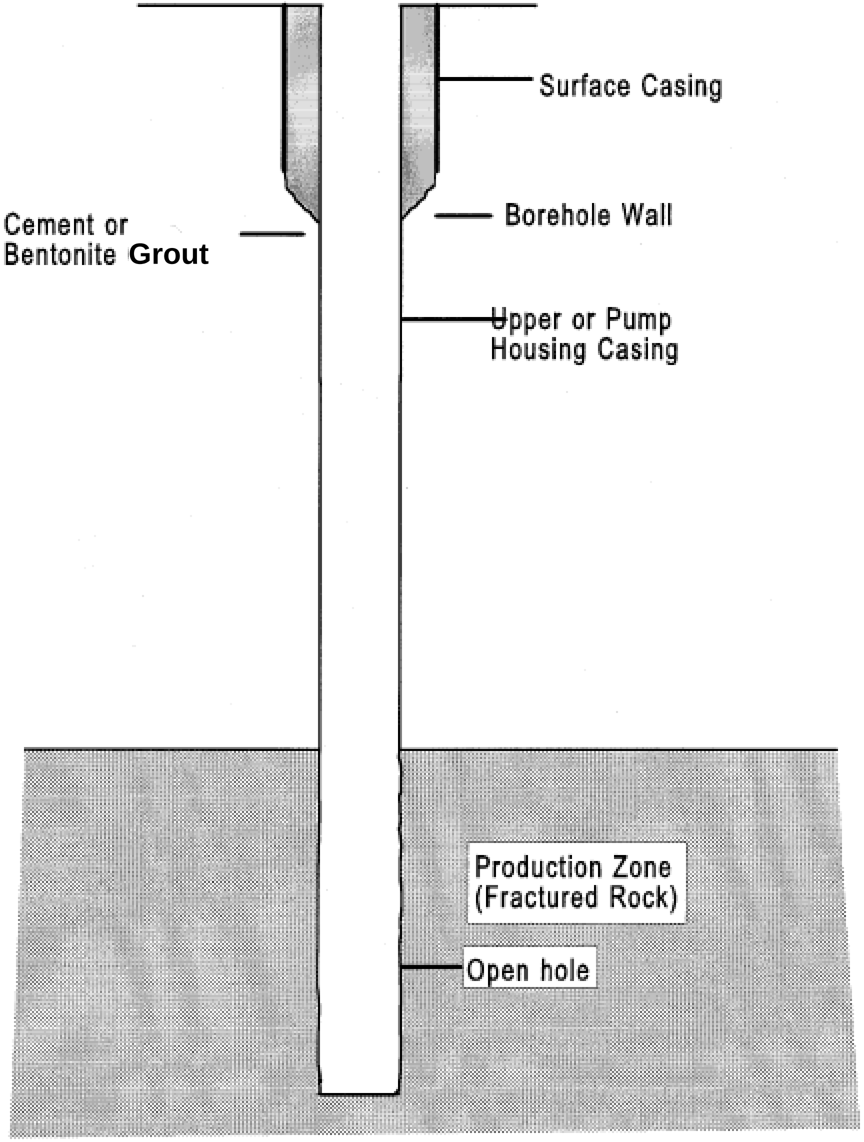


Figure 1 *Open hole well completion.*

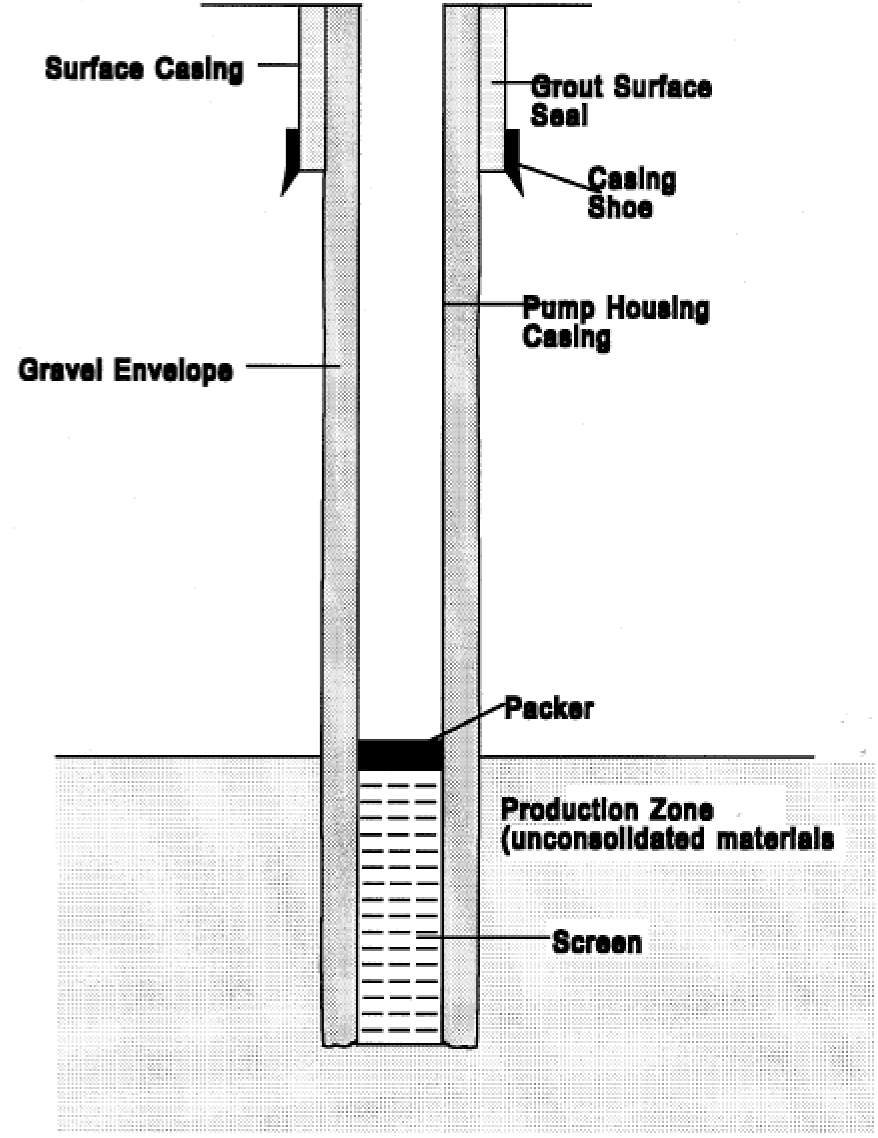


Figure 2 *Gravel envelope well.*

Well completed in hard rock formations in which the water is produced from fractures in the rock

Well, completed in unconsolidated materials (sand, gravel, clay, soil, and mixtures thereof), is more complex

Test holes and well logs

- Using hand / mechanized **Augur drill**, test holes are drilled
- **Rotary percussion drills**, Churn and other drilling mechanisms helps in drilling to reach shallow or deep aquifers
- Test drills are made to understand the subsurface formations and their capability to hold groundwater – aquifer characteristics.
- Driller’s log and Geologist’s or Lithological log are two important loggings helps in understanding the aquifer / water holding formation

- A small-diameter pilot hole / test hole can be drilled before drilling the well bore.
- From information obtained from the pilot hole, a driller or consultant can determine aquifer formations and groundwater quality at various depths and then optimize the final well design for the specific hydrogeological conditions at the site.
- Appropriate materials (screen, casing, gravel) can then be acquired in a timely fashion prior to the final drilling.

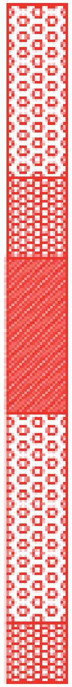
- **Driller’s log** – Record on technical / cost details of drilling operations like, equipment / tools used, difficulties and set backs, rate of penetration of rig into the formation, etc.
- **Litho log** – Record of particulars of rocks encountered / cored during drilling, colour of sludge, length of core recovered, core lost, total drilled in the run, any special feature such as water loss and the depth of such loss, details of mineralization, structures, etc.
- **Caliper log** – useful determine the physical characters of subsurface stratum, such as variation in the diameter of the bore hole at a certain depth, thickness of formations, compactness, hardness, etc.

Geological cross sections of aquifer

Drilling log

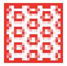
Drawing (PVC pipe / Back-fill / Formation type)	Depth (meter)	Description of the formation	hard / soft fine / coarse	Color(s) of the sample
	1	Sand	fine	yellow/brown
	2	Sand	fine	yellow/brown
	3	Sand	fine	yellow/brown
	4	Sand	fine	yellow/brown
	5	Sand	fine	yellow/brown
	6	Sand	fine	yellow/brown
	7	Sandy Clay	....	brown
	8	Sandy Clay	....	brown
	8.5	Sandy Clay	....	brown
	9	Clay	compact	grey
	10	Clay	compact	grey
	11	Clay	compact	grey
	12	Clay	compact	grey
	13	Clay	compact	grey
	14	Clay	compact	grey
	15	Sand	coarse	yellow
	16	Sand	coarse	yellow
	17	Sand	coarse	yellow
	18	Sand	coarse	yellow
	19	Sand	coarse	yellow
	20	Sand	coarse	yellow
	21	Sand	coarse	yellow
	21.5	Sand	coarse	yellow
	22	Sandy Clay	....	grey/brown
	23	Sandy Clay	....	grey/brown
	....	....	....	....

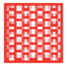
Drilling log

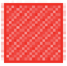


Drawing (PVC pipe / Back-fill / Formation type)	Depth (meter)	Description of the formation	hard / soft fine / coarse	Color(s) of the sample
	1	Sand	fine	yellow/brown
	2	Sand	fine	yellow/brown
	3	Sand	fine	yellow/brown
	4	Sand	fine	yellow/brown
	5	Sand	fine	yellow/brown
	6	Sand	fine	yellow/brown
	7	Sandy Clay	....	brown
	8	Sandy Clay	....	brown
	8.5	Sandy Clay	....	brown
	9	Clay	compact	grey
	10	Clay	compact	grey
	11	Clay	compact	grey
	12	Clay	compact	grey
	13	Clay	compact	grey
	14	Clay	compact	grey
	15	Sand	coarse	yellow
	16	Sand	coarse	yellow
	17	Sand	coarse	yellow
	18	Sand	coarse	yellow
	19	Sand	coarse	yellow
	20	Sand	coarse	yellow
	21	Sand	coarse	yellow
	21.5	Sand	coarse	yellow
	22	Sandy Clay	....	grey/brown
	23	Sandy Clay	....	grey/brown
	....	....	....	....

By hatching, now the permeable, semi permeable and impermeable layers become visible. Following hatching styles are used:


Permeable


Low permeable


Impermeable

Appendix 1. Lithologic Logs

Geological cross sections of an aquifer acquired using Litholog

Well 2

Latitude/longitude: 39° 32′29.7″/102° 40′02.5″, North American Datum of 1983
Land surface altitude: 4,310 feet, North American Vertical Datum of 1929
Date well completed: 8/20/2008
Log prepared by L.R. Arnold

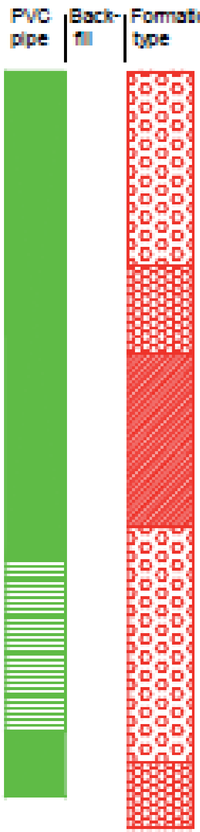
[Depth intervals in feet below land surface; split spoon blows in blows per 6 inches; mm, millimeters; ft, feet; ±, about; %, percent; <, less than; $CaCO_3$, calcium carbonate]

Depth	Sample type	Description[2]
0–24	cuttings	Sand, slightly silty (±10%), fine to medium grained with ±10% coarse, subangular to subrounded, ±75% quartz, ±20% feldspar, ±5% lithics, loose, pale yellowish brown (10YR 6/2) to dark yellowish brown (10YR 6/6), dry to damp, eolian sand.
24–35	cuttings	Sand, slightly gravelly to gravelly (10–20%), fine to coarse grained, gravel up to 22 mm in size, subangular to subrounded, ±70% quartz, ±25% feldspar, ±5% lithics, medium dense, dark yellowish orange (10YR 6/6), damp, Ogallala Formation.
35–47	cuttings	Gravel, sandy (±30%), sand is fine to coarse grained, gravel up to 25 mm in size, subangular to subrounded, ±45% quartz, ±50% feldspar, ±5% lithics, medium dense, dark yellowish orange (10YR 6/6), damp, Ogallala Formation.
47–88	cuttings	Clayey sand, ±30% clay, fine to coarse grained, more coarse grained and slightly gravelly (5–10%) below 67 ft, subangular to subrounded, ±75% quartz, ±20% feldspar, ±5% lithics, low plasticity, dense, dark yellowish orange (10YR 6/6) to moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
88–157	cuttings and on bit	Sandy clay, ±40% sand, sand is fine to coarse grained, with minor (<5%) gravel up to 10 mm in size, subangular to subrounded, ±70% quartz, ±20% feldspar, ±10% lithics (dark and $CaCO_3$), low plasticity, hard, pale yellowish brown (10YR 6/2), moist, Ogallala Formation.
157–168	split spoon[1] 160–161 ft blows: 26/60	Sand, slightly gravelly (10–15%), fine to coarse grained, gravel up to 20 mm in size, subangular to subrounded, very dense, grayish orange (10YR 7/4) to dark yellowish orange (10YR 6/6), moist, Ogallala Formation.
168–186	cuttings	Clayey sand, 30–40% clay, fine to coarse grained, minor gravel (<5%) up to 7 mm in size, subangular to subrounded, ±65% quartz, ±25% feldspar, ±10% lithics (dark and $CaCO_3$), low plasticity, dense to very dense, moderate yellowish brown (10YR 5/4), moist, Ogallala Formation.
186–189	none	Hard drilling and minor chatter. Probably gravel with clay.
189–205	split spoon[1] 190–191 ft blows: 21/16	Silty clay, slightly sandy (±10%), sand is fine grained, low plasticity, mottled with caliche, contains thin (a few inches) gravel layers, hard, moderate yellow (5Y 7/6) to dark yellowish orange (10YR 6/6), moist, Ogallala Formation.

[1]Split spoons are driven into sediments by dropping a 140-pound weight 30 inches onto the drive stem.

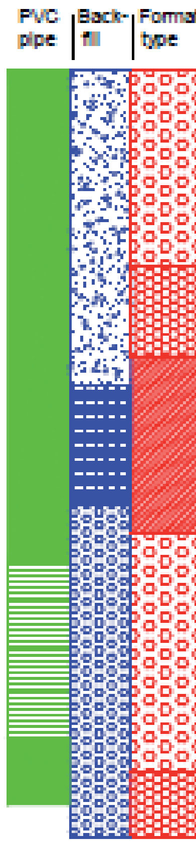
[2]Color codes in description refer to the Munsell color system (Geological Society of America, 1995).

Drilling log



Depth (meter)	Description of the formation	hard / soft fine / coarse	Color(s) of the sample
1	Sand	fine	yellow/brown
2	Sand	fine	yellow/brown
3	Sand	fine	yellow/brown
4	Sand	fine	yellow/brown
5	Sand	fine	groundwater
6	Sand	fine	yellow/brown
7	Sandy Clay	....	brown
8	Sandy Clay	....	brown
8.5	Sandy Clay	....	brown
9	Clay	compact	grey
10	Clay	compact	grey
11	Clay	compact	grey
12	Clay	compact	grey
13	Clay	compact	grey
14	Clay	compact	grey
15	Sand	coarse	yellow
16	Sand	coarse	yellow
17	Sand	coarse	yellow
18	Sand	coarse	yellow
19	Sand	coarse	yellow
20	Sand	coarse	yellow
21	Sand	coarse	yellow
21.5	Sand	coarse	yellow
22	Sandy Clay	....	grey/brown
23	Sandy Clay	....	grey/brown
......	....	....	....

Drilling log



Depth (meter)	Description of the formation	hard / soft fine / coarse	Color(s) of the sample
1	Sand	fine	yellow/brown
2	Sand	fine	yellow/brown
3	Sand	fine	yellow/brown
4	Sand	fine	yellow/brown
5	Sand	fine	groundwater
6	Sand	fine	yellow/brown
7	Sandy Clay	....	brown
8	Sandy Clay	....	brown
8.5	Sandy Clay	....	brown
9	Clay	compact	grey
10	Clay	compact	grey
11	Clay	compact	grey
12	Clay	compact	grey
13	Clay	compact	grey
14	Clay	compact	grey
15	Sand	coarse	yellow
16	Sand	coarse	yellow
17	Sand	coarse	yellow
18	Sand	coarse	yellow
19	Sand	coarse	yellow
20	Sand	coarse	yellow
21	Sand	coarse	yellow
21.5	Sand	coarse	yellow
22	Sandy Clay	....	grey/brown
23	Sandy Clay	....	grey/brown
......	....	....	....

In this example a 6 meter well-screen was installed between 15 and 21 meter below ground level. And a 1.5 meter sump was attached to the bottom end of the well-screen.

Blind PVC casing pipe and sump

Well-screen

Cuttings

Sanitary seal

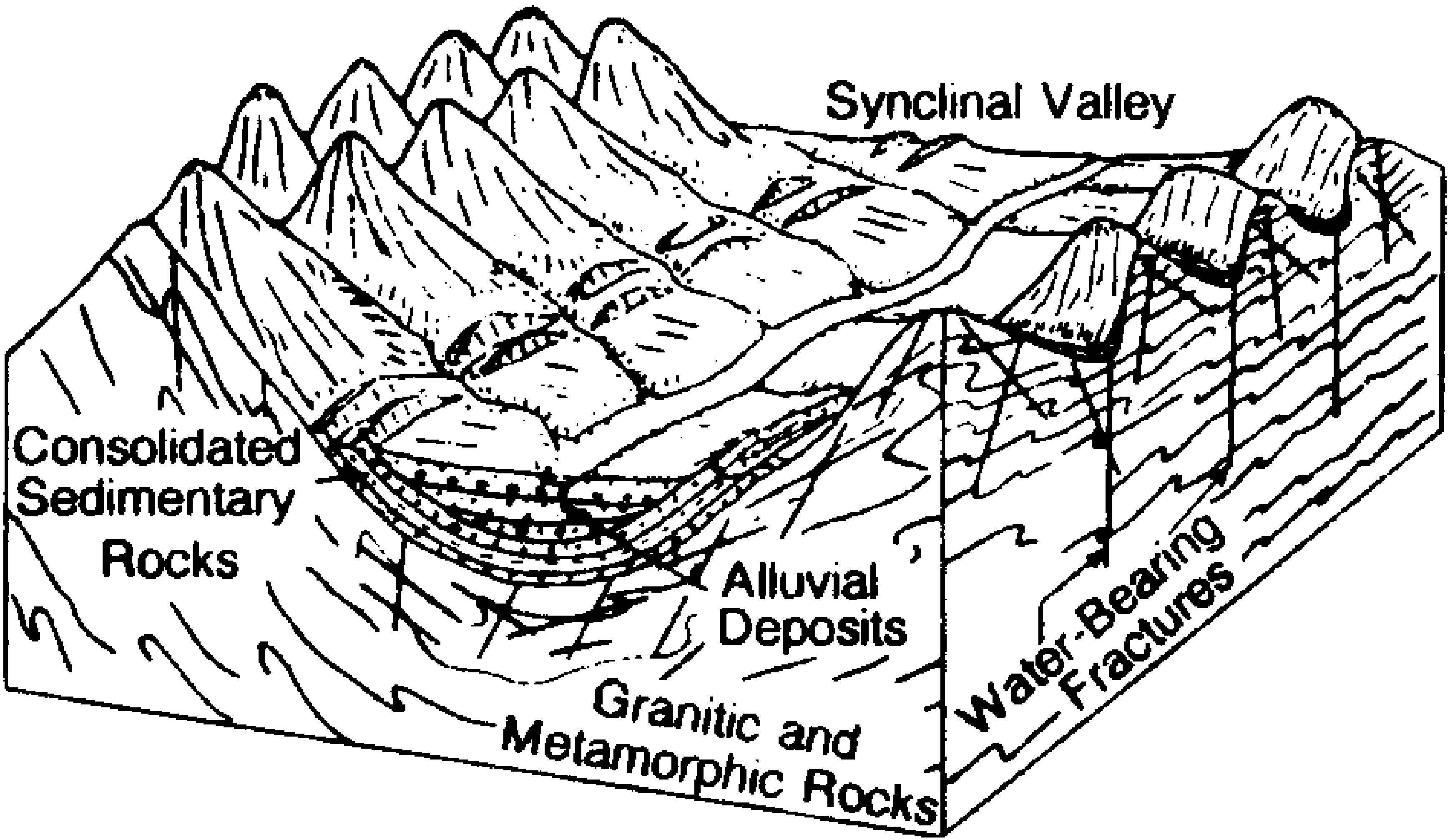
Gravel pack

Note: This drilling log is designed to be filled in by both people who can write and who cannot write. The drawings are intended to assist in visualizing the geological layers and well completion details.

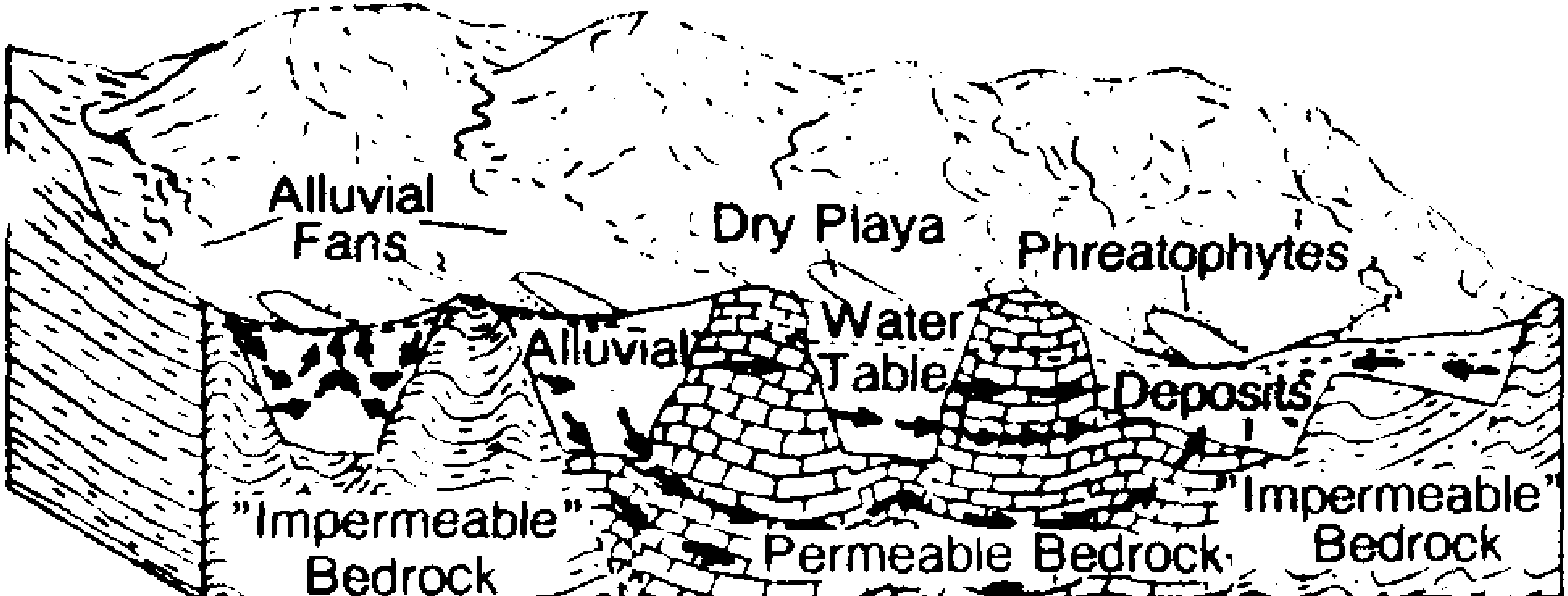
- Resistivity logging or electrical logging, optical / acoustic logging, gamma ray logging, are some of the other types of bore hole geophysical surveys to study the **aquifer characters / characteristics** of subsurface lithology
- It is also possible to conduct **Pump Test / Well Inventory Survey** within the bore hole / dug well using proper equipment like, electric motor pump and water level indicator.
- The aquifer characteristics like **Transmissivity (T), Permeability (K) , Storage co-efficience (S) & Specific yield / safe yield (SY)** of the aquifer can be estimated through this pump test data.
- The diameter of the entire test bore hole is measured at constant depth intervals initially.
- Then wherever necessary at frequent and at lesser depth intervals, dia measurements are made and plotted for detailed study.

- Sample plot of **caliper log** from a test hole shows the formation hardness
- If the diameter is maintained as per the predesigned drill size, then, formation is indurated / cemented sufficiently
- If the diameter is enlarged than the original size, that indicates the looseness or friable and soft nature of the uncompacted sediments.
- The sudden variation in the diameter indicates the lithological contact or boundary of different types of formations.

2D Block Diagrams of certain known Aquifers / formations derived out of combination of data collected through surveys

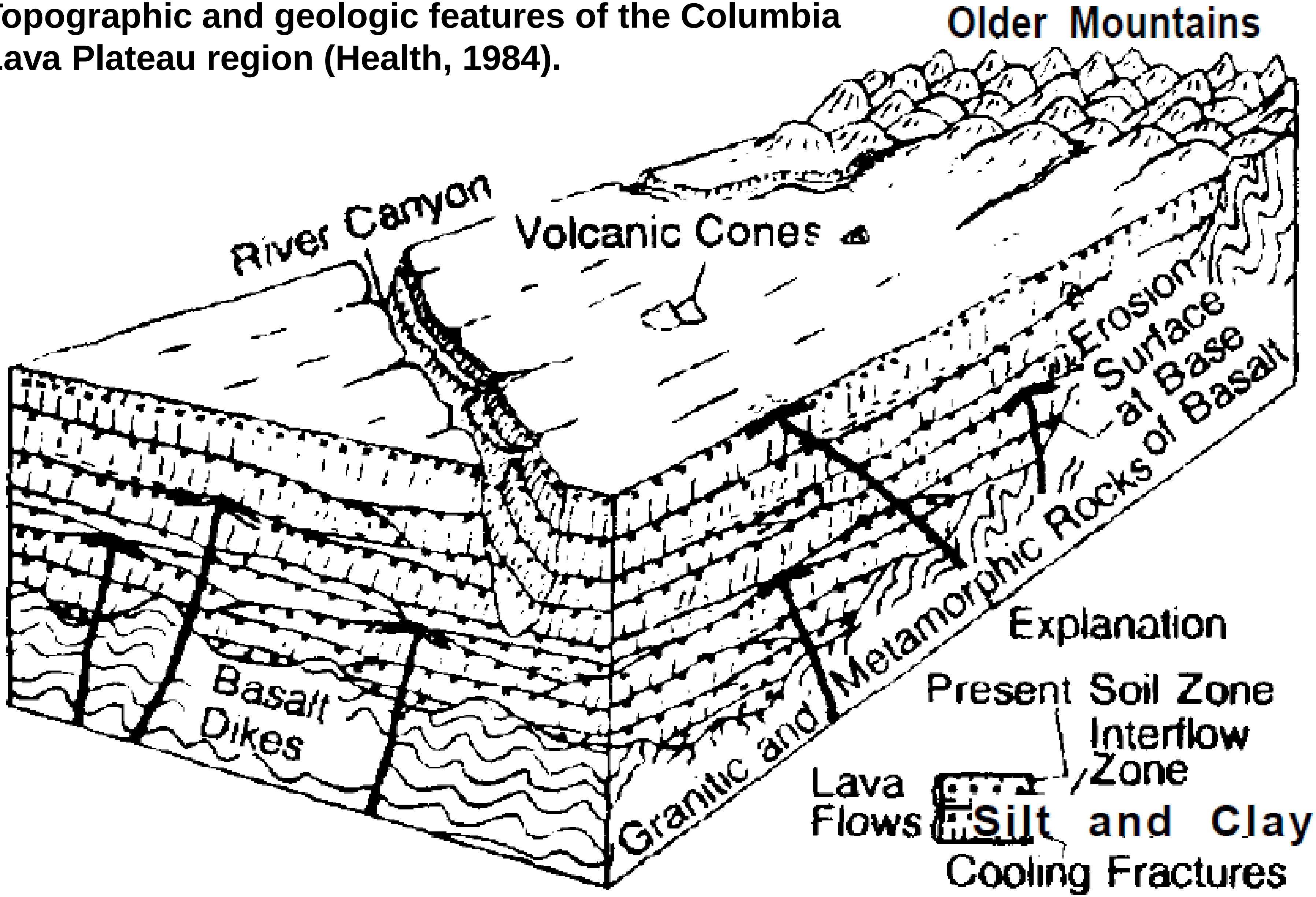


Topographic and geologic features In the southern Rocky Mountains part of the Western Mountain Ranges region (Heath, 1984)

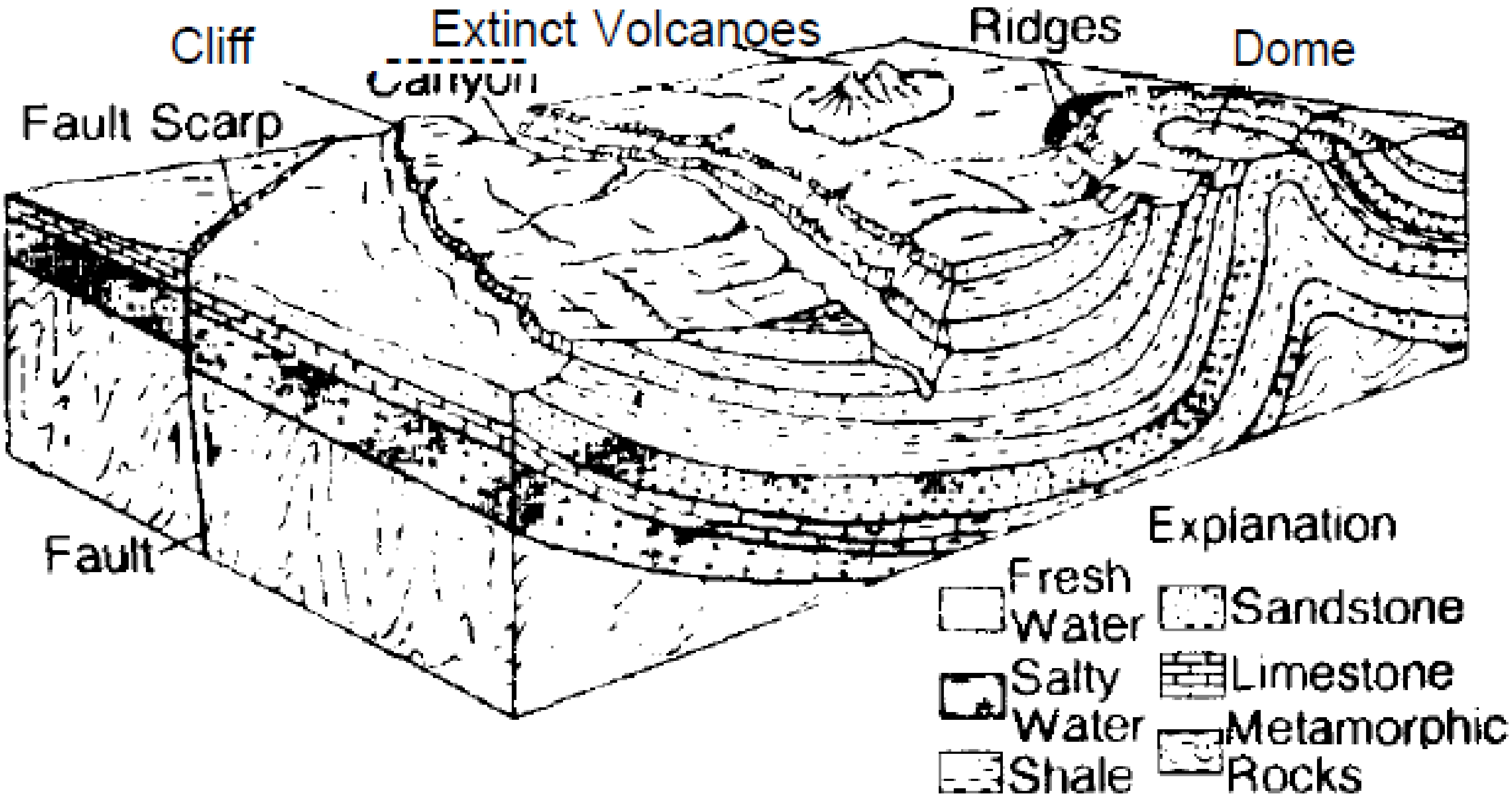


Undrained Closed Basin	Partly Drained Closed Basin	Drained Closed Basin	Sink	Partly Drained Tributary Area

Topographic and geologic features of the Columbia Lava Plateau region (Health, 1984).

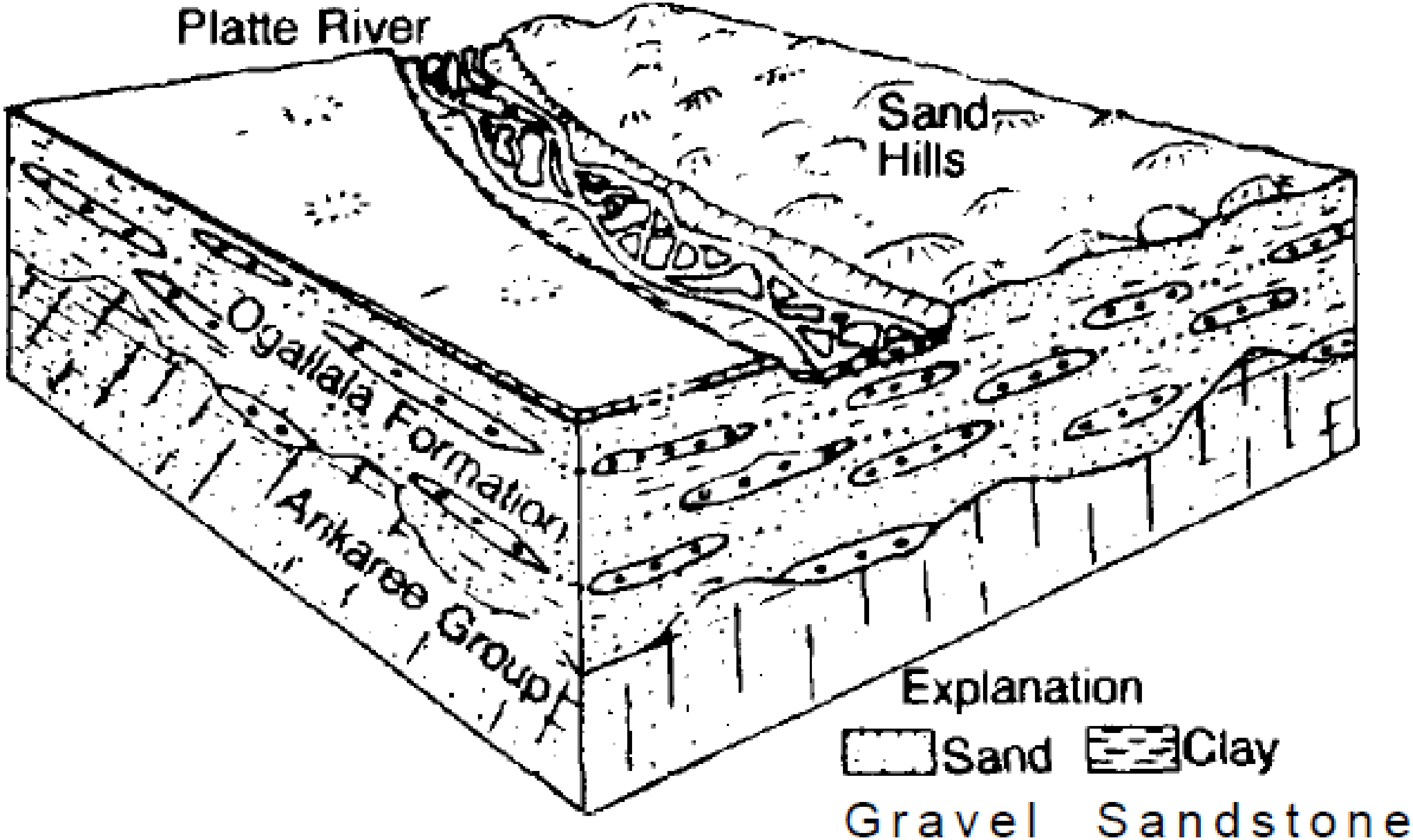


(b)



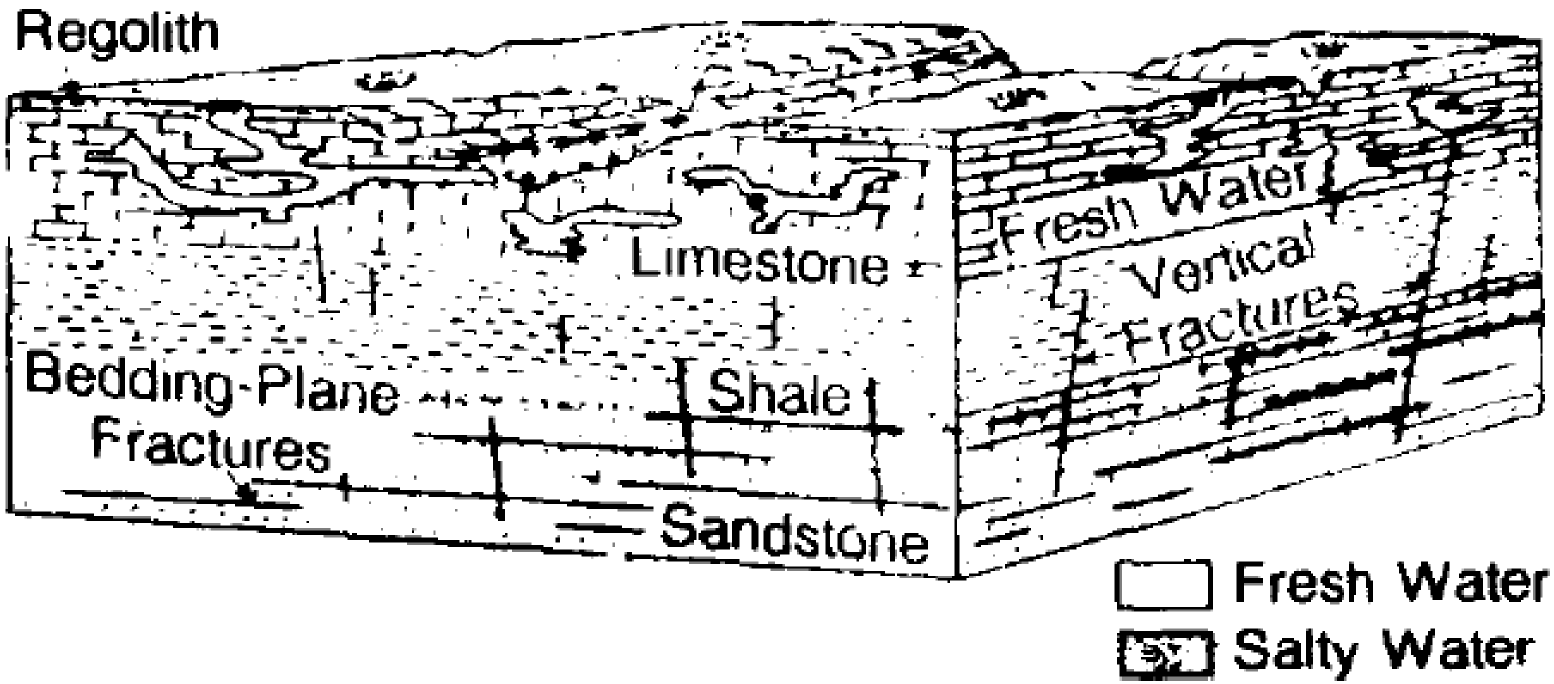
(b)

Figure 5b. Topographic and geologic features of the Colorado Plateau and Wyoming Basin region (Heath, 1984).



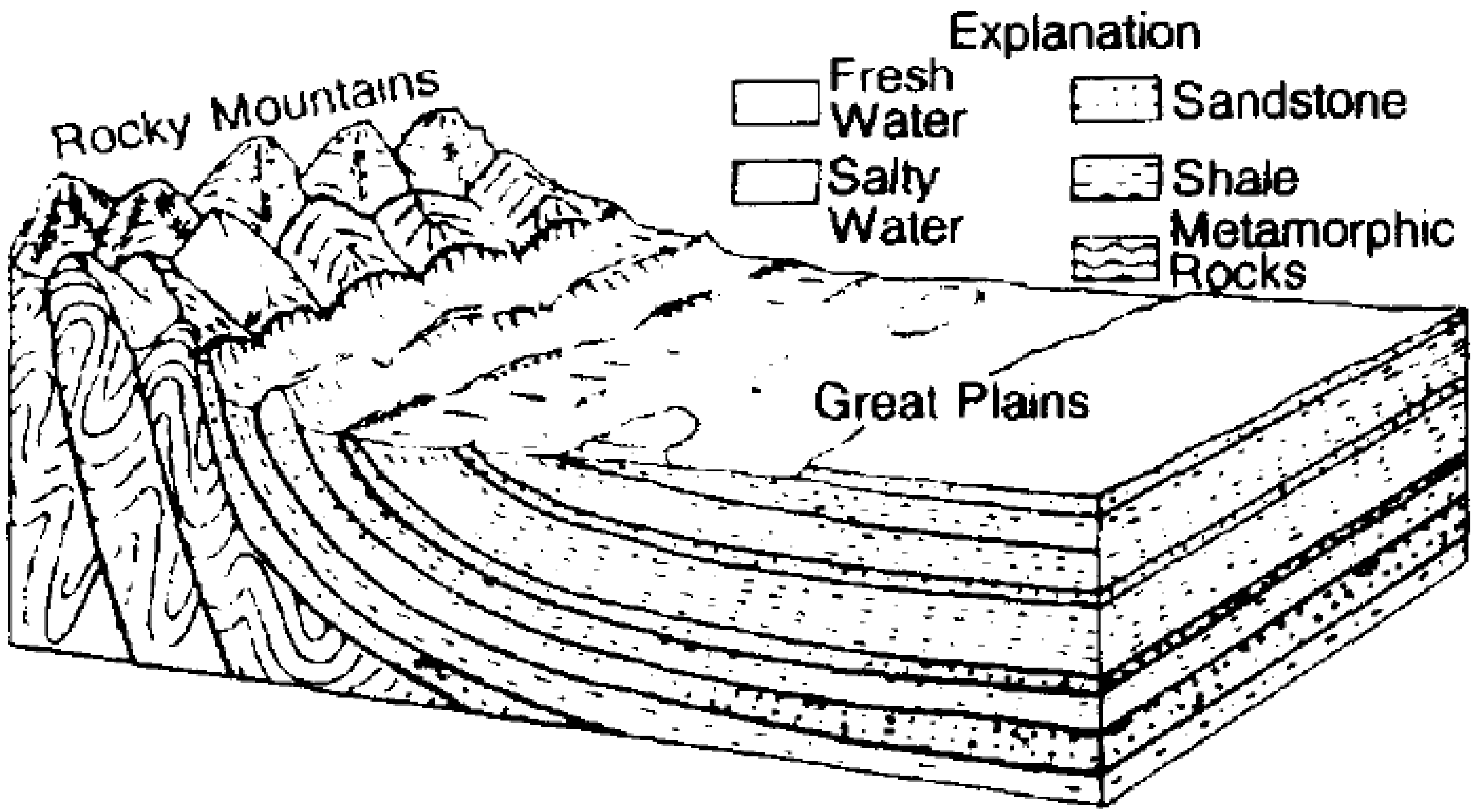
(b)

Figure 6b. Topographic and geologic features of the High Plains region (Heath, 1984).



(b)

Figure 7b. Topographic and geologic features of the Nonglaciated Central region (Heath, 1984).



(c)

Figure 7c. Topographic and geologic features along the western boundary of the Nonglaciated Central region (Heath, 1984).

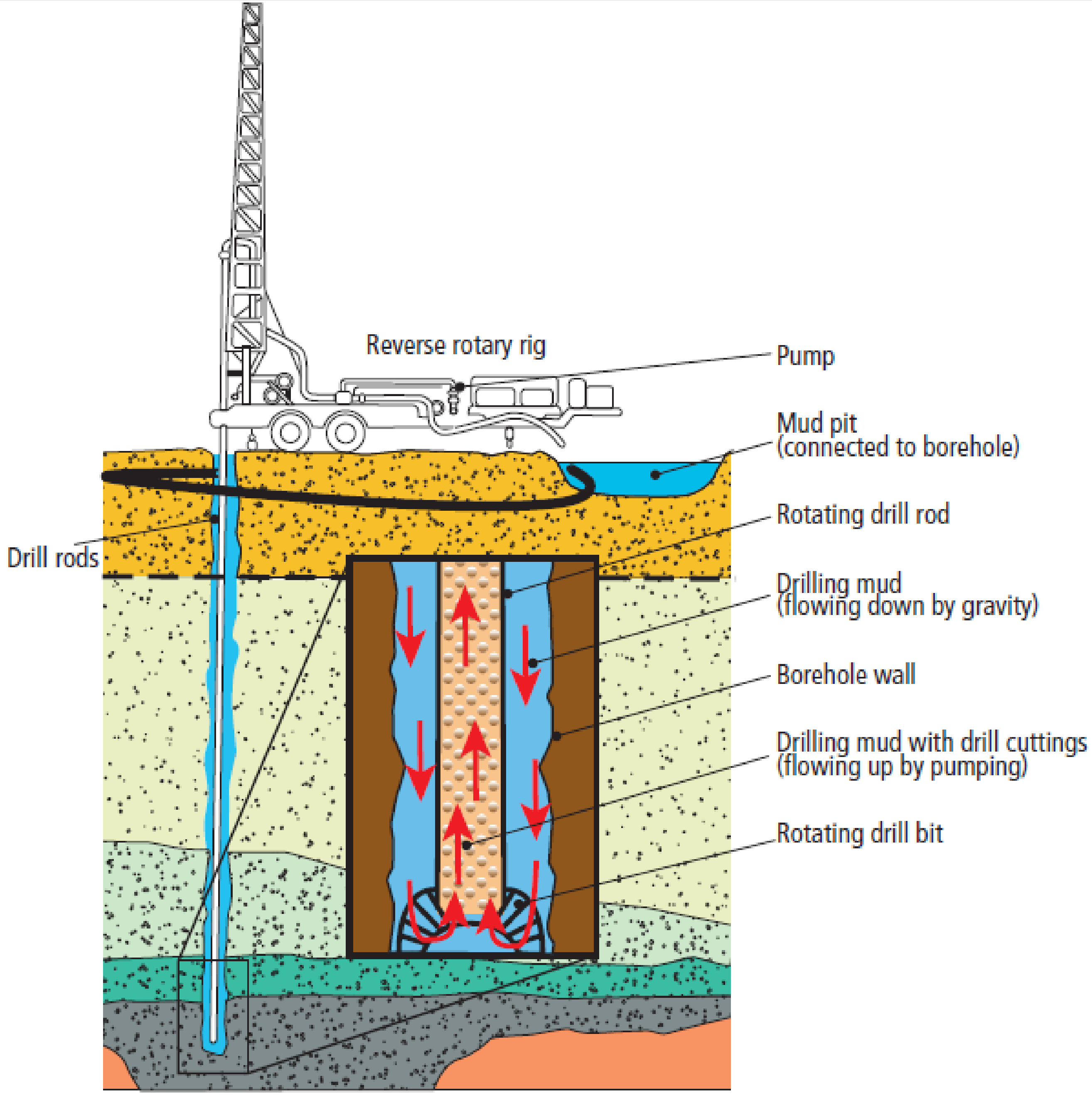


Figure 2. Principles of reverse rotary drilling. (adapted from Driscoll, 1996. Johnson

- Once the well bore is drilled, and logging is done, then the driller installs
  - **well casing** and **well screens** and fills the annulus around the casing with a **gravel** (filter) **pack** and the appropriate **cement and bentonite seal** to prevent water from leaking between uncontaminated and contaminated aquifers or from the land surface into the well (*bentonite is a special type of clay used to* seal against water leaks).
- Then the driller **develops the well**, implements an **aquifer test**, completes the **sanitary seal** of the well head, and installs a **pump** and **power source**.
- Proper design, construction, development, and completion of the well will result in a long life for the well (as long as half a century or more) and efficient well operation

Darcy’s Law

- Darcy’s law states the principle which governs the movement of fluid in the given substance.
- Darcy’s law equation that describes the capability of the liquid to flow via any porous media like a rock.
- The basis of this law is, the **flow** between two points is **directly proportional** to the **pressure differences** between the points, the **distance** and the **connectivity of flow** within rocks between the points.

- Measuring the interconnectivity is known as **permeability**.
- **“The volume of water which passes through a bed of sand of a given nature is proportional to the pressure and inversely proportional to the thickness of the bed traversed”.**
- In analyzing the sub surface movement of water, the actual paths of the water molecules as they flow through **pores**, **cracks** and **crevices** of the soil or other aquifer material are taken as **smooth paths**.

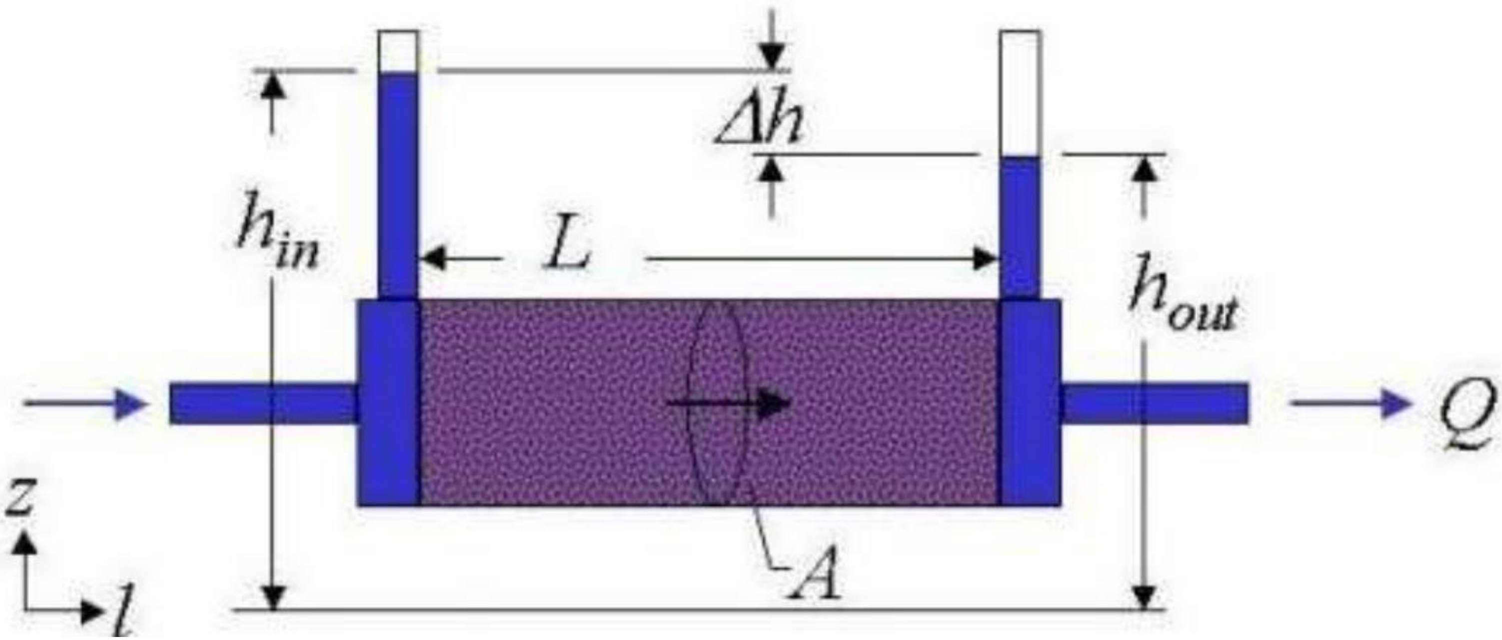
Using the specific sign convention, Darcy's law is expressed as:

$$Q = -KA\ dh/dl$$

Wherein:

- Q is the rate of water flow
- K is the hydraulic conductivity
- A is the column cross section area
- dh/dl indicates hydraulic gradient.

Darcy's law refers to many unit systems. A medium that has a permeability of 1 Darcy allows a flow of 1 cm^3/s of a liquid with viscosity 1 cP under 1 atm/cm pressure gradient acting across an area of 1 cm^2 .



LIMITATIONS OF DARCY'S LAW

Darcy's law can be applied to many situations but do not correspond to these assumptions:

- Unsaturated and Saturated flow.
- Flow in fractured rocks and granular media.
- Transient flow and steady-state flow.
- Flow in aquitards and aquifers.
- Flow in Homogeneous and heterogeneous systems.

Groundwater flow in Homogeneous and Heterogeneous media

- When water flows from a soil of low permeability into a soil of higher permeability, less area is required to accommodate the same quantity of water and lower gradients are sufficient.
- If the flow is from high permeability into lower permeability, steeper (or higher) gradients are required and a relatively more area is needed to accommodate the flow (Cedergren, 1976).
- If layers of beds of porous media of different porosity are considered and it is assumed that each layer is homogeneous and isotropic.

- Then each layer is however characterized by a different hydraulic conductivity rendering the sequence as a whole heterogeneous.
- It was found that for horizontal flow, the most permeable unit dominates the system.
- For vertical flow the least permeable unit dominates the system.
- Under the same hydraulic gradient, horizontal flow is of the order of six orders of magnitude faster than vertical flow (Domenico and Schwartz, 2000).

Findings:

- Under the same hydraulic gradient, fluid flow faster in homogeneous porous media than in heterogeneous porous medium;
- Fluid flows faster in a mixed heterogeneous porous media than layered heterogeneous porous media and
- the least permeable medium dominates in the permeability of both bed layers and mixed heterogeneous medium.

For further Ref.: Fluid Flow in Homogeneous and Heterogeneous Porous Media. Available from: https://www.researchgate.net/publication/267788911_Fluid_Flow_in_Homogeneous_and_Heterogeneous_Porous_Media

Groundwater Quality

- For any water body to function adequately in satisfying the desired use, it must have corresponding degree of purity.
- Drinking water should be of highest purity. As the magnitude of demand for water is fast approaching the available supply, the concept of management of the quality of water is becoming as important as its quantity.
- Each water use has specific quality need.
- Therefore, to set the standard for the desire quality of a water body, it is essential to identify the uses of water in that water body.
- In India, the Central Pollution Control Board (CPCB) has developed a concept of *designated best use*.
- According to this, out of the several uses of water of a particular body, the use which demands highest quality is termed its *designated best use*.
- Five *designated best uses* have been identified by CGWP.
- This classification helps the water quality managers and planners to set water quality targets and design suitable restoration programs for various water bodies.

Designated Best Uses of Water Source: CPCB

Designated Best Use	Class	Criteria
Drinking Water Source without conventional treatment but after disinfection	A	1.Total Coliforms Organism MPN/100ml shall be 50 or less 2. pH between 6.5 and 8.5 3. Dissolved Oxygen 6mg/l or more 4. Biochemical Oxygen Demand 5 days 20 °C, 2mg/l or less
Outdoor bathing (Organised)	B	1.Total Coliforms Organism MPN/100ml shall be 500 or less 2. pH between 6.5 and 8.5 3. Dissolved Oxygen 5mg/l or more 4. Biochemical Oxygen Demand 5 days 20 °C, 3mg/l or less
Drinking water source after conventional treatment and disinfection	C	1. Total Coliforms Organism MPN/100ml shall be 5000 or less 2. pH between 6 and 9 3. Dissolved Oxygen 4mg/l or more 4. Biochemical Oxygen Demand 5 days 20 °C, 3mg/l or less
Propagation of Wild life and Fisheries	D	1. pH between 6.5 and 8.5 2. Dissolved Oxygen 4mg/l or more 3. Free Ammonia (as N) 4. Biochemical Oxygen Demand 5 days 20 °C, 2mg/l or less
Irrigation, Industrial Cooling, Controlled Waste disposal	E	1. pH between 6.0 and 8.5 2. Electrical Conductivity at 25 °C micro mhos/cm, maximum 2250 3. Sodium absorption Ratio Max. 26 4. Boron Max. 2mg/l
Note: MPN – most probable number	Below-E	Not meeting any of the A, B, C, D & E criteria

Characteristics	Designated best use				
	A	**B**	**C**	**D**	**E**
Dissolved Oxygen (DO) *mg/l, min*	6	5	4	4	-
Biochemical Oxygen demand *(BOD)mg/l, max*	2	3	3	-	-
Total coliform organisms MPN/100ml, max	50	500	5,000	-	-
pH value	6.5-8.5	6.5-8.5	6.0-9.0	6.5-8.5	6.0-8.5
Colour, Hazen units, *max.*	10	300	300	-	-
Odour	Un-objectionable			-	-
Taste	Tasteless	-	-	-	-
Total dissolved solids, *mg/l, max.*	500	-	1,500	-	2,100
Total hardness (as $CaCO_3$), *mg/l, max.*	200	-	-	-	-
Calcium hardness (as $CaCO_3$), *mg/l, max*.	200	-	-	-	-
Magnesium hardness (as $CaCO_3$), *mg/l, max.*	200	-	-	-	-
Copper (as Cu), *mg/l, max.*	1.5	-	1.5	-	-
Iron (as Fe), *mg/l, max.*	0.3	-	0.5	-	-
Manganese (as Mn), *mg/l, max.*	0.5	-	-	-	-
Cholorides (as Cu), *mg/l, max.*	250	-	600	-	600
Sulphates (as SO_4), *mg/l, max.*	400	-	400	-	1,000
Nitrates (as NO_3), *mg/l, max.*	20	-	50	-	-
Fluorides (as F), *mg/l, max.*	1.5	1.5	1.5	-	-
Phenolic compounds (as C_2H_5OH), *mg/l, max.*	0.002	0.005	0.005	-	-
Mercury (as Hg), *mg/l, max.*	0.001	-	-	-	-
Cadmium (as Cd), *mg/l, max.*	0.01	-	0.01	-	-
Selenium (as Se), *mg/l, max.*	0.01	-	0.05	-	-
Arsenic (as As), *mg/l, max.*	0.05	0.2	0.2	-	-
Cyanide (as Pb), *mg/l, max.*	0.05	0.05	0.05	-	-
Lead (as Pb), *mg/l, max.*	0.1	-	0.1	-	-
Zinc (as Zn), *mg/l, max.*	15	-	15	-	-
Chromium (as Cr^{6+}), *mg/l, max.*	0.05	-	0.05	-	-
Anionic detergents (as MBAS), *mg/l, max.*	0.2	1	1	-	-
Barium (as Ba), *mg/l, max.*	1	-	-	-	-
Free Ammonia (as N), *mg/l, max*	-	-	-	1.2	-
Electrical conductivity, *micromhos/cm, max*	-	-	-	-	2,250
Sodium absorption ratio, *max*	-	-	-	-	26
Boron, *mg/l, max*	-	-	-	-	2

In India, CPCB has identified water quality requirements in terms of a few chemical characteristics, known as primary water quality criteria. Further, Bureau of Indian Standards has also recommended water quality parameters for different uses in the standard IS 2296:1992.

Water Quality Standards in India (Source IS 2296:1992)

Drinking Water Specifications (IS 10,500:1991)

Drinking Water Specifications (IS 10,500:1991)		
Characteristics	**Desirable limit**	**Permissible limit**
Essential Characteristics		
Colour, Hazen Units, Max	5	25
Odour	Unobjectionable	-
Taste	Agreeable	-
Turbidity, NTU, Max	5	10
pH value	6.5 to 8.5	-
Total Hardness (as $CaCo_3$), mg/l, Max	300	600
Iron (as Fe), mg/l, Max	0.3	1.0
Chlorides (as Cl), mg/l, Max	250	1,000
Residual free chlorine, mg/l, Max	0.2	-

Note: PAH *– Polycyclic Aromatic Hydrocarbons*

Characteristics	Desirable limit	Permissible limit
Dissolved solids, *mg/l, Max*	500	2,000
Calcium as (Ca), *mg/l, Max*	75	200
Magnesium (as Mg), *mg/l, Max*	30	75
Copper (as Cu), *mg/l, Max*	0.05	1.5
Manganese (as Mn), *mg/l, Max*	0.1	0.3
Sulphate (as So_4), *mg/l, Max*	200	400
Nitrate (as No_3), *mg/l, Max*	45	100
Flouride (as F), *mg/l, Max*	1.0	1.5
Phenolic compounds (as C_6H_5OH), *mg/l, Max*	0.001	0.002
Mercury (as Hg), *mg/l, Max*	0.001	-
Cadmium (as Cd), *mg/l, Max*	0.01	-
Selenium (as Se), *mg/l, Max*	0.01	-
Arsenic (as As), *mg/l, Max*	0.05	-
Cyanide (as CN), *mg/l, Max*	0.05	
Lead (as Pb), *mg/l, Max*	0.05	-
Anionic detergents (as MBAS), *mg/l, Max*	0.02	1.0
Chromium (as Cr^{6+}), *mg/l, Max*	0.05	-
PAH, *mg/l, Max*	-	-
Mineral oil, *mg/l, Max*	0.01	0.03
Pesticides, *mg/l, MAX*	Absent	0.001
Alkalinity, *mg/l, Max*	200	600
Aluminum (as Al), *mg/l, Max*	0.03	0.2
Boron, *mg/l, Max*	1	5

Guidelines for Evaluation of Irrigation Water Quality - CGWB

Guidelines are available to evaluate quality of water for irrigation. For irrigation, water can be classified in five classes depending upon its chemical properties.

Water class	Sodium (Na) %	Electrical conductivity (mS/cm)	SAR	RSC meq/l
Excellent	< 20	< 250	< 10	< 1.25
Good	20 - 40	250 – 750	10 – 18	1.25 – 2.0
Medium	40 - 60	750 – 2,250	18 – 26	2.0 – 2.5
Bad	60 – 80	2,250 – 4,000	> 26	2.5 – 3.0
Very bad	> 80	> 4,000	> 26	> 3.0

A colour coding frequently used to depict the quality of water drinking on maps

Blue water	**This water can be directly used for drinking, industrial use, etc.**
Green water	**Water contained in soil and plants is termed as green water**
White water	**Atmospheric moisture is white water**
Brown or grey water	**Various grades of wastewater are shown by brown or grey colour**

Application of H and O isotopes in groundwater studies

- The stable oxygen and hydrogen isotopes in various sources of water can be estimated and applied to evaluate time sequence characteristic and the ratio of groundwater recharge.
- Moreover, the meteoric water line analysis and multivariate statistical analysis can be adopted to analyze the spatial distribution characteristic.
- The ratio of groundwater recharge can be used to evaluate different contribution portions in the proximal fan (Modflow) and the upstream mountain blocks (stable base flow analysis).
- The mixing simulation (Phreeqc) are used to verify the δ18O and δD values with the experimental data.
- From a case study, the δ18O and δD seasonal analysis results suggest that the δ18O in the rainfall has a wide distribution range and the highest variability, followed by the river water, and the of δ18O in the groundwater has the most stable distribution range.
- Although the result is the typical distribution characteristic of oxygen and hydrogen isotopes, it can provide for the information of the spatial-temporal groundwater recharge

- The isotope material balance result of the recharge ratio indicates that the main recharge source in the wet and dry season is the river water in both the upstream mountain blocks and the proximal fan, especially in the upstream mountain blocks.
- This suggests that due to the distinct geological conditions, the great fluidity results in a rapid interaction between the surface water and the groundwater. According to the meteoric water line, the wet season is distinctly lighter than the dry season.
- The study site can be divided into four regions: the northern mountain blocks, the northern proximal fan, the southern proximal fan, the southern mountain blocks.
- This suggests that the groundwater has specific regional characteristic.

The multivariate statistical analysis (the factor and the cluster analysis) result shows the study site can be divided into three groups by regional traits as follows:

(1) Zone 1; the northern upstream mountain blocks, which belong to the mainstream of the Choushui river, and have the lighter composition of oxygen and hydrogen isotopes.
(2) Zone 2; the southern upstream mountain blocks, which belong to the tributary of the Choushui river, and have the heavier composition of oxygen and hydrogen isotopes.
(3) Zone 3; the northern and the southern proximal fan, which has the values of oxygen and hydrogen isotopes between Zone 1 and Zone 2. Also, the result indicates that Zone 1, Zone 2, and Zone 3 have unlike regional traits, resulting in the sources of recharge being different.

By the stable base flow analysis, the recharge in the upstream mountain blocks is 1,095 million tons/year, and the result corresponds well to the previous study of Lee and Chen (2011).

By the Modflow model, the recharge in the proximal fan of the Choushui River alluvial fan is estimated to be 249 million tons/year, which is similar to Lee (2000) using the one-dimensional unsaturated zone long-term hydrological model with 213 million tons/year.

The recharge of the upstream mountain blocks is 74.1 % from the river and 25.9 % from the rainfall.

WATER WELL DESIGN

- The overall **objective** of the design is
  - to create a structurally stable,
  - long-lasting,
  - efficient well
- that has enough space
  - to house pumps or other extraction devices,
  - allows ground water to move effortlessly and
  - sediment-free from the aquifer into the well at the desired volume and quality,
  - and prevents bacterial growth and material decay in the well.

- A well consists of a bottom sump, well screen, and well casing (pipe) surrounded by a gravel pack and appropriate surface and borehole seals (Figure 1).
- Water enters the well through perforations or openings in the well screen.
- The purpose of the screen is to keep sand and gravel from the gravel pack (described below) out of the well while providing ample water flow to enter the casing.
- The screen should also be designed to allow the well to be properly developed
- Wells can be screened continuously along the bore or at specific depth intervals.
- The latter is necessary when a well taps multiple aquifer zones, to ensure that screened zones match the aquifer zones from which water will be drawn.

- The purposes of the blank well casing between and above the well screens are
  - to prevent fine and very fine formation particles from entering the well,
  - to provide an open pathway from the aquifer to the surface, to provide a properhousing for the pump, and
  - to protect the pumped ground water from interaction with shallower ground water that may be of lower quality

➢The annular space between the well screen, well casing, and borehole wall is filled with gravel or coarse sand (called the *gravel pack or filter pack).*

➢*The gravel pack prevents sand* and fine sand particles from moving from the aquifer formation into the well.

➢The gravel pack does not exclude fine silt and clay particles; where those occur in a formation it is best to use blank casing sections.

➢The uppermost section of the annulus is normally sealed with a bentonite clay and cement grout to ensure that no water or contamination can enter the annulus from the surface.

➢The depth to which grout must beplaced varies by county.

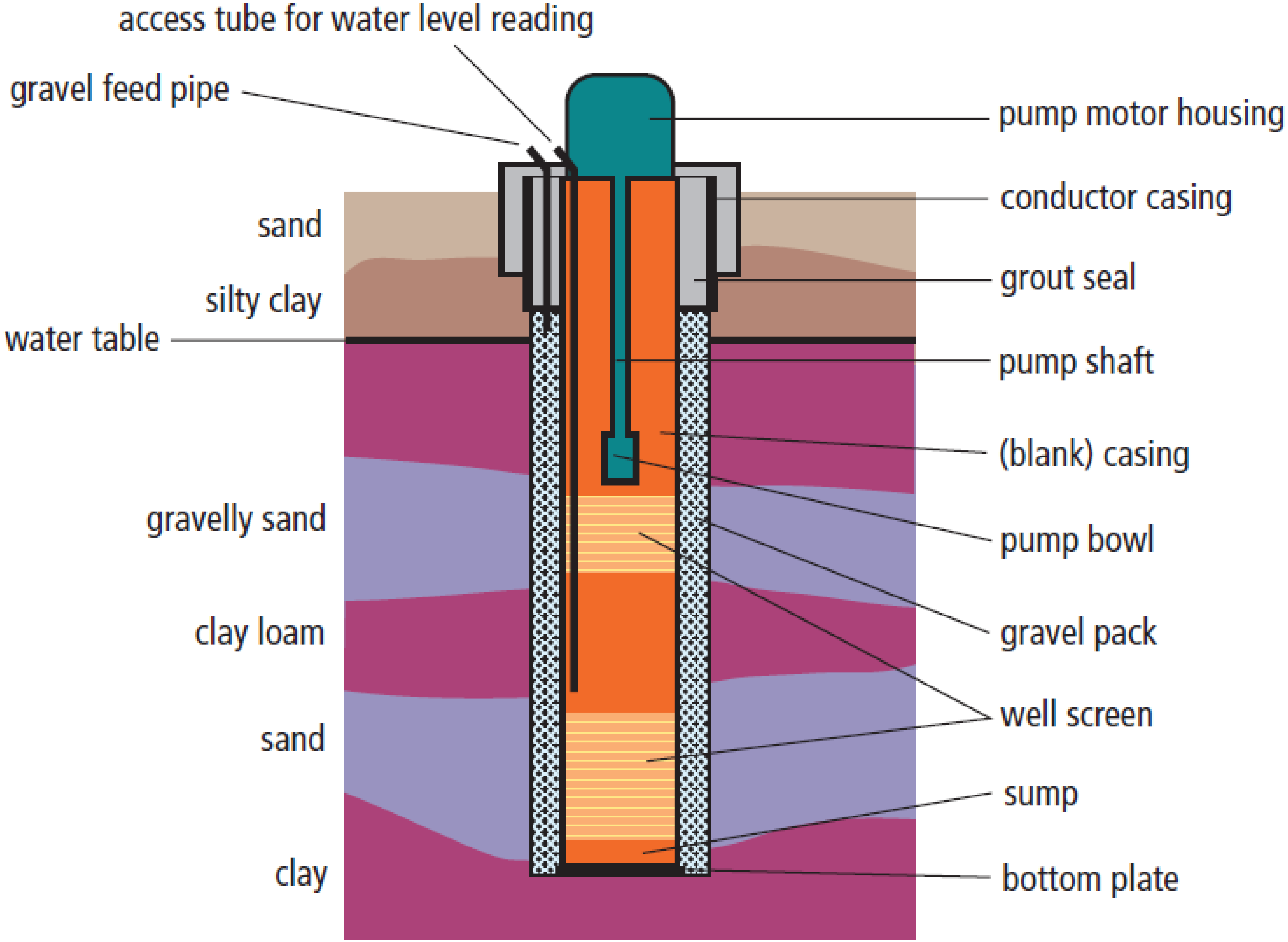
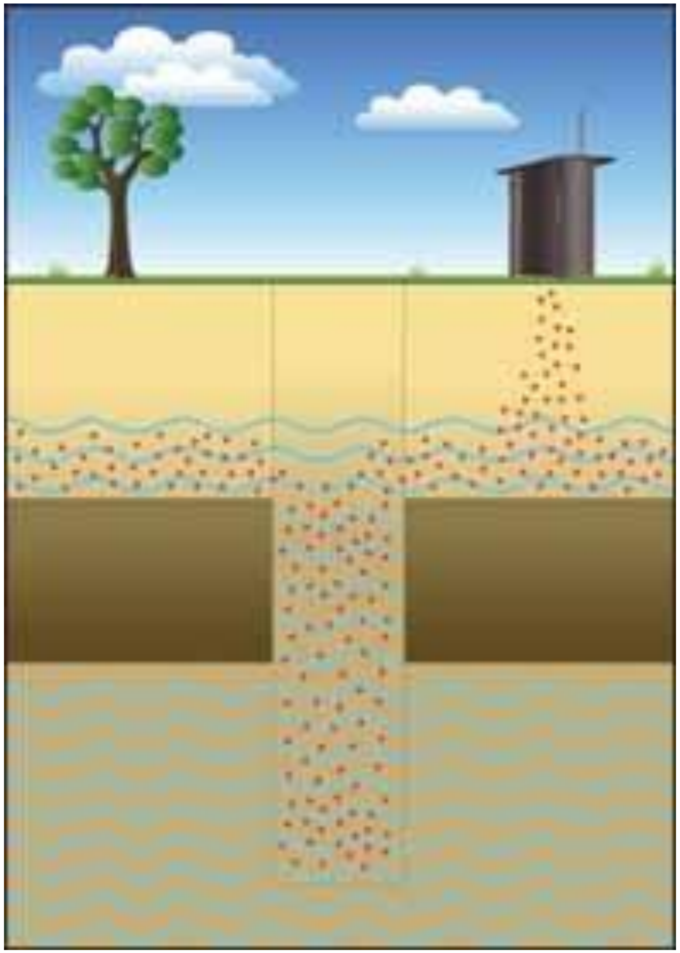


Figure 1. Components of a well.

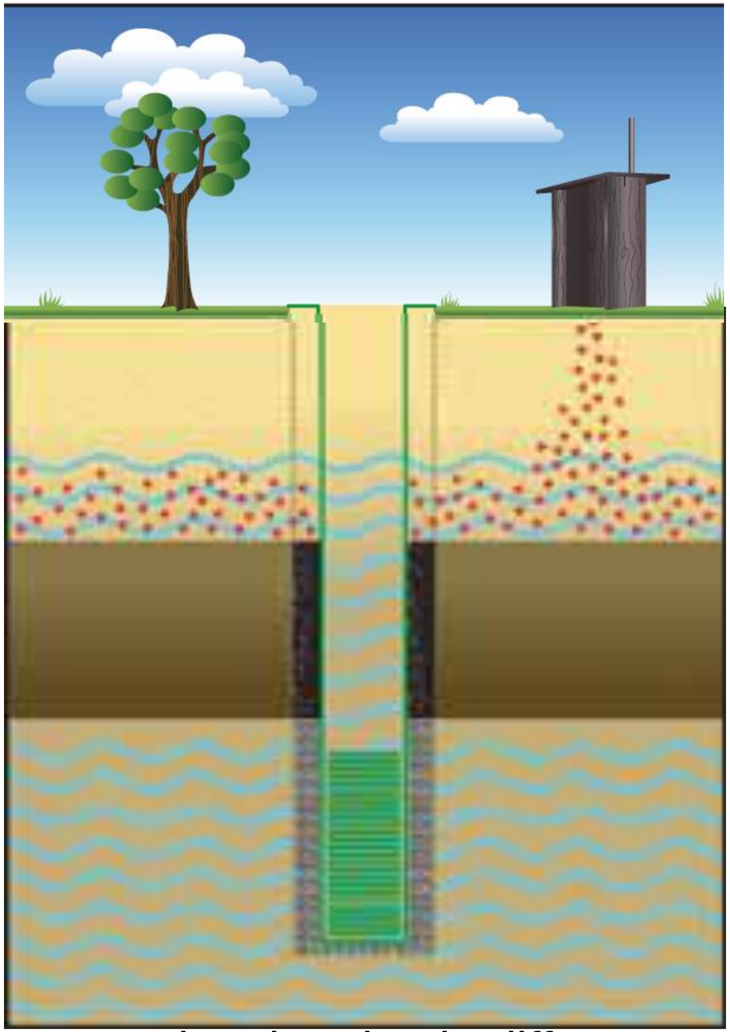
- In alluvial aquifers, which commonly contain alternating sequences of coarse material (sand and gravel) and fine material, the latter construction method is much more likely to provide clean, sediment-free water and is more energy efficient than the installation of a continuous screen.
- Hardrock wells, on the other hand, are constructed very differently. Often, the borehole of a hardrock well will stand open and will not need to be screened or cased unless the hard rock crumbles easily.

- At the surface of the well, a surface casing is commonly installed to facilitate the installation of the well seal. The **surface casing** and **well seal** protect the well against contamination of the gravel pack and keep shallow materials from caving into the well.
- Surface casing and well seals are particularly important in hardrock wells to protect the otherwise open, uncased borehole serving as a well.

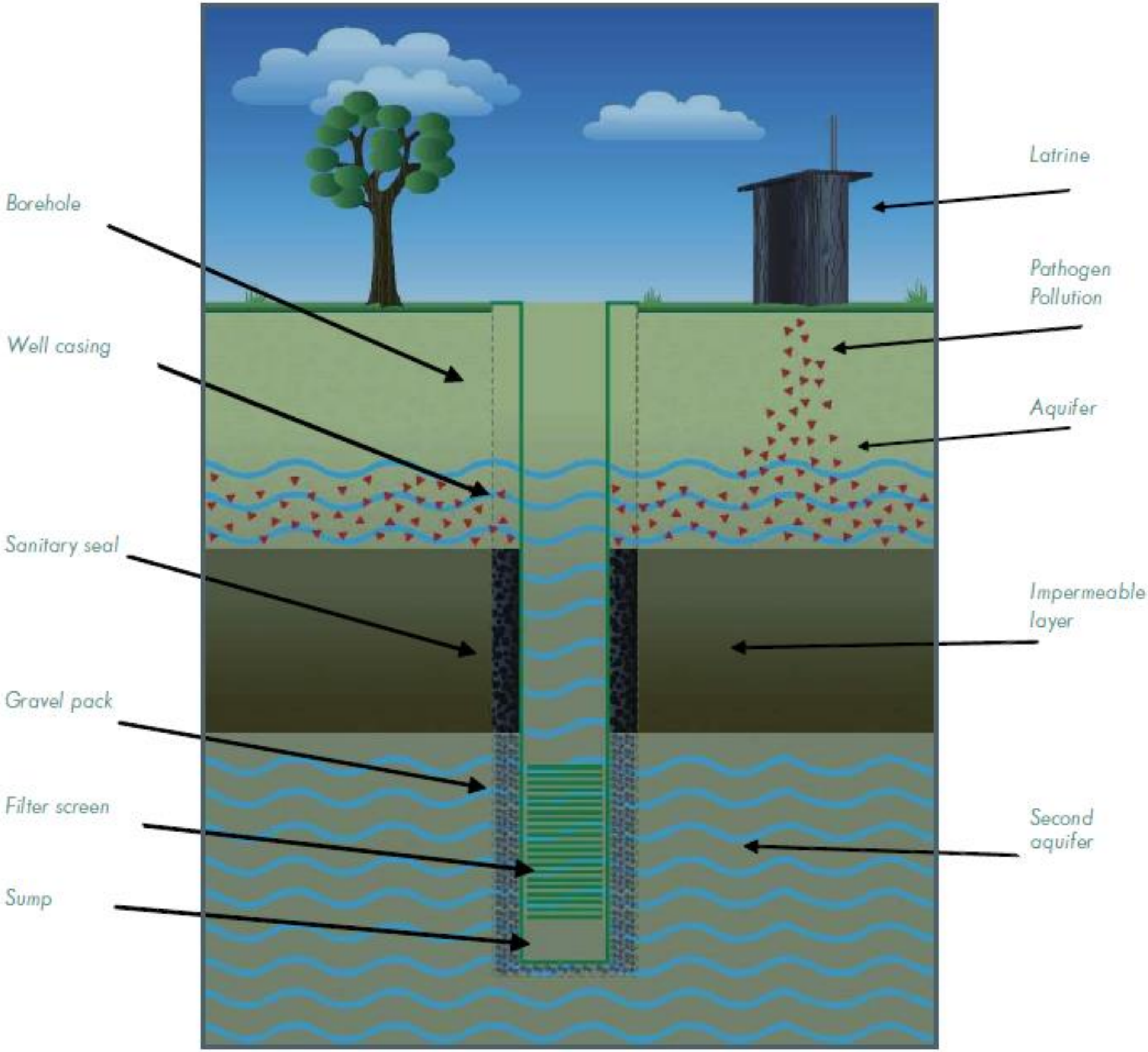
To prevent pathogens and chemicals from entering the filter screen and polluting the second aquifer *a* ***sanitary seal*** has to be placed

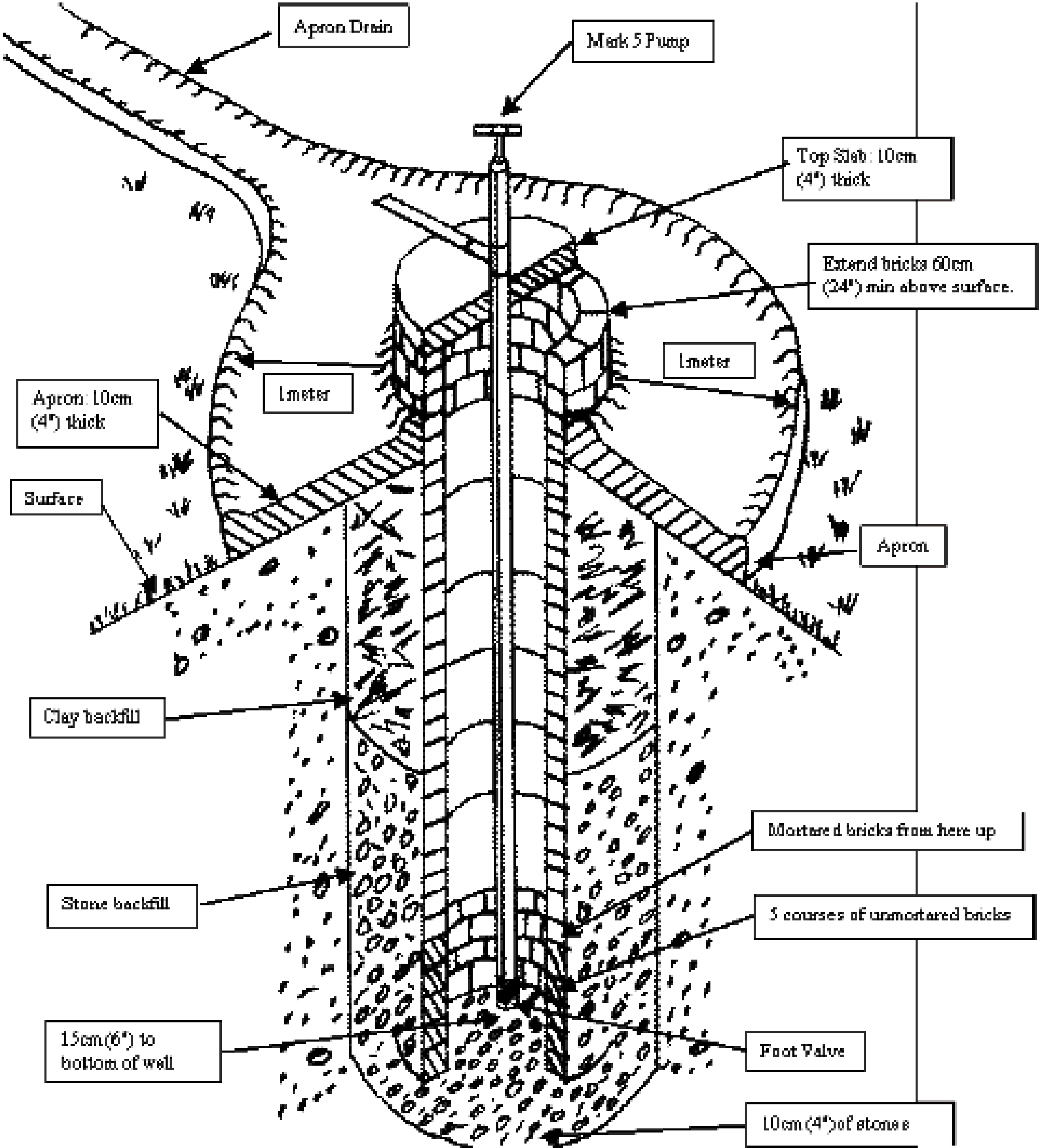


Bacteria migration in different aquifers



Bacteria migration in different aquifers with installed well and sanitary seal


Borehole
Well casing
Sanitary seal
Gravel pack
Filter screen
Sump
Latrine
Pathogen
Pollution
Aquifer
Impermeable
layer
Second
aquifer



A typical **protected shallow well fitted with a hand pump** – Dissected to show the internal components

Well design

- Factors influencing well design and construction techniques are:
  - Geologic and hydrogeologic conditions – occurrence and movement of groundwater and contaminant transport in the subsurface
- Well design includes the following
  - Well casing (large diameter pipe inserted in to the borehole)
  - Perforation – slot size, intake strength & length, intake type, corrosion and chemical degradation resistance
  - Filter packing – dimension, materials used

HOW WELLS ARE DESIGNED?

- Water wells come in all shapes and sizes and need to be designed to suit the geologic conditions, the purpose for needing the water and to comply with local regulations.
- A water well must be deep enough to reach the saturated rocks or sediments in the aquifer.
- In low yielding rocks the well may be drilled several hundred feet deeper than the level of ground water in order to provide some water storage in the well column.
- **One hundred feet depth** in a **six-inch diameter** well below the water table **stores 150 gallons** of water.

- The well’s diameter must be large enough to take the pump equipment necessary to move the water to the surface.
- Most home wells use **four-inch diameter pumps**.
- The well casing lining the drilled hole must extend down far enough to reduce the risk of any surface or near surface contamination.
- The well may need a screen to allow for the efficient flow of water from the aquifer into the well.
- In some cases it may be necessary to place additional casing to seal off parts of the drilled hole where, for example, the water may have high iron content, or some other unwanted chemical attribute.

- Not only do the above factors form part of well design considerations but there may also be decisions about whether to use **steel** or **plastic casing**, about whether to use **steel, stainless steel or plastic screens** and whether the **screens should be wire wrap, slotted or louver**.
- In many states there are regulatory requirements and construction codes that the well contractor has to follow, particularly concerning depth of casing and grout material used to seal the annular space between the hole and the casing.
- Critical decisions related to **well depth**, **diameter** and **positioning of screens** (if needed) are usually made on a **site by site basis** depending on the driller’s experience in the local area, the drilling equipment selected for constructing the well, and on the specific information on water strikes (i.e., aquifers) and rock conditions found during the drilling process.

The **screen** plays a critical role in the performance of the well since it provides the filtering of the water entering the well.

- A well screen is an engineered device that may be used in wells to help maximize inflow from the aquifer and allow for long-term satisfactory operation of the well.
- **Well screens** are typically **installed** in wells where the aquifer is comprised of **loose** or **unstable material**.
- The screen prevents rock fragments from entering the well, helps support the wall of the well and allows water to enter slowly.
- Turbulent flow can more easily transport unwanted rock particles and agitated water may release minerals and clog up the well.
- A commonly used screen type for water wells uses a continuous slot construction, made by wrapping and welding a continuous length of wire or plastic around vertical rods.
- Well Screens are also made by precision machine slotting (vertical or horizontal slots) or by making louver openings.
- Screens are made in many different slot or opening sizes and are usually installed by fixing the screen to the end of the casing, which is then lowered down the well to the selected water-producing zone(s) of the aquifer.

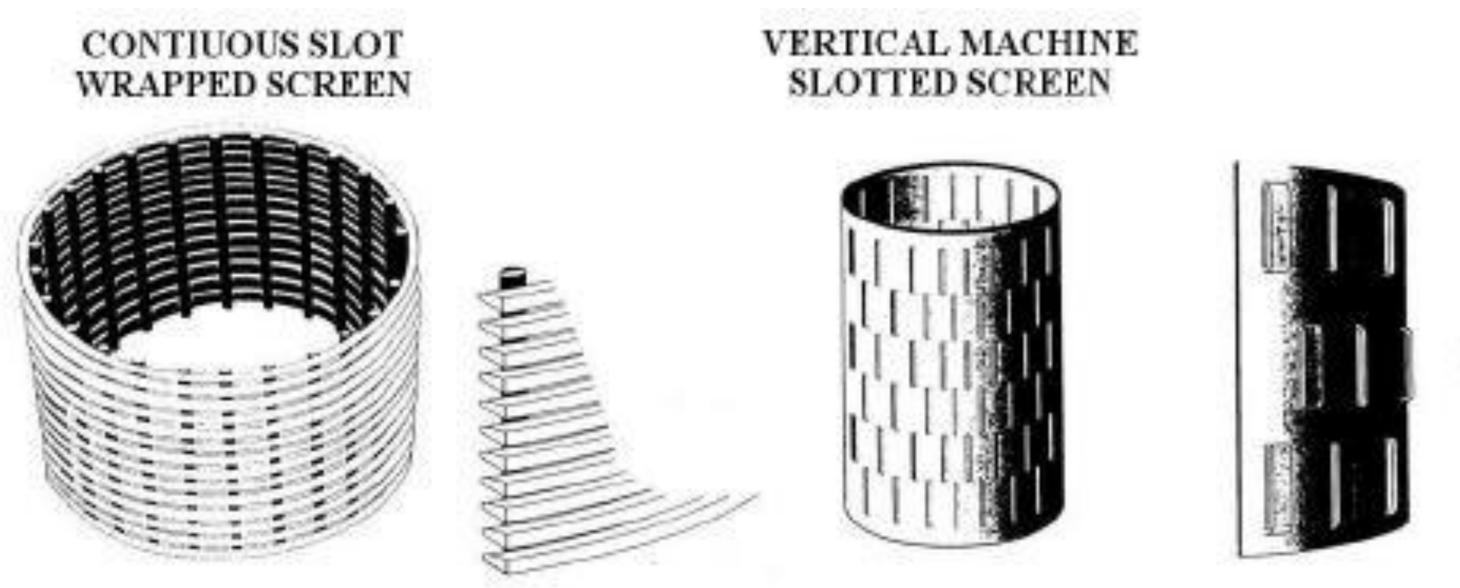
Casing

Casing is a term that refers to tubular material extending from the surface to some depth in the well. It is installed to accommodate the sealing of the well, to stabilize the walls of the borehole, or to allow the installation of screen or liner (tubular products not extending to the surface).

Gravel

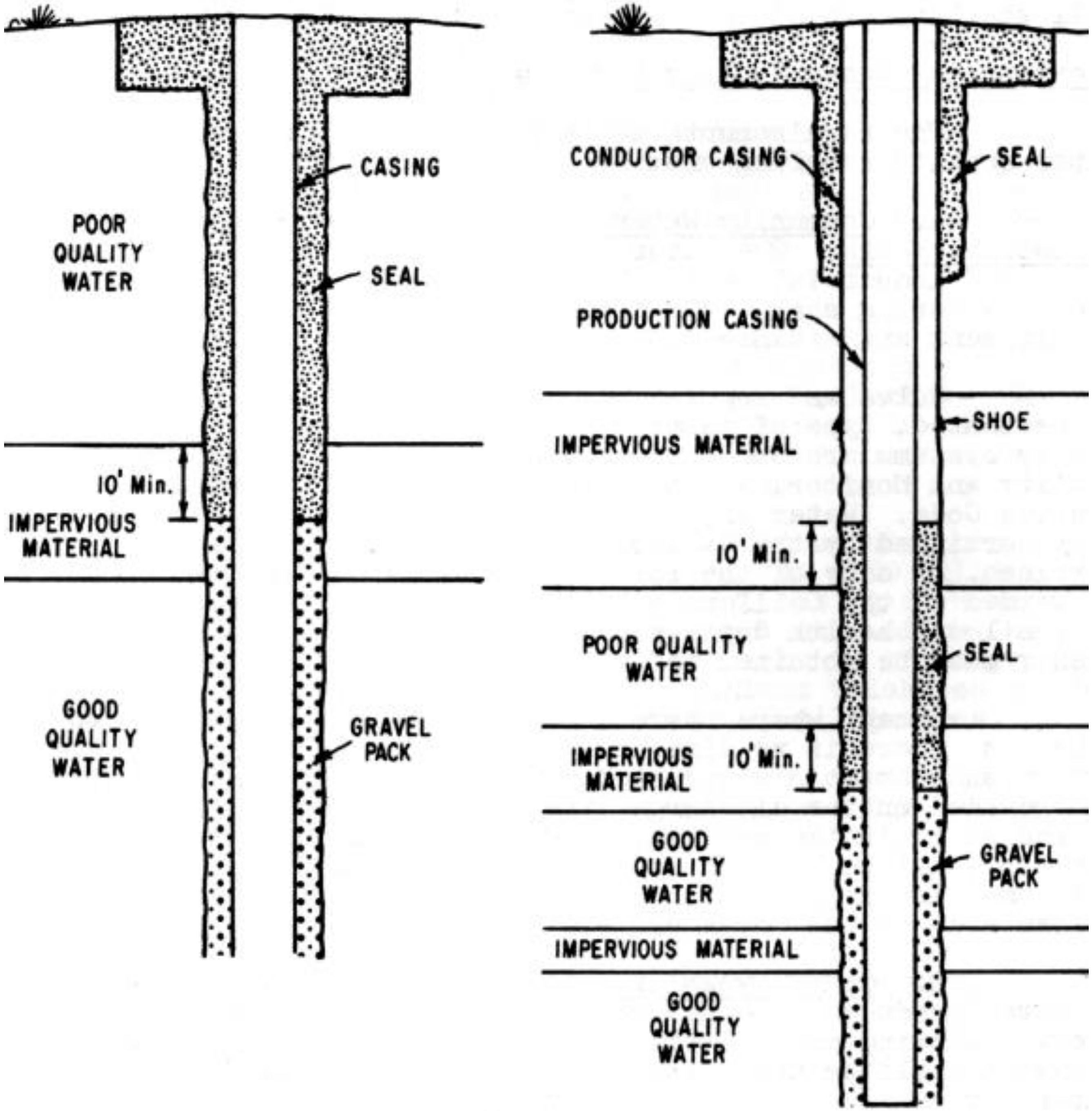
Gravel is sometimes placed outside the screen to support the aquifer materials (called ***formation stabilizer****) or to* increase near bore permeability and to assist in filtering aquifer materials (called ***artificial filter****). Regardless of function,* the common term for the practice is *gravel pack. The importance* of the selection of the size distribution of the gravel material is much greater when it is intended to serve as an artificial filter.

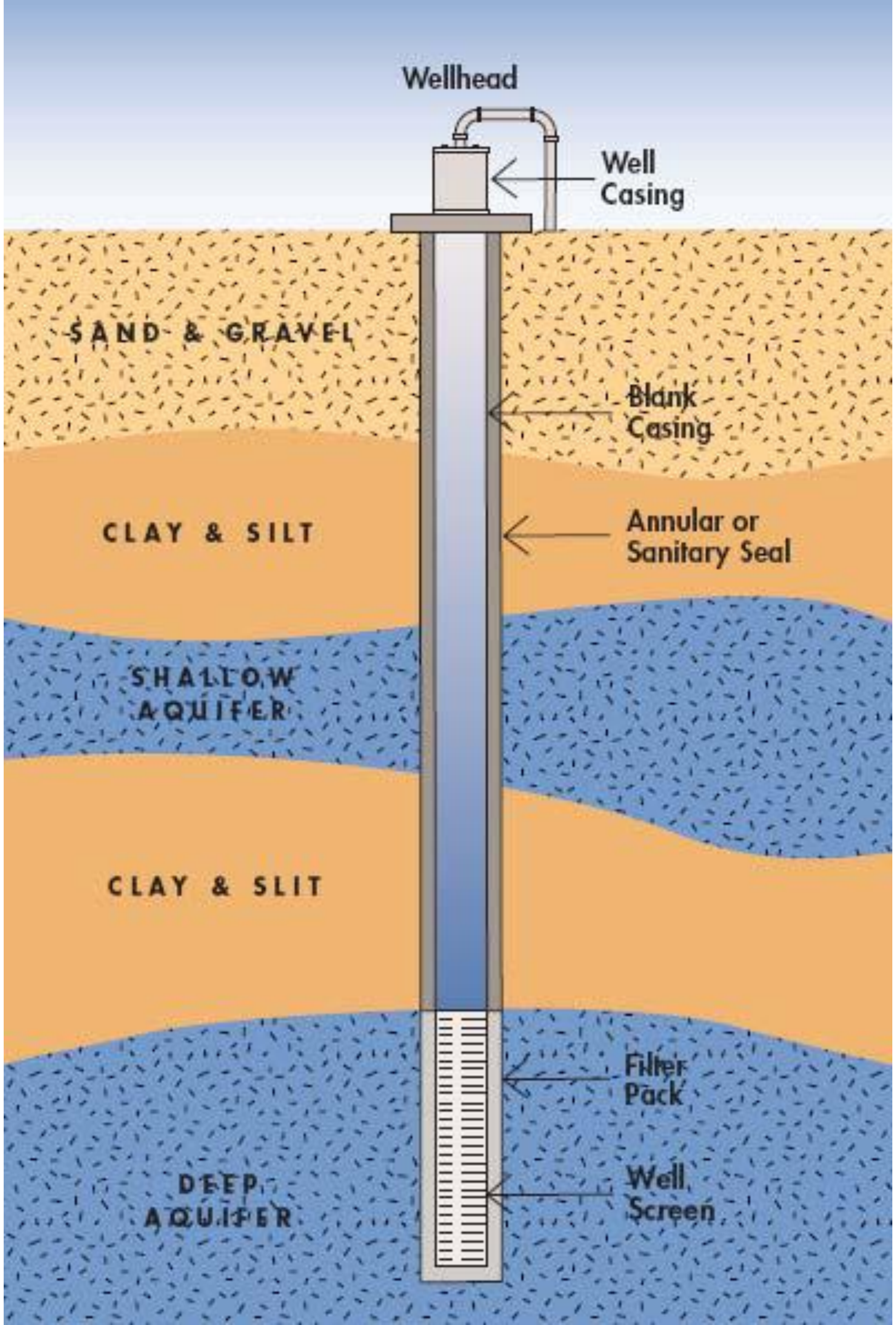
- For high yield wells a “**gravel pack**” is sometimes used to fill up the space between the well screen and the drilled hole.
- Placing the gravel in the well next to the screen can be a tricky business, but the **highly permeable gravel** can really help make the well efficient.
- Selecting the **size of gravel** to be used is yet another important well design decision.



- For wells where **freezing temperatures** occur, there has to be a way of **diverting water** from the well **to the home below ground**.
- To achieve this, a special adaptor is used that connects the vertical pipe coming from the well inside the casing to a horizontal pipe that takes water from the well to the home.
- This connection is usually made about six feet below ground surface by means of a "**pitless adaptor**".
- This device not only connects the well pipe to the house pipe, but also helps support the weight of the pump and pipes.
- The design of the adaptor fitting with an "O ring" seal, also allows the pump to be removed from the well for servicing or replacement.

Typical well seal profiles





Wellhead
Well Casing
SAND & GRAVEL
Blank Casing
CLAY & SILT
Annular or Sanitary Seal
SHALLOW AQUIFER
CLAY & SLIT
Filter Pack
DEEP AQUIFER
Well Screen

MATRIX NUMBER 1

General Hydrogeologic Conditions & Well Design Requirements

Unconsolidated; saturated; invasion of formation by drilling fluid permitted; casing diameter 2 inches or less; total well depth O to 15 feet.

DRILLING METHODS / CRITERIA FOR EVALUATION OF DRILLING METHODS	Versatility of Drilling Method	Sample Reliability	Relative Drilling Cost	Availability of Drilling Equipment	Relative Time Required for Well Installation and Development	Ability of Drilling Technology to Preserve Natural Conditions	Ability to Install Design Diameter of Well	Relative Ease of Well Completion and Development	TOTAL
Hand Auger	1	5	9	10	5	9	6	4	49
Driving	1	1	10	10	5	5	1	4	37
Jetting	2	1	8	10	5	1	1	1	29
Solid Flight Auger	3	4	7	9	10	4	5	2	44
Hollow Stem Auger	10	10	9	9	10	8	10	9	75
Mud Rotary	8	10	8	10	7	4	10	5	62
Air Rotary	NA	NA	NA	NA	NA	NA	NA	NA	NA
Air Rotary with Casing Hammer	7	5	6	4	6	9	10	10	57
Dual Wall Rotary	7	8	6	1	6	9	10	9	56
Cable Tool	9	10	5	7	4	10	10	10	65

EXPLANATORY NOTES:

1. Unconsolidated formations, predominantly saturated, with saturation exerting significant influence on the choice of drilling technology.
2. Borehole stability problems are potentially severe.
3. The anticipated use of the monitoring well permits the use of drilling fluid and additives in construction.
4. The shallow depth of up to 15 feet. and small completed well diameter of 2 inches or less allows maximum flexibility in equipment.
5. Samples collected in solid flight auger, hollow-stem auger, mud rotary and cable-tool holes are taken by standard split-spoon (ASTM D1586) or thin-wall sampling (ASTM D1587) techniques, at 5-foot intervals.

- A well is improperly designed if hydrogeologic conditions, water quality or well intake design are not compatible with the purpose and use of the well.

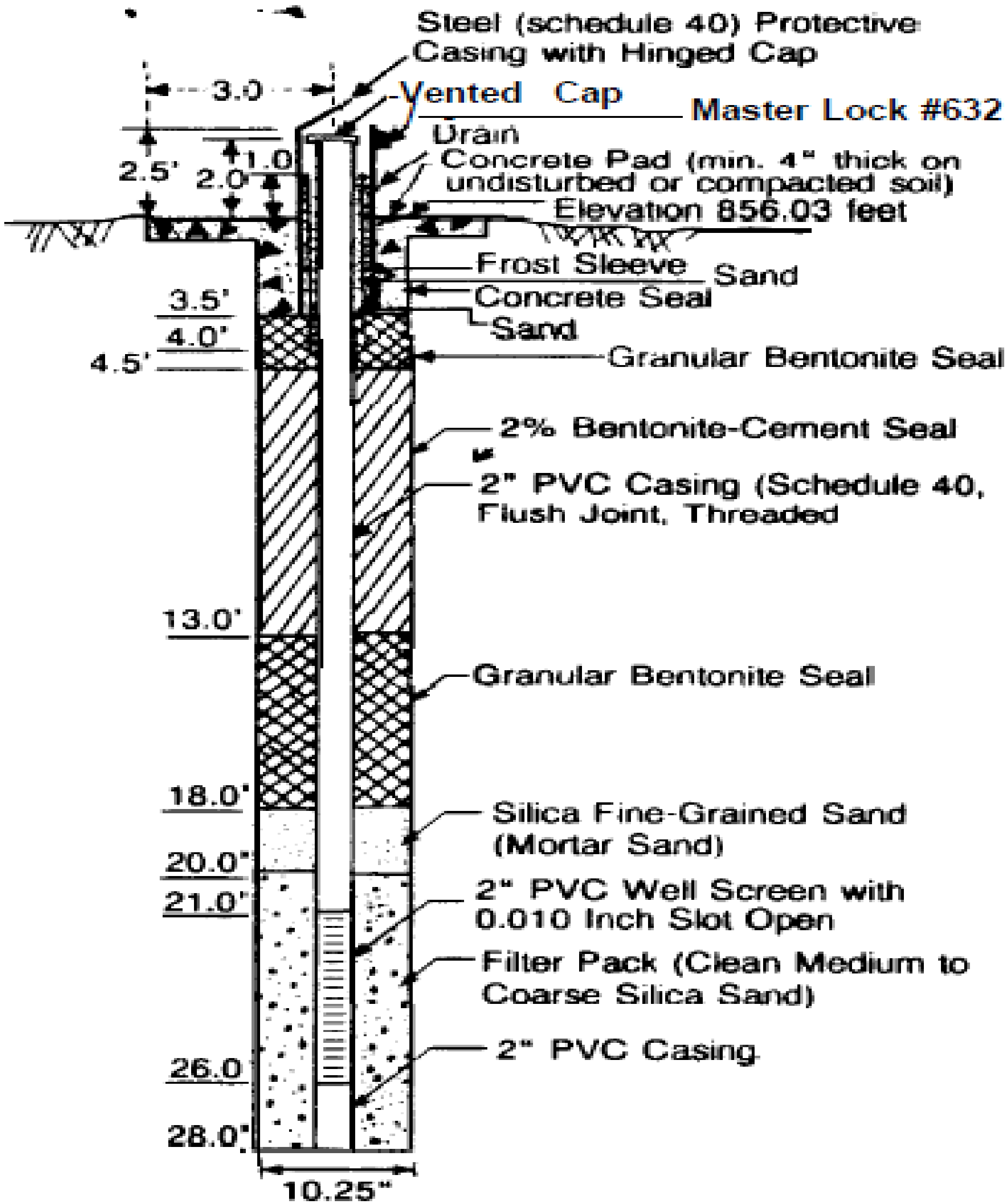
- For example, if water is withdrawn during the exploitation / sampling process and the well screen is plugged, the hydrostatic pressure on the outside of the casing may be great enough to cause **collapse of the well & intake** if the strength of the material was not sufficient for the application.

- This is particularly true if the well intake material was chemically incompatible with the ground water and was weakened due to chemical reactions.

- Another example is where the operational life of the well exceeds the design life.

- Poorly designed and underdeveloped wells also exhibit **greater water level drawdown** than do properly constructed wells, an effect referred to as ***poor well efficiency***.
- Poor well efficiency occurs when ground water cannot easily enter the well screen because of a lack of open area in the screen, a **clogged gravel pack**, **bacterial slime build-up**, or a borehole wall that is clogged from **incomplete removal of drilling mud deposits**.
- The result is a significant increase in pumping costs.
- Note that well efficiency should not be confused with pump efficiency.
- The latter is related to selection of a properly sized pump, given the site-specific pump lift requirements and the desired pumping rate.
- Once the well is completed and developed, it is a good practice to conduct an ***aquifer test*** *or* ***pump test***.

Well Number 7H
Start 8/13/87 8:00 a.m. -1:00 p.m.
Finish 8/14/87 10 a.m. -12:00 p.m.
Drilling Method Hollow Stem Auger



ESTIMATION OF AQUIFER CHARACTERISTICS & WELL PROTECTION / WELLHEAD PROTECTION

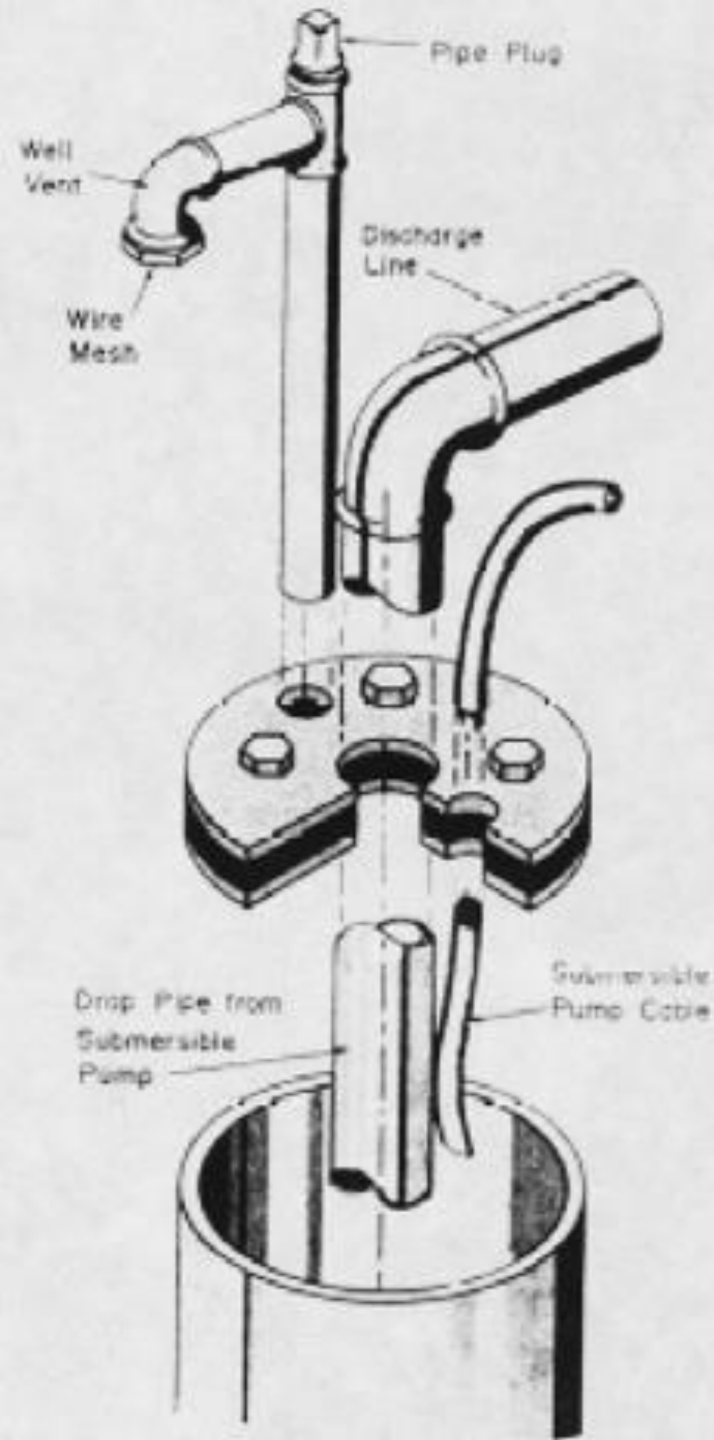
- *For an **aquifer test** or **pump test**, the well is pumped at a constant rate or* with stepwise increased rates, typically for 12 hours to 7 days, while the initial and the subsequent water levels after pumping in the well are checked and recorded frequently as they decline from their standing water level to their pumping water level.
- By incorporating the rates of recoupment of prior water level (before pumping) along with the horse power of the motor used to pump, inlet and outlet pipe diameters and the number of hours pumped, it is possible to estimate the aquifer characteristics data (T, K, S, SY).
- Aquifer tests are used to determine the efficiency and capacity of the well and to provide information about the permeability of the aquifer.
- The information about the pumping rate and resulting pumping water levels is also critical if you are to order a properly sized pump.
- Once the well development and aquifer test pumping equipment is removed, it may be useful to use a specialized video camera to check the inside of the well for damage, to verify construction details, and to make sure that all the screen perforations are open.

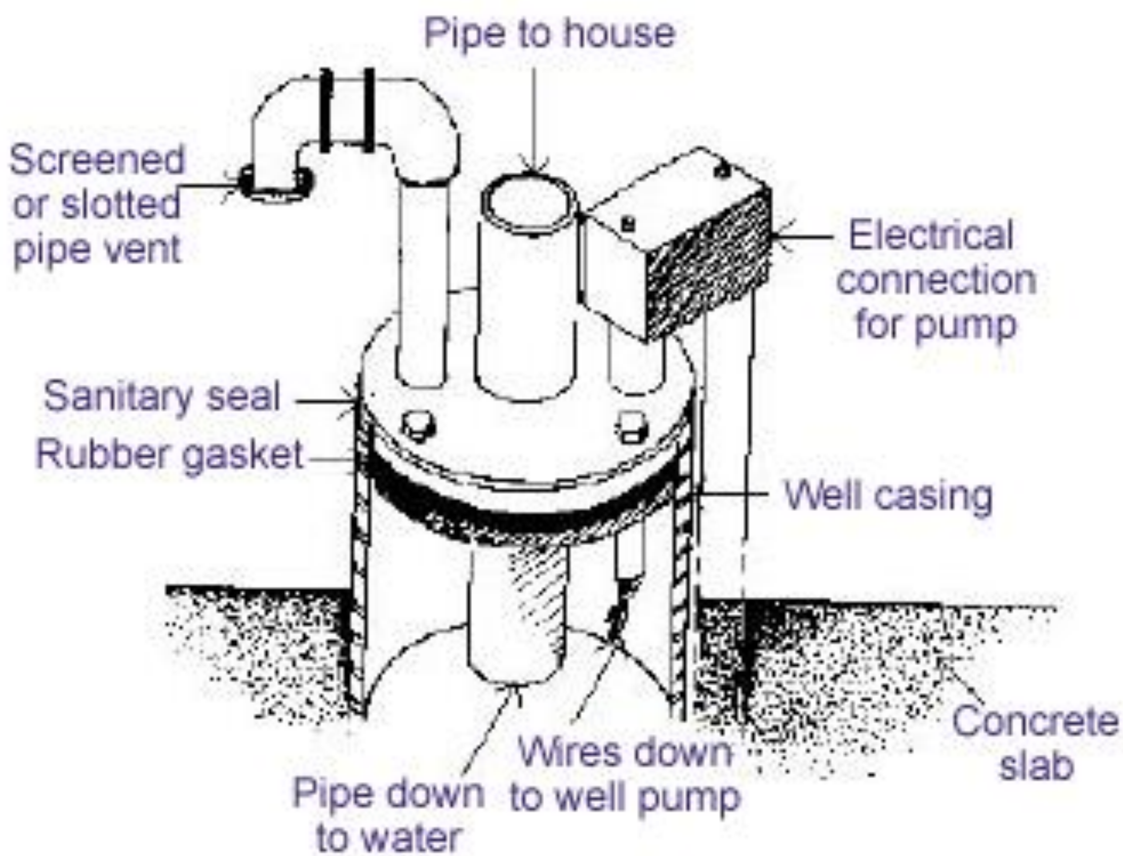
- The construction of the final **well seal** is intended to provide protection from leakage and to keep runoff from entering the wellhead

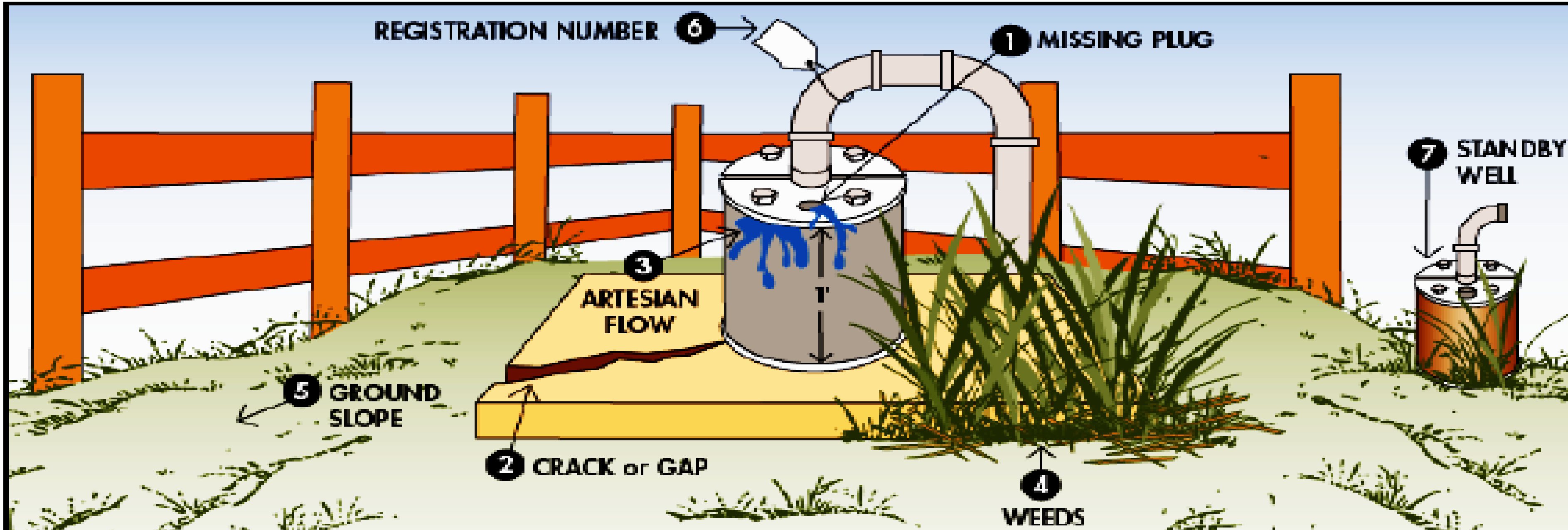
- It is also important to install backflow prevention devices, especially if the well water is mixed with chemicals such as fertilizer and pesticides near the well.

- A **backflow prevention device** is intended to keep contaminated water from flowing back from the distribution system into the well when the pump is shut off.

Properly completed well with elevated concrete seal (but with leaking lubricant).


Pipe Plug
Well Vent
Discharge Line
Wire Mesh
Drop Pipe from Submersible Pump
Submersible Pump Cable


Pipe to house
Screened or slotted pipe vent
Electrical connection for pump
Sanitary seal
Rubber gasket
Well casing
Concrete slab
Wires down to well pump
Pipe down to water



Guidelines for well inspection / maintenance

1. Look for openings that insects, rodents, water, or anything else can enter. Cap, seal, or otherwise plug them.
2. Look for cracks in the concrete pad that would allow water, and any contaminants it may be carrying, to follow the well casing down into your drinking water aquifer. Seal cracks, or re-pour a new concrete pad.
3. If water is flowing out the top of the well, call a licensed well contractor to stop the flow. In addition to being a waste of water, if water can leak out, contaminants can seep in.
4. Remove weeds, leaves, and other debris from around your well. These can create great homes for rodents and other pests. Remember, do not use herbicides or any other chemical near the well.
5. Make sure the ground slopes away from your well and that your well casing extends at least one foot above the ground to ensure that surface water does not collect or flow near the well.
6. Make sure your well registration number is still visible on your well. This is a local legal requirement. Call the District if you need a new, free registration tag at 408-256-2607, extension 2660
7. If you have an inactive well, turn the pump on several times during the year to make sure that everything is functioning properly. Inspect and maintain your inactive well following the same guidelines as for your active well. If you never plan to use the well again, you are legally required to properly destroy it. Properly destroying the well will prevent it from being an accidental pathway of contamination into your active well, your neighbor's well, or the groundwater. *(NOTE: All inactive wells are required to be permitted as "standby wells" by the District.)*

Figure 15: Guidelines for well inspection[48] (Santa Clara p. 5)

Well Development

- ‘Well development’ is an important procedure to maximize the yield of the well and optimize the filtering capacity of the gravel pack by removing fines and drilling fluid additives from the well and the surrounding aquifer and settlement of the gravel pack.

- The **main factors** affecting well development are based on the geologic material.
- The **procedure** for well development includes:
    - Installation of well intakes at the prescribed settings
    - Ensure uniform distribution and maintenance of proper height of filter pack above the well intakes
    - Placement of Bentonite seals in the intended locations &
    - Emplacement of a secure surface seal for the well.

WELL DEVELOPMENT

- After the well screen, well casing, and gravel pack have been installed, the well is *developed to clean the borehole and casing of drilling fluid and to properly settle the* gravel pack around the well screen.
- A typical method for well development is to **surge** or **jet water** or **air in and out of the well screen openings**.
- This procedure may take several days or perhaps longer, depending on the size and depth of the well.
- A properly developed gravel pack keeps fine sediments out of the well and provides a clean and unrestricted flow path for ground water.
- Proper well design and good well development will result in lower pumping costs, a longer pump life, and fewer biological problems such as iron-bacteria and slime build-up.
- Poorly designed and underdeveloped wells are subject to more frequent pump failures because sand and fines enter the well and cause significantly more wear and tear on pump turbines.

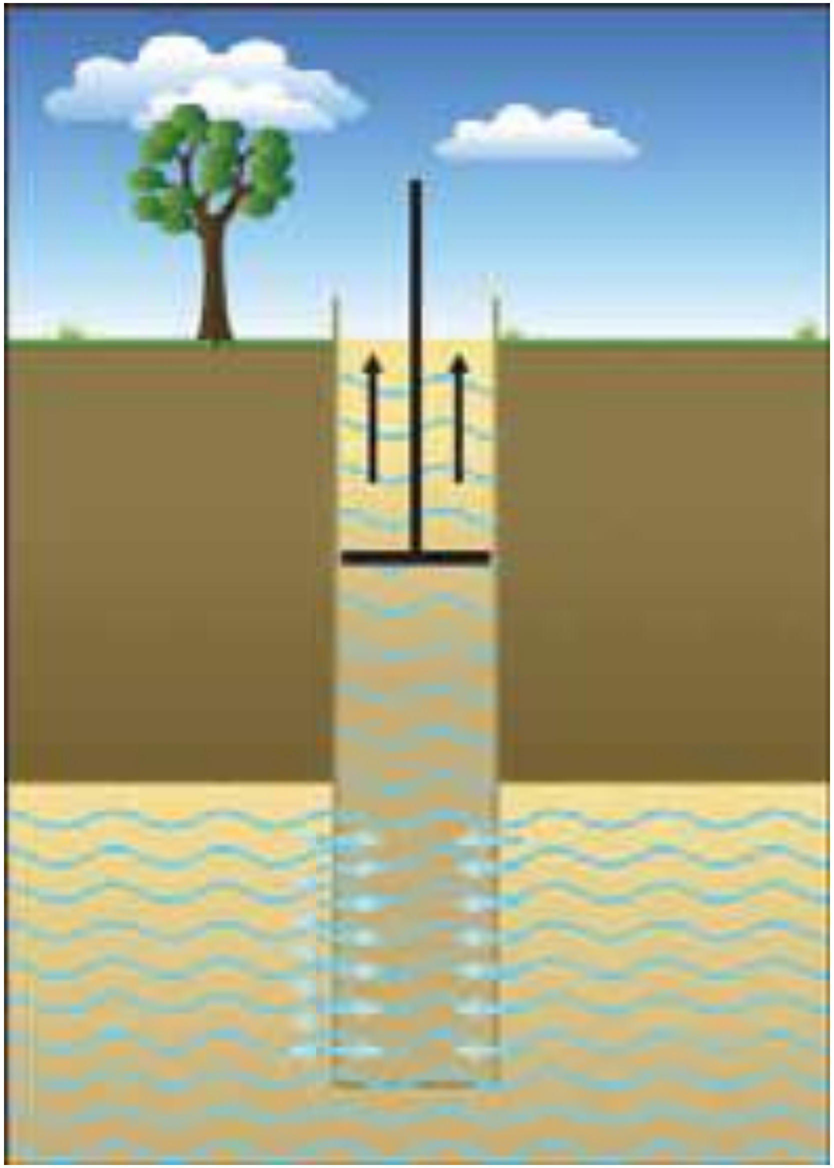
- *For an **aquifer test / Pump Test**, the well is pumped at a constant rate or* with stepwise increased rates, typically for 12 hours to 7 days, while the water levels in the well are checked and recorded frequently as they decline from their standing water level to their pumping water level.
- Aquifer tests are used to determine the efficiency and capacity of the well and to provide information about the permeability of the aquifer, i.e., **Transmissivity (T), Permeability (K) , Storage co-efficient (S) & Specific yield / safe yield (SY)** together called as **Aquifer characteristics**.
- The information about the pumping rate and resulting pumping water levels is also critical to order a properly sized pump.
- Once the well development and aquifer test pumping equipment is removed, it may be useful to use a specialized video camera to check the inside of the well for damage, to verify construction details, and to make sure that all the screen perforations are open.

- Poorly designed and underdeveloped wells also exhibit greater water level drawdown than do properly constructed wells, an effect referred to as ***poor well efficiency***.
- Poor well efficiency occurs when ground water cannot easily enter the well screen because of a lack of open area in the screen, a clogged gravel pack, bacterial slime build-up, or a borehole wall that is clogged from incomplete removal of drilling mud deposits.
- The result is a significant increase in pumping costs.
- Note that well efficiency should not be confused with pump efficiency.
- The latter is related to **selection of a properly sized pump**, given the **site-specific pump lift requirements** and the **desired pumping rate**.

- Proper **design**, **construction, development**, and **completion of the well** will result in a **long life for the well** (as long as half a century or more) and **efficient well operation**.

Methods of well development

1. Surging with a surge Mock / surge block / plunger
2. Bailing
3. Pumping: - discontinuous pumping, - over pumping and - backwashing through the pump till water becomes clearer
4. Airlift pumping and
5. Air surging and jetting.



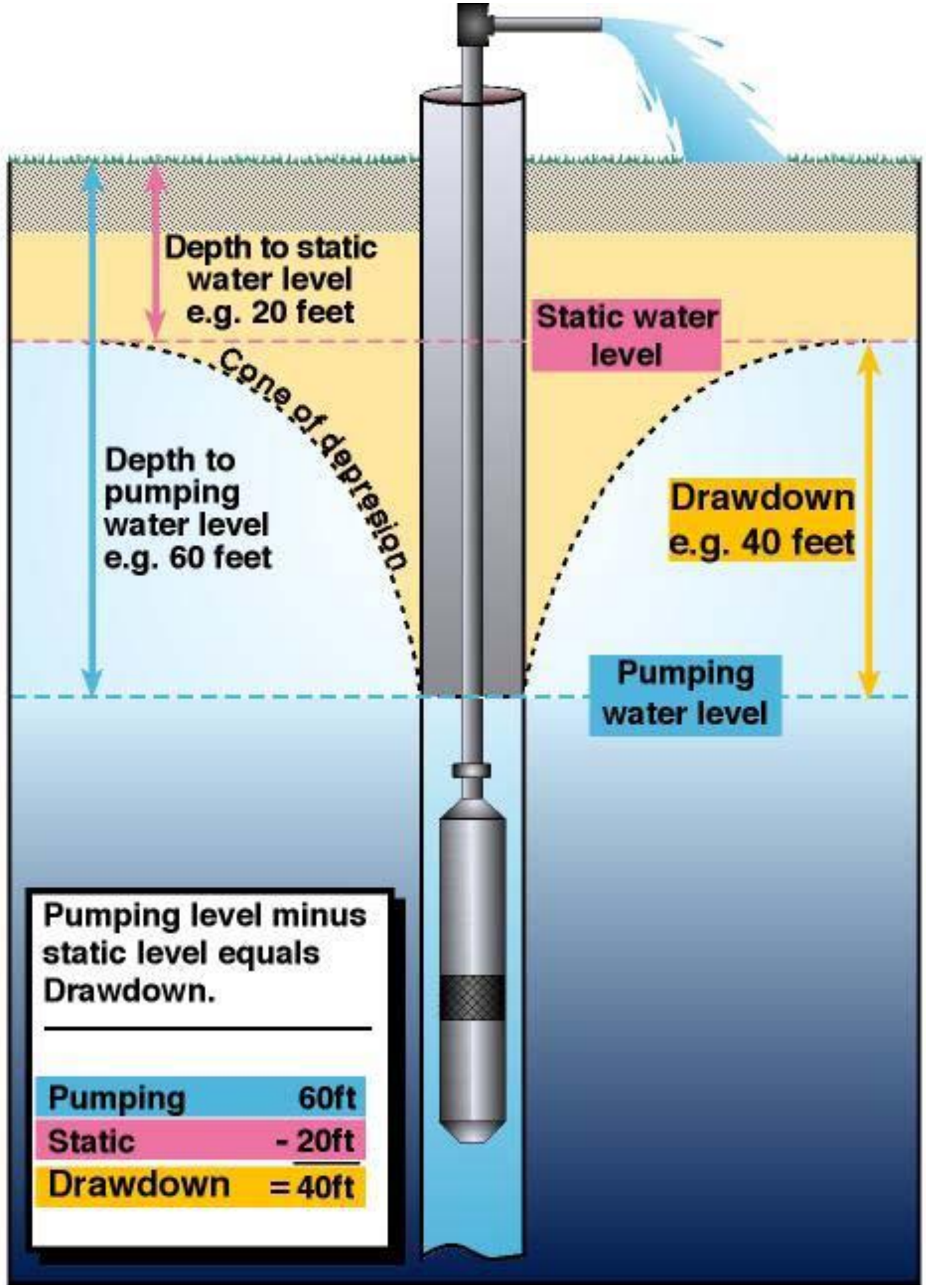
Surging with a **surge Mock / surge block / plunger**

- ✓ A surge block consists of a set of wooden discs with rubber valves or alternatively a flexible flat seal (for example, made of a thick rubber sheet).
- ✓ A surge block closely fits in the PVC casing and is operated as a plunger. It is brought *beneath the water level in the well.*
- ✓ *Then, by moving the surge block up and down, water* is forced into and out of the aquifer (shock waves), washing the aquifer and gravel pack, and mobilizing the fines which they contain.

Motorized centrifugal pump

Well development by hand

Re-development by airlifting



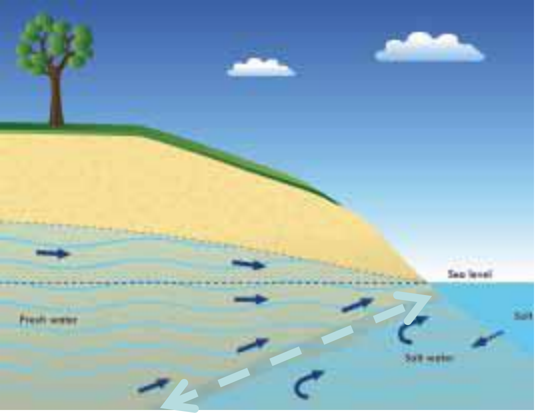
Depth to static water level e.g. 20 feet
Static water level
Cone of depression
Depth to pumping water level e.g. 60 feet
Drawdown e.g. 40 feet
Pumping water level
Pumping level minus static level equals Drawdown.
Pumping 60ft
Static - 20ft
Drawdown = 40ft

Theory of Up-coning

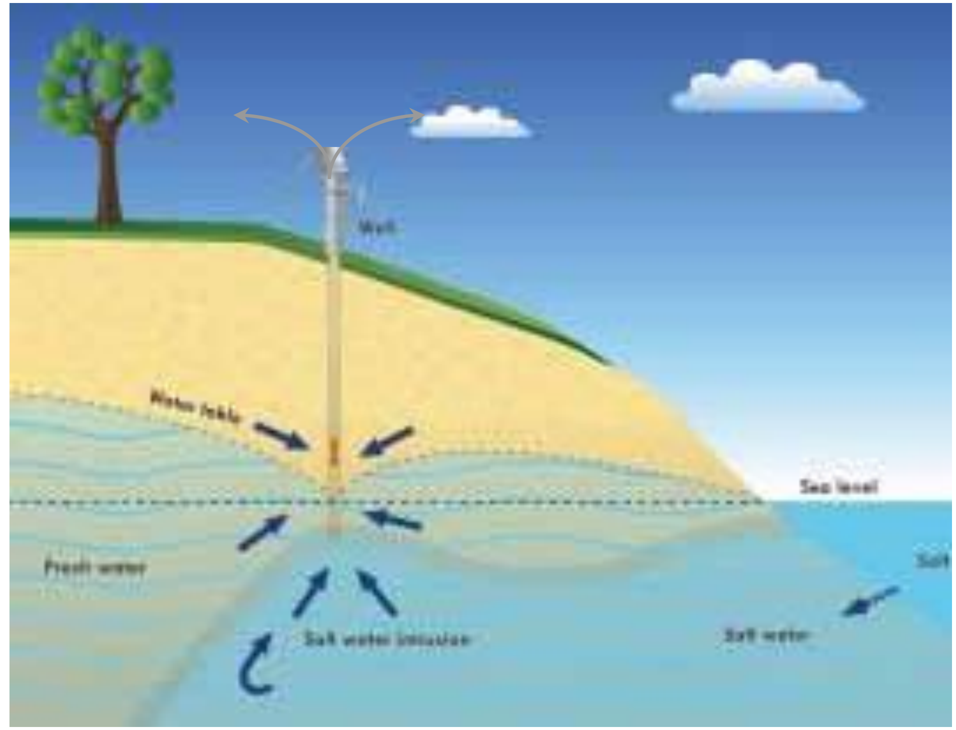
- In **coastal aquifers**, where the fresh water lies above saline water, and is pumped by a well, the interface rises below the well due to drawdown of the groundwater table around the well.

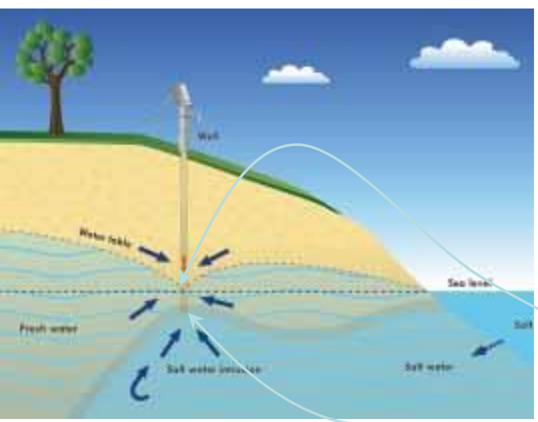
- The pressure on the interface is reduced and saline water rises as a conical mound beneath the well.

- This phenomenon is known as up-coning. If the top of the conical mound reaches the well, saline water will begin to mix with fresh water, and degrade the quality of the well water [Fig.1].



Fresh water on top of salt water



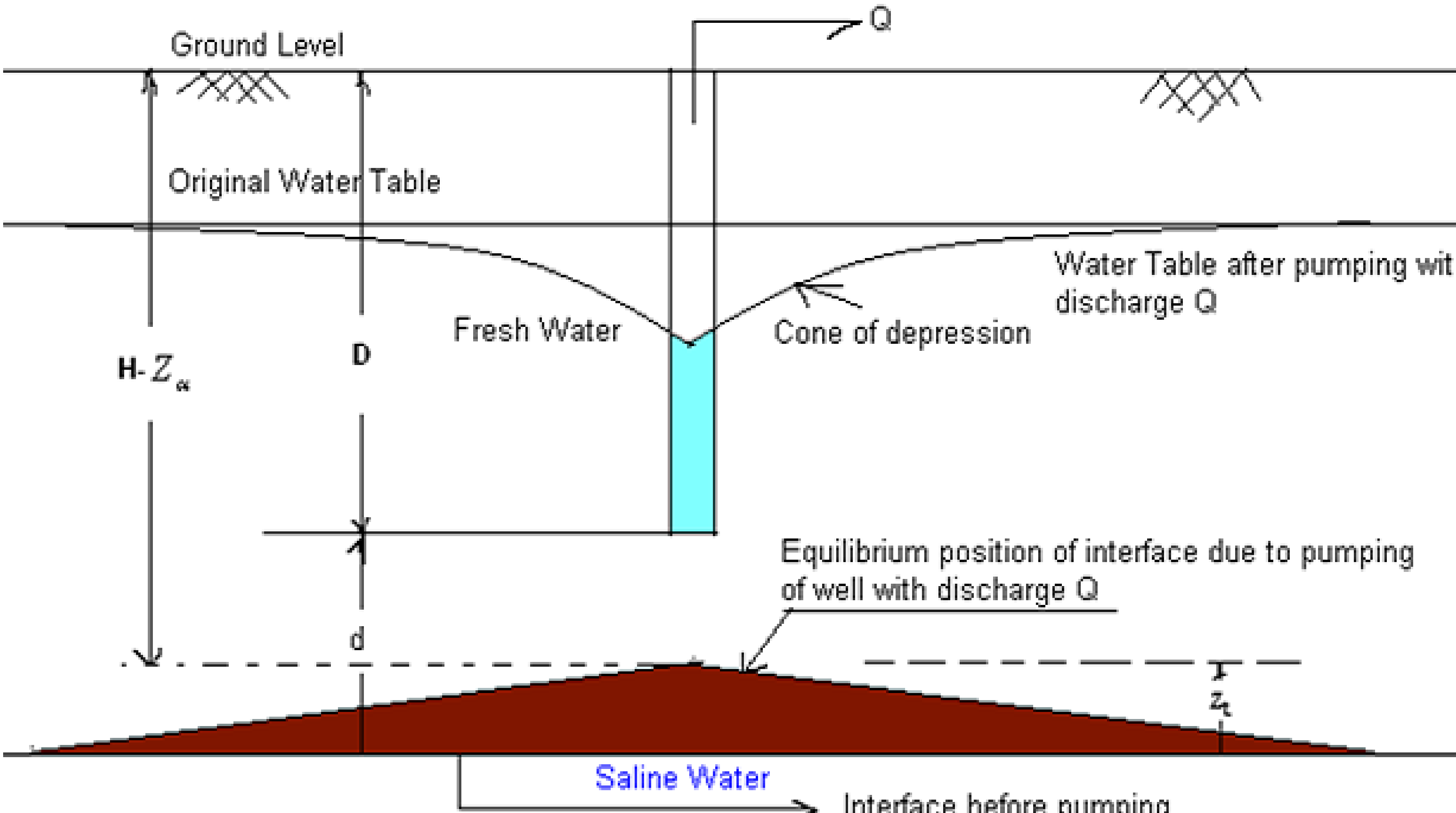


Salt water intrusion

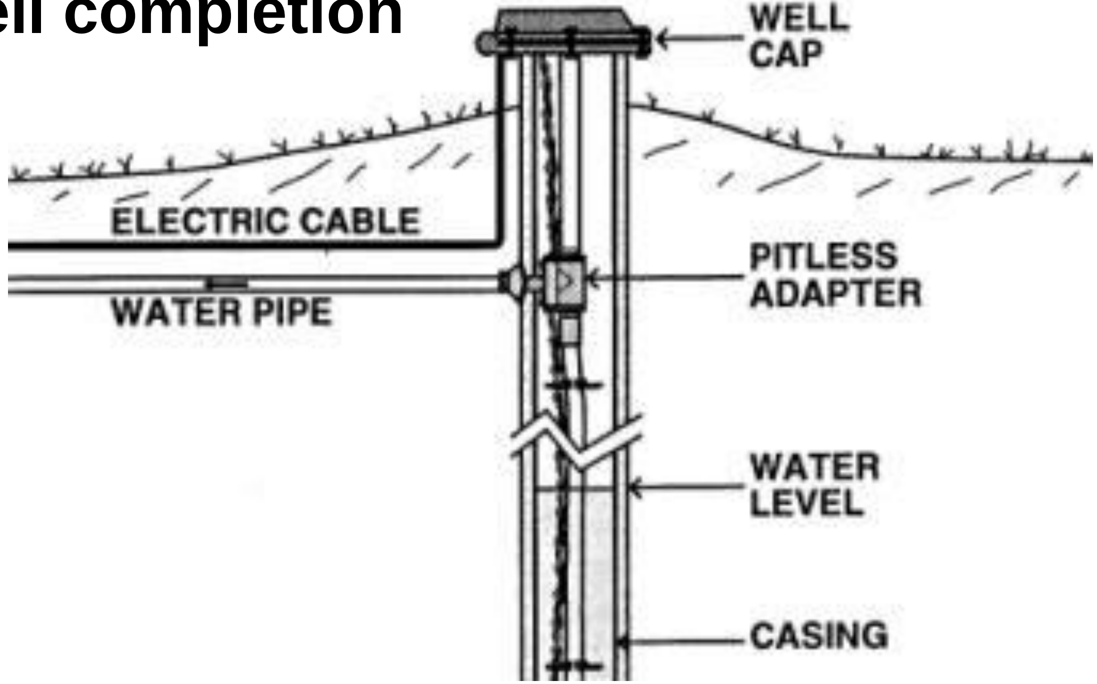
On depressing the water table because of over exploitation / uncontrolled groundwater pumping –a **Cone of Depression** of water table above and **Up-coning of saline water** below are resulted.

Due to this, the thickness of groundwater becomes thinner and the water level goes down to the Mean Sea Level and it leads to a decrease in the pressure of water table surface and increase in pressure by the **saline water interface**. Thus, leads to **Salt / sea water intrusion** in to the potential groundwater and permanent damage to the aquifers.

Figure 1: Up-coning of saline water beneath a pumped well

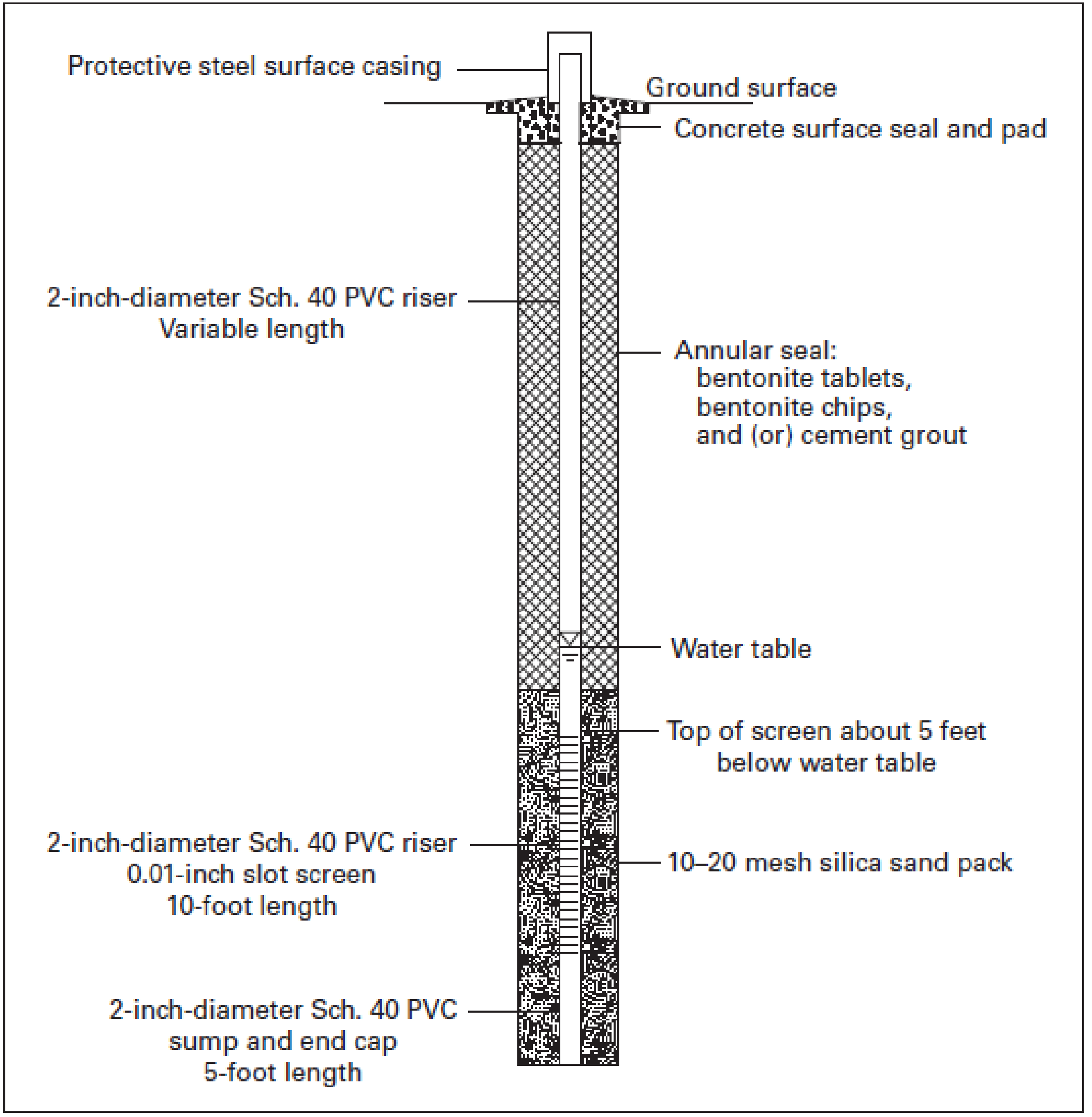


Well completion



- All wells should have a secure cap to prevent insects or debris from entering the well.
- However, the well cap should not have a perfect airtight seal.
- There must be an air vent so that when the water level drops because of pumping, the space created by the falling water level can be replaced by air.
- If a well is constructed in an area prone to flooding the casing should be extended up to above the likely flood level.

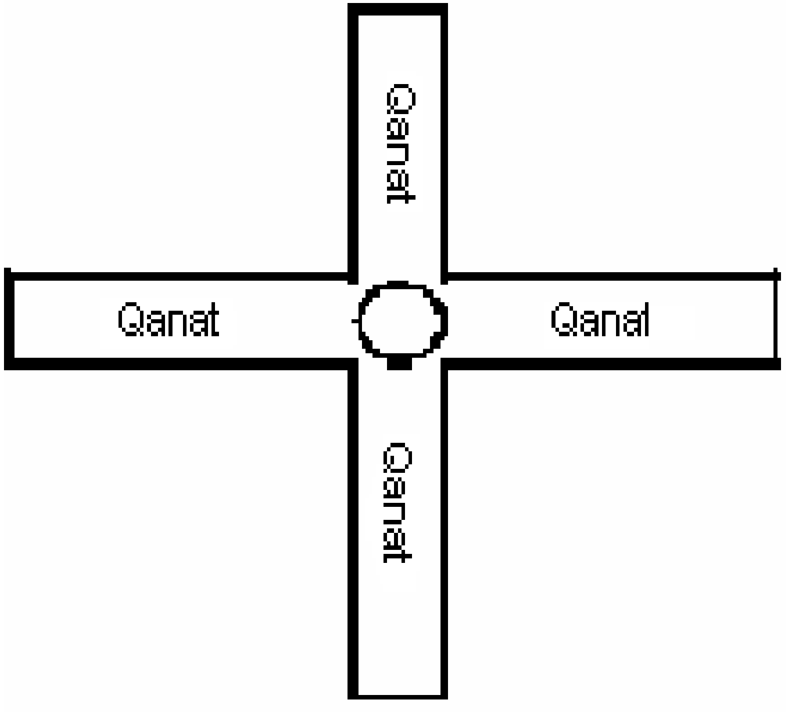
Schematic diagram of groundwater monitoring in High Plains – well completions.



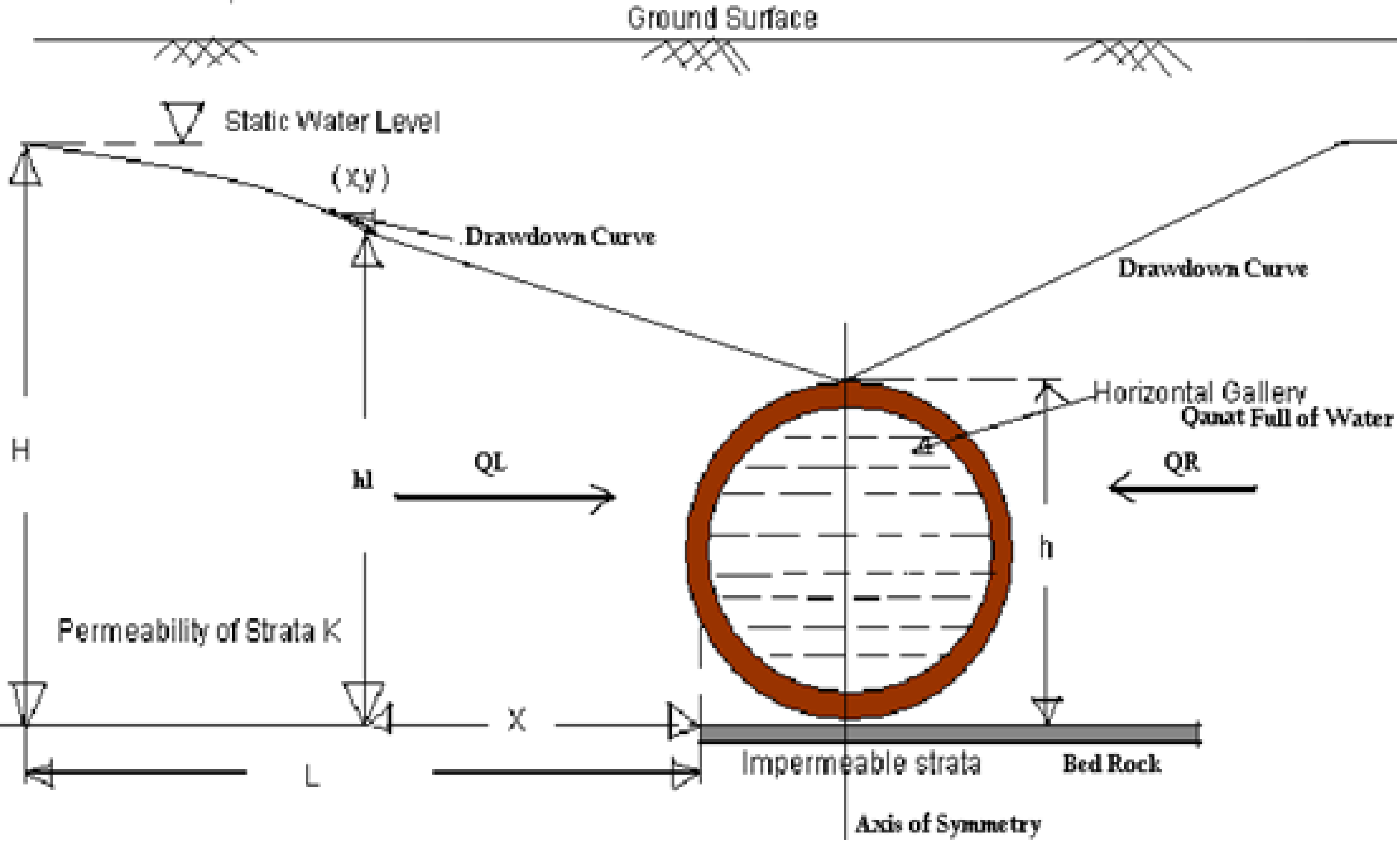
HORIZONTAL WELL – QANAT'S DESIGN

- Horizontal wells are commonly used in *bank filtration, where surface water is* extracted via recharge through river bed sediments into horizontal wells located underneath or next to a stream.
- The oldest known wells, *Qanats, are hand-dug horizontal* shafts extending into the mountains of the old Persian empire in present-day Iran.
- In coastal arid regions, deep tube wells are not preferable because of possibility of upconing of saline water.
- Shallow tube wells or deep tube wells with low discharge may be used, but the discharge being low may not suffice to meet projected needs.
- In this context, horizontal infiltration galleries called qanats coupled with vertical risers can be constructed in the fresh water zone to avoid problems with up-coning.

- The qanats may be pipes of permeable material of 0.5 to 1.5m diameter, set at a depth of 1 to 5m with gravel packing and wire nets at close intervals so that water can seep with low velocities into the gallery.
- This water can be pumped out and utilized while effectively preserving the quality of groundwater.
- The number of qanats is variable; four qanats have been used in the present design.



Plan of horizontal *qanats and vertical riser*



Discharge through horizontal *qanat with flow of water coming from both* directions

- *Drilling System Description: Directional drilling methods use specialized bits coupled with electronic* transmitters in the drillhead to locate and steer as the borehole is advanced.
- Components required for directional drilling include a drilling rig, a mud system, drill bits, reaming bits, and a guidance system.
- Depending on the equipment used, bent sub assemblies and sophisticated surface locating equipment may be used.
- Directional drilling rigs typically consist of a carriage that slides on a frame and holds the drill rods at an angle of 0 to 45 degrees as shown in Figure 2.
- Drilling rigs are available in a wide range of sizes and are rated on their pullback capacity.
- Rigs range from less than 5,000 to over 1,000,000 pounds of pullback force. Small and mid-size rigs typically are used for environmental applications.

Basic Principles and Description of Major Elements: Wells can be designed as either continuous (surface to surface) or blind (surface to end of horizontal section). Figure 3 illustrates the two types.

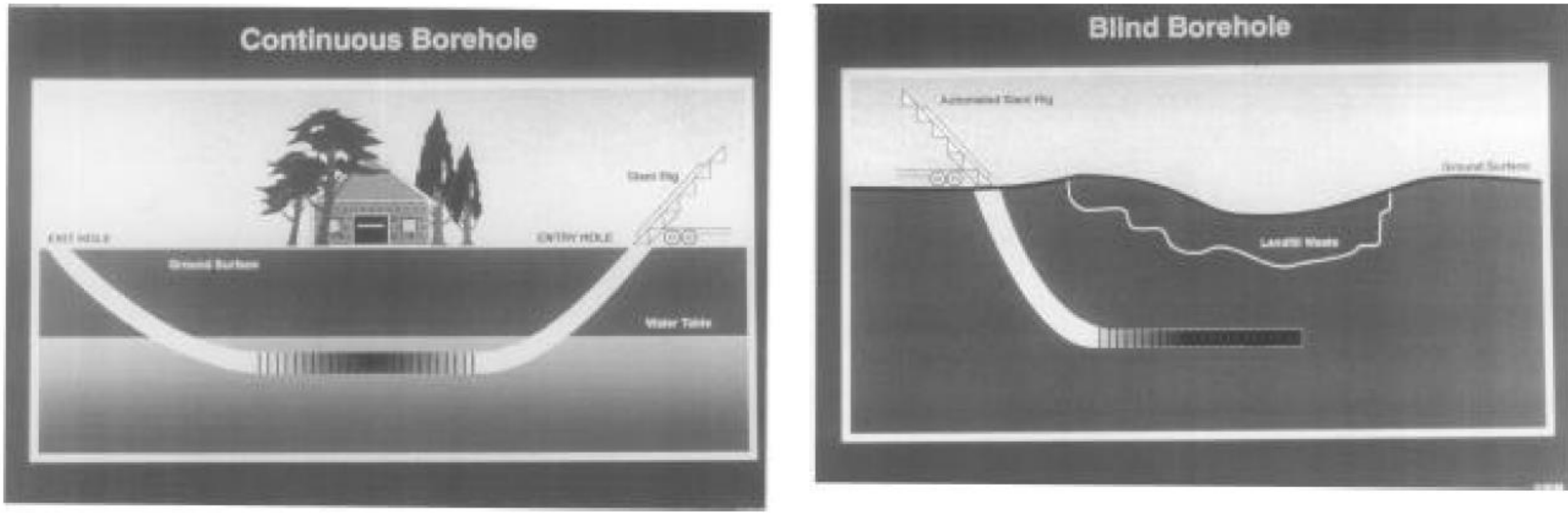
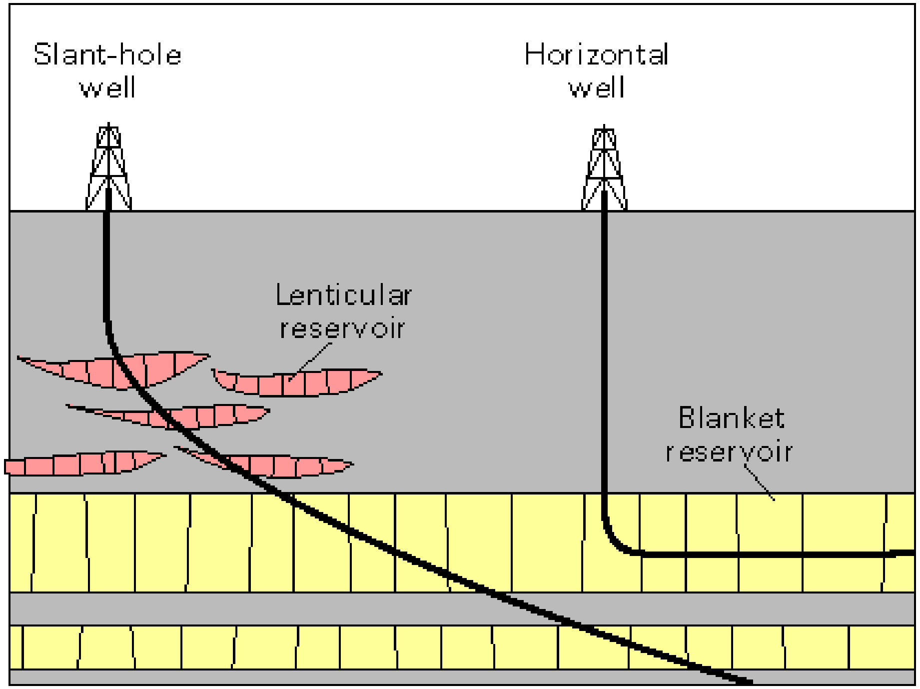


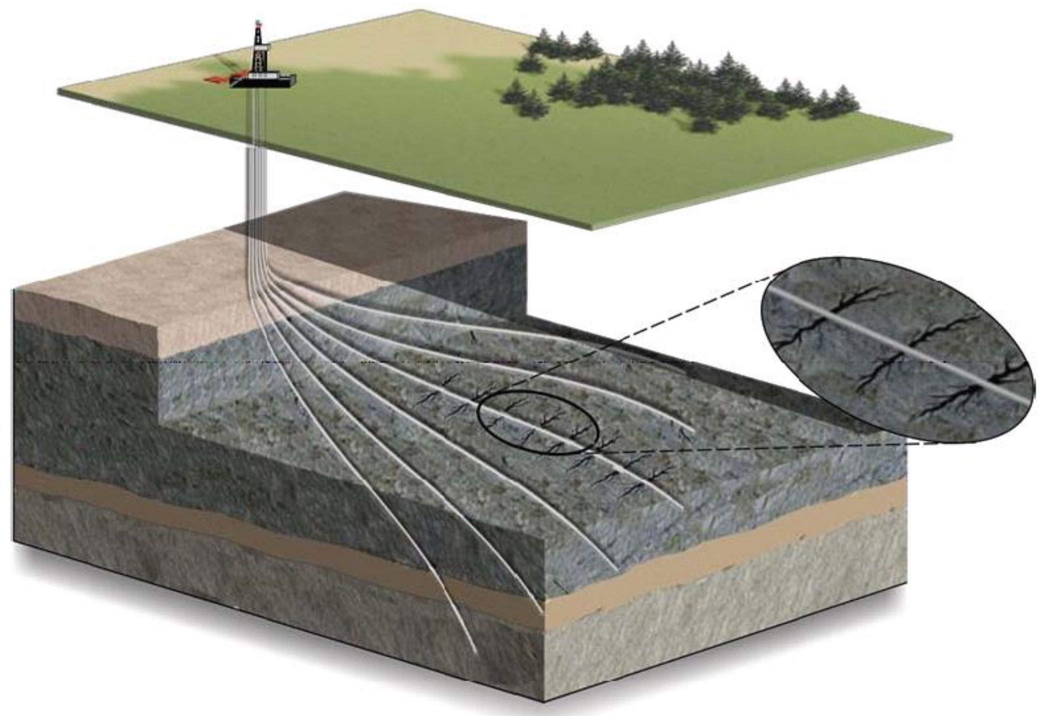
Figure 3. Horizontal environmental well types.

Horizontal environmental wells are designed to enhance access to soil and ground-water contamination and to increase the remediation efficiency compared to the baseline technology (vertical wells) by vastly increasing the per-well zone of influence.

Another class of horizontal wells

- The drilling of a horizontal well begins vertically or directionally at the ground surface and then
- proceeds horizontally to a depth and length depending on desired installation parameters.
- Careful monitoring and steering of drilling direction/progress is required with horizontal installations, and
- this is accomplished using various types of downhole sensing equipment (electronic transmitters/ receivers, wirelines).
- Two general types of horizontal wells have been applied to remediation activities, **trenched** and **directionally-drilled**.
- The drilling of **trenched horizontal wells** involves the excavation of a relatively large diameter borehole, with simultaneous installation of well materials and backfill.
- **Directional drilling of a horizontal well** produces a smaller diameter borehole and is more similar to vertical well installation in that well materials are installed following the completion of drilling activities.


Slant-hole
well
Horizontal
well
Lenticular
reservoir
Blanket
reservoir



Well Rehabilitation
or
Re-development of Wells

- After a well has been in use for several years and the yield decreases (becomes less), re-development of the well can be considered. Re-developing a well is easily performed using the same procedure as described above: by ***surge block*** *and* ***discontinuous pumping****.*

Well Rehabilitation / Redevelopment …contd…

The Factors affecting well performance are:

1. **Aquifer properties**, such as
   a) Subsurface heterogeneity
   b) Presence of low-permeability units or
   c) Closed / tight / water barren fractures
2. **Contaminant properties**, such as
   a) Level of sorption to soil due to a separate non-aqueous phase &
   b) Partitioning to a separate non-aqueous phase
3. **Adequacy of removal of plume** from source and the **size** of the plume itself
4. **System design**, such as
   a) Location of extraction wells and
   b) Depth/length of screen interval.

Objective of Well rehabilitation is:

- To reclaim existing wells (may be old) than simply abandoning them.

The **Methods** are:

- (1) Over pumping
- (2) Backwashing or hydraulic surging
- (3) Mechanical Surging
- (4) Air Lift Surging
- (5) Hydraulic Jetting &
- (6) Ultrasound.

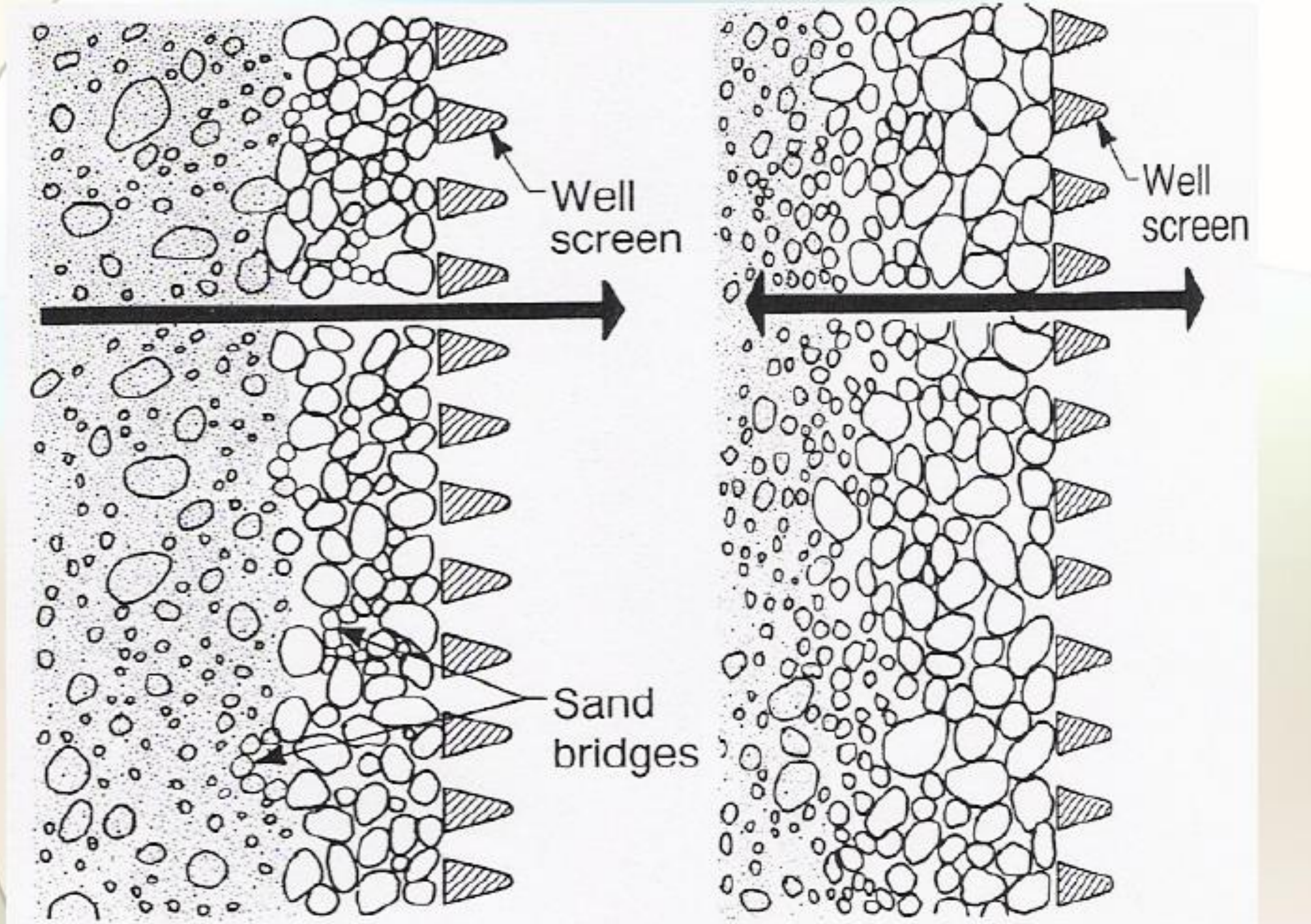
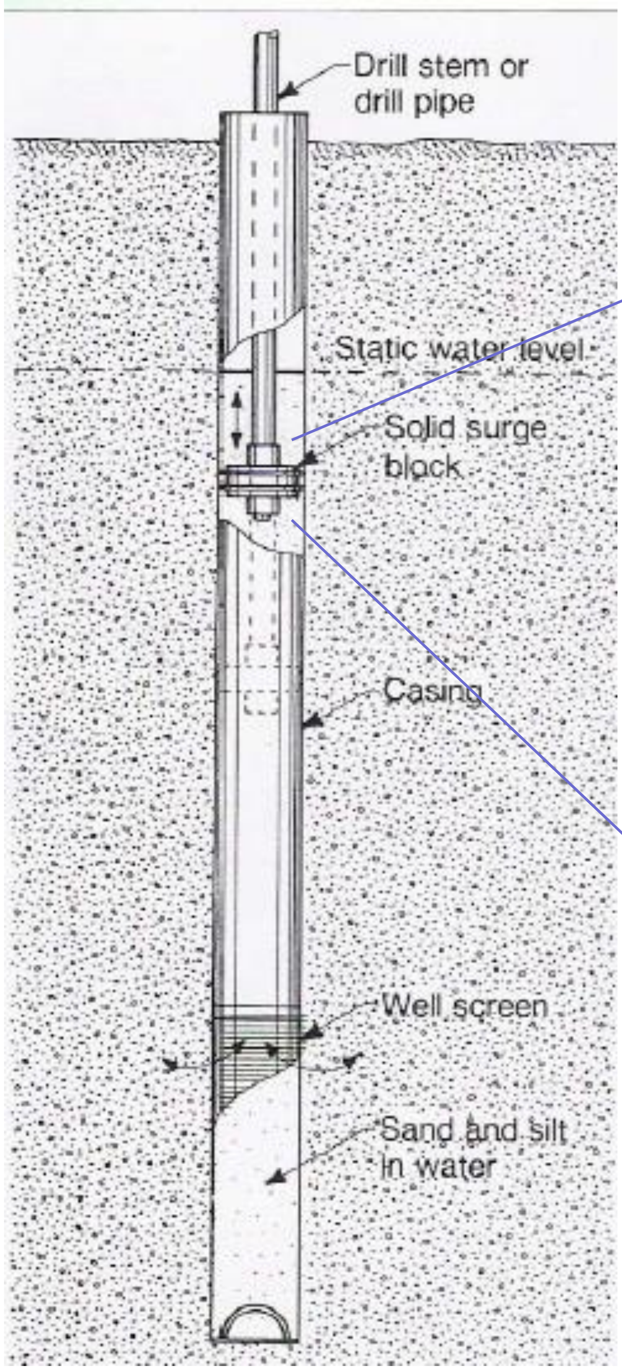
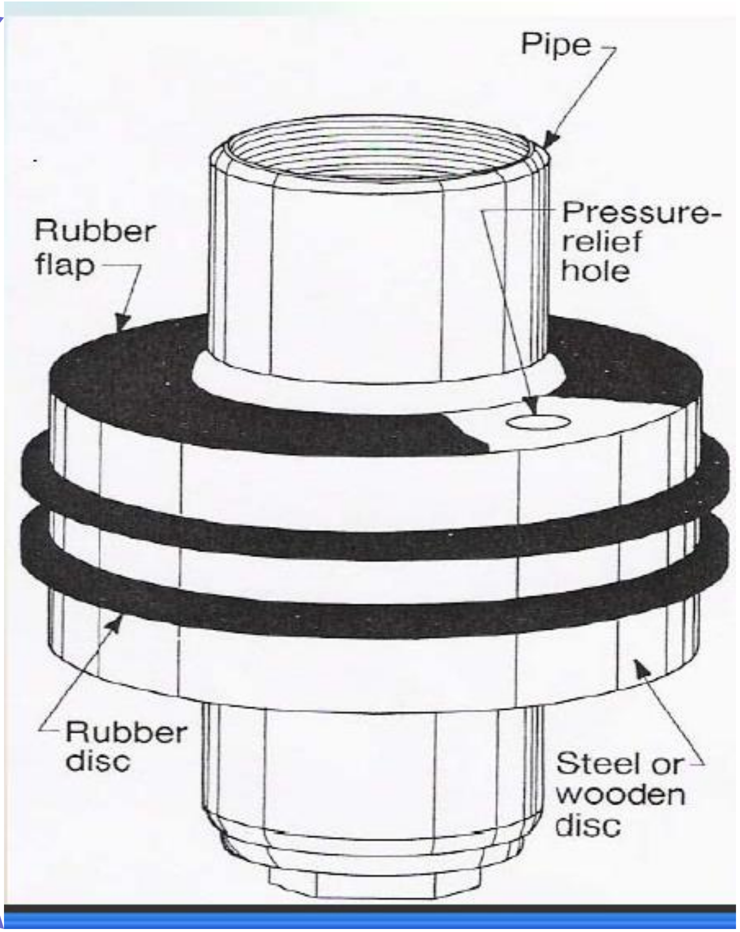
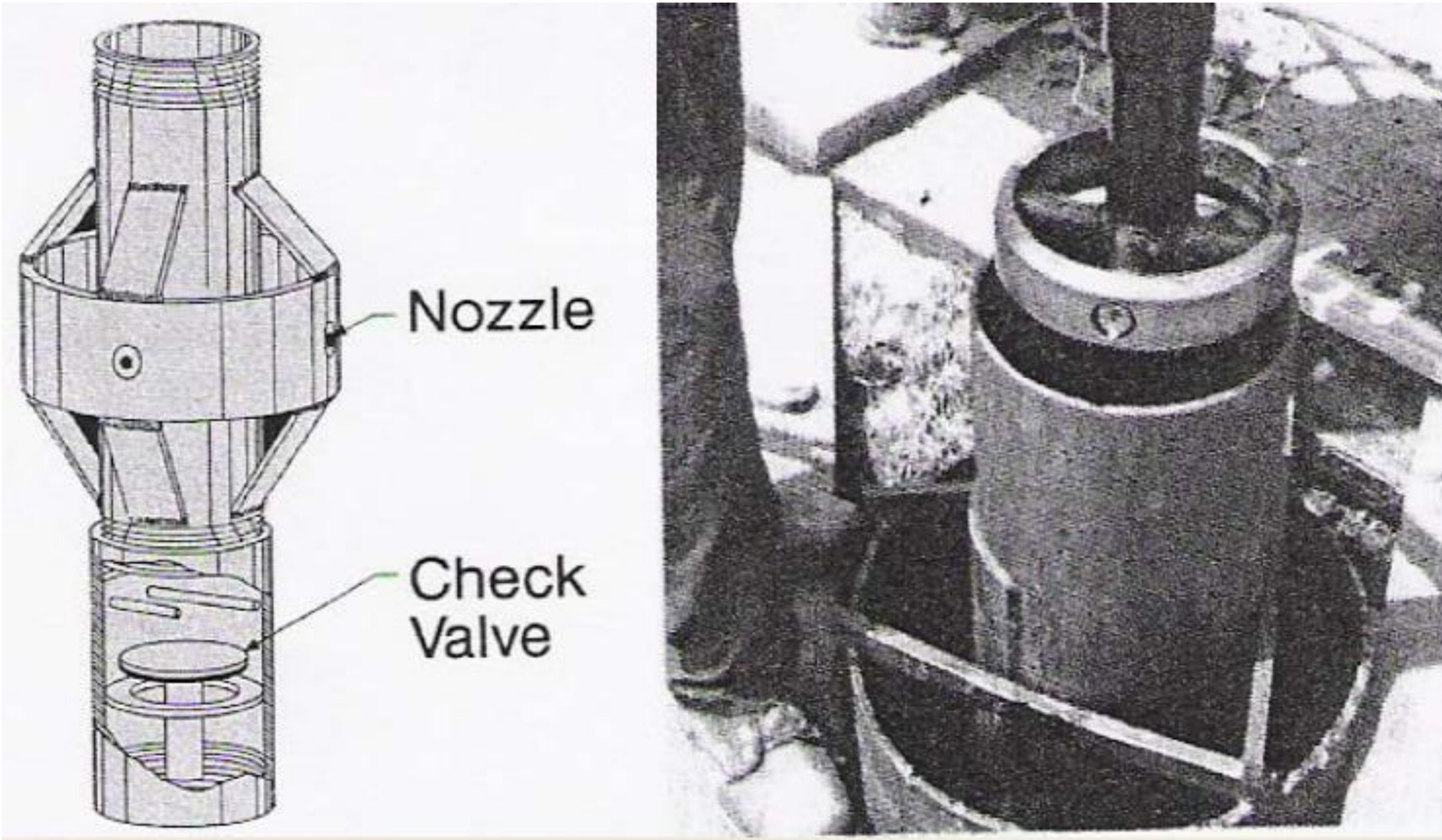


Figure 7: Back washing effect on breaking down bridge of particles.

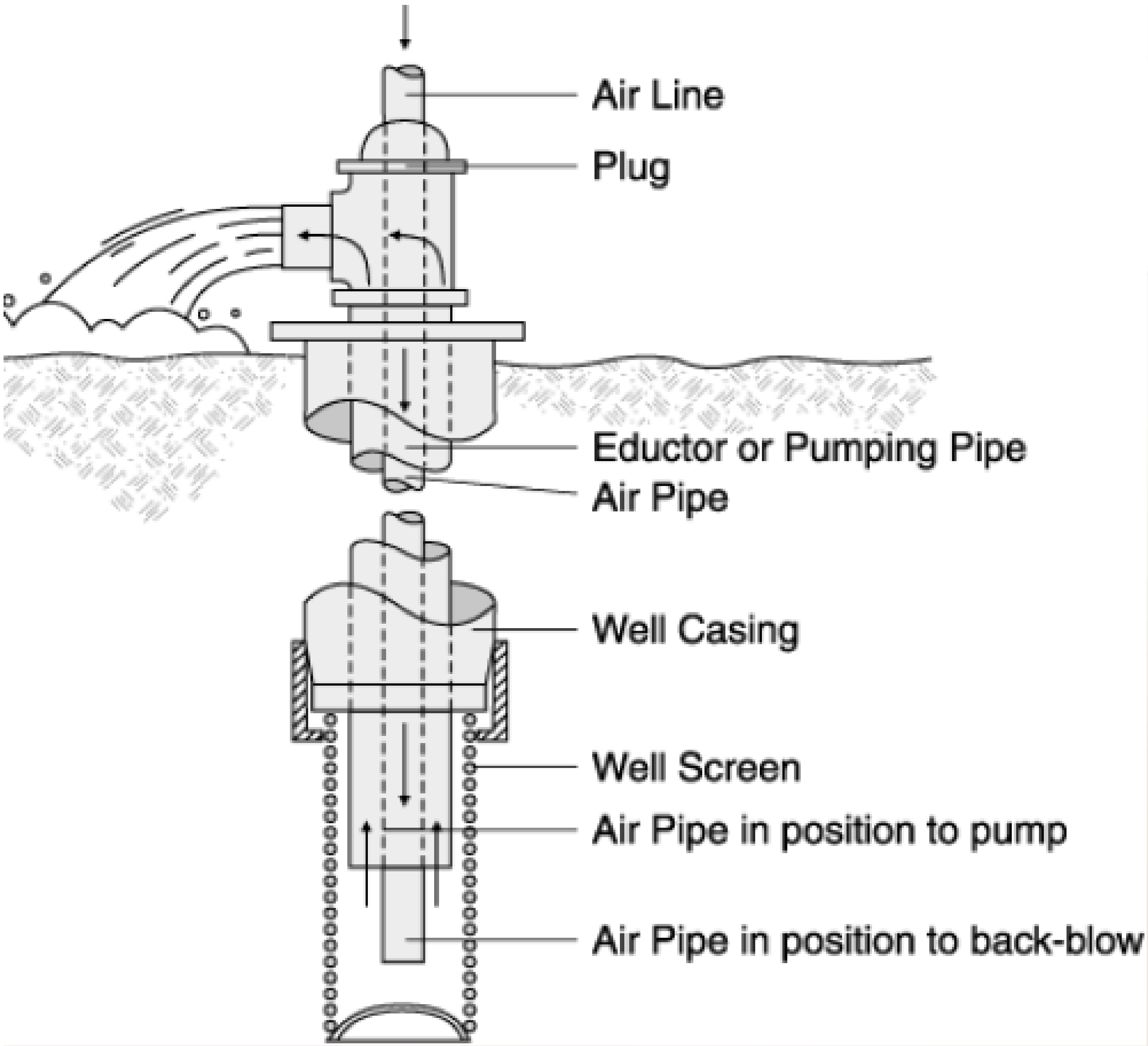




Mechanical surging by using solid surge block



ıre 15: Four-nozzle jetting tool designed for jet development of well screens.



Well redevelopment using airlift pumping and agitation

AQUIFER DEVELOPMENT TECHNIQUES

1 Use of acid
2 Use of explosives
3 Disinfection of wells by chlorination
4. Use of hydrochloric acid in carbonate lithology

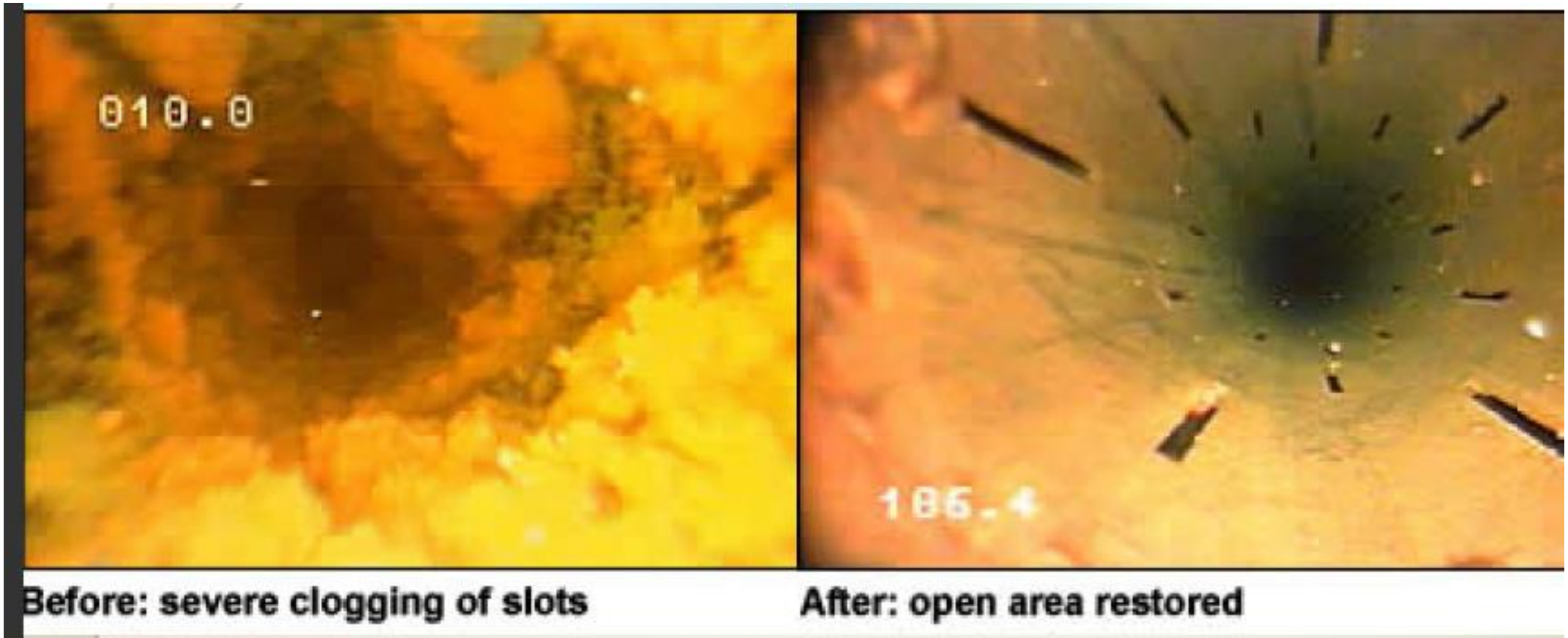
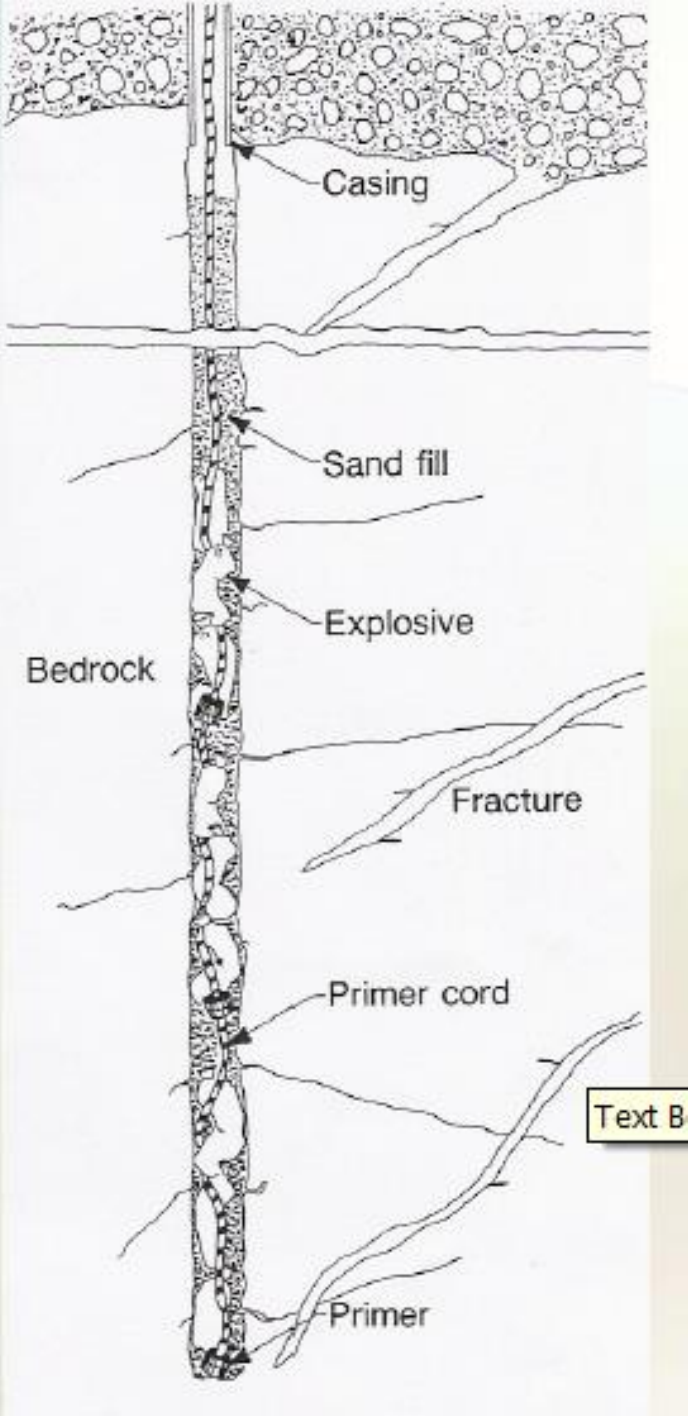


Figure 21: The effect of using Acidisation on a borehole before and after using acid



HYDROFRACTURING

Placement of explosives in the well as prescribed by the expert in such a way it should not cause damages to the settlements and structures due to blasting.

Blasting of required amount of explosives in the tube well / dug cum bore well at the prescribed depth /

New network of fractures developed due to blasting are connecting the major nearby water bearing fracture / lineaments

Due to this interconnectivity of water bearing major fractures located nearby, the existing dry wells can be replenished with water by recharging the aquifer through the movement of groundwater from the adjacent major fractures.

Pumping Equipment

- According to the specific yield of aquifer
  - Very high yielding alluvial aquifer/limestone cavernous / glacial till – high horse power
- Type of the aquifer (shallow or deep, non-flowing or artesian)
  - Shallow – jet pump/ low hp
  - Deep – submersible – high power jet pump
  - Flowing artesian – simple tap or hand pump
- type and horse power of pump can be determined

Groundwater Extraction methods

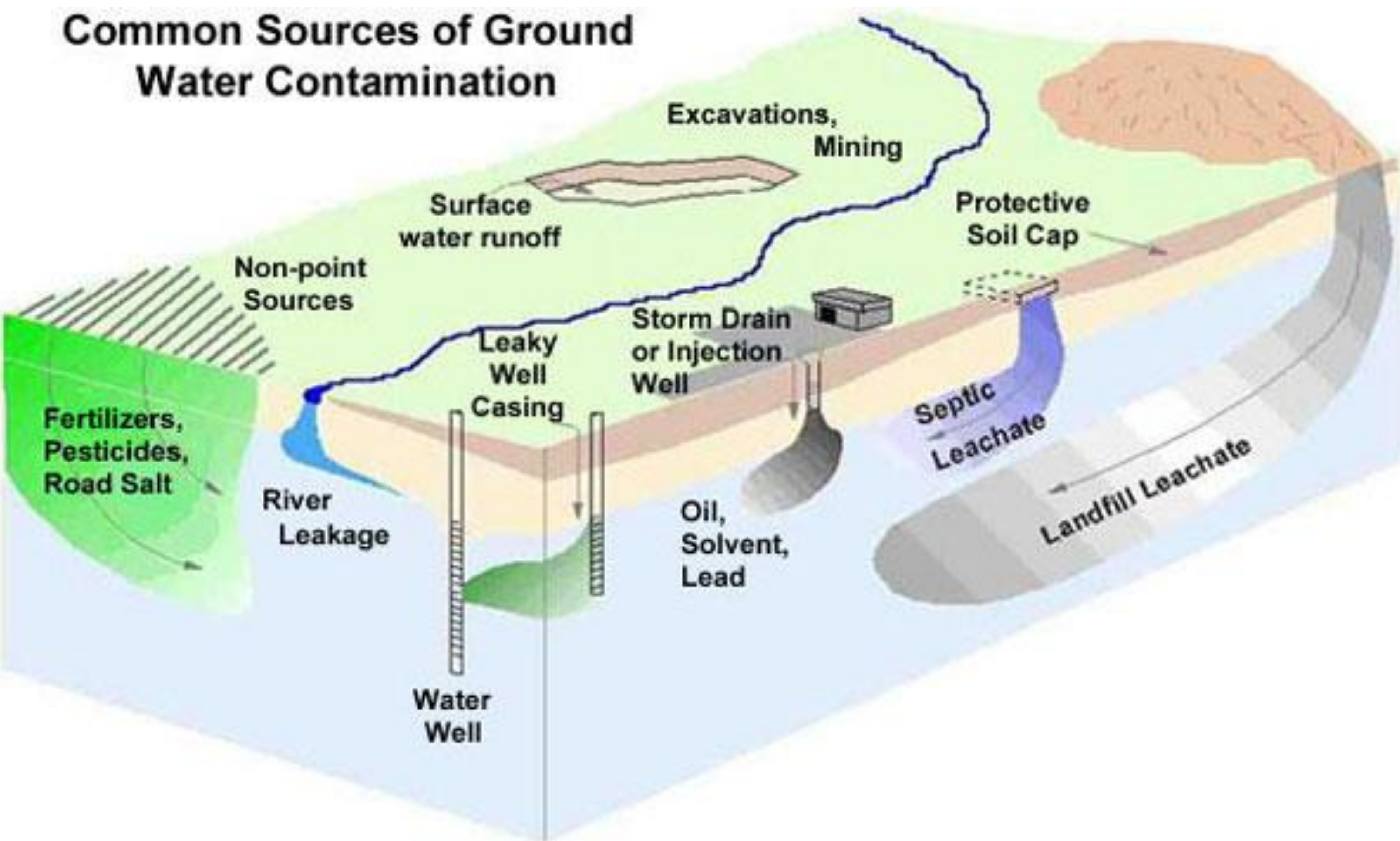
- Again according to the need and the availability of gw in the aquifer
- Hard / crystalline / metamorphic / fractured aquifers – extract with time intervals for recuperation of gw into the well -
- Continuous extraction is possible if the conduit fractures are interlinked naturally or by hydro-dynamite/hydro-fracturing artificially.

GROUNDWATER ASSESSMENT & BUDGETTING

- GWProspecting & Quantification – Ground survey data & GIS
- GWQuality mapping - *RS, -do-
- User community – domestic, agriculture & industrial need estimation – GW Requirement assessment
- GW availability vs Requirement – will lead to GW Budgetting and
- Finally, provide suggestions for further improvement through various action plan mapping.

GROUNDWATER ISSUES

- **GW decline** – too rapid now-a-days due to climate change as a result, fluctuations in rainfall intensities from the normal
- Blockage of **natural recharge corridors / catchment areas / water infiltration zones** by irregular and improper developmental activities – constructions and road pavements…
- Reduction of air / soil moisture led to local temperature increase, as a result desertification of humid areas
- Imbalance in hydrostatic pressure lead to land subsidence,
- **Groundwater quality deterioration** & contamination / pollution of water
- Soil erosion and reservoir siltation reduced storage capacity of reservoirs – which indirectly led to reduced infiltration / natural recharge.


Common Sources of Ground Water Contamination
Excavations, Mining
Surface water runoff
Protective Soil Cap
Non-point Sources
Storm Drain or Injection Well
Leaky Well Casing
Septic Leachate
Fertilizers, Pesticides, Road Salt
River Leakage
Landfill Leachate
Oil, Solvent, Lead
Water Well

GROUNDWATER CONSERVATION STRATEGIES

- RS, GS (ground survey) and GIS based development of Land management models for improving the efficiency of natural recharge – statistical / conventional methods.
- RS, GS and GIS based delineation of sites and mechanisms suitable for artificial recharge – to improve the GWL and GWQ status strategically through
  - Pits, Percolation ponds, Check dams, Enechelon dams, Batteries of wells, Subsurface dykes, Agro-pumping, Desiltation, Furrowing & Flooding, Hydrofracturing, …..
  - Or the combination of them can be suggested for effective recharge.
  - Suitable alignments for construction of canal / water conveyance structures along palaeochannels, etc., can be suggested to bring the excess monsoonic surface water available and cause floods in the adjacent water-excess-watersheds.