UNIT - V

MINING METHODS FOR GROUNDWATER

Mining Methods for Groundwater: Test holes and well logs – Well design - Well development - Methods for constructing shallow wells & deep wells – Well completion – Pumping equipment – Protection of wells – Well rehabilitation – Horizontal wells – Groundwater Extraction methods. 9 Hrs

Dr.A.Balukkarasu

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 pump less hand-dug wells of varying degrees of formality, and they remain a very important source of potable water in some rural developing areas where they are routinely dug and used today.

- For many 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,
  - 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.

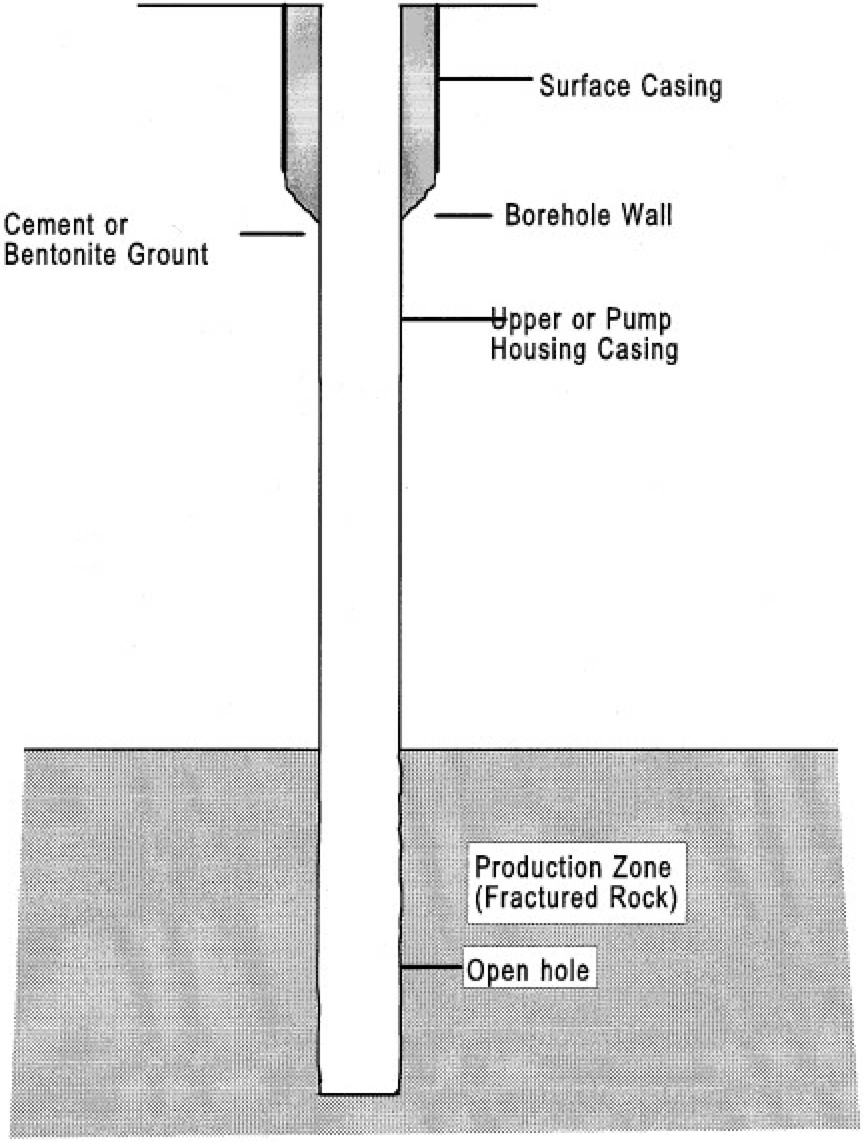


Figure 1 Open hole well completion.

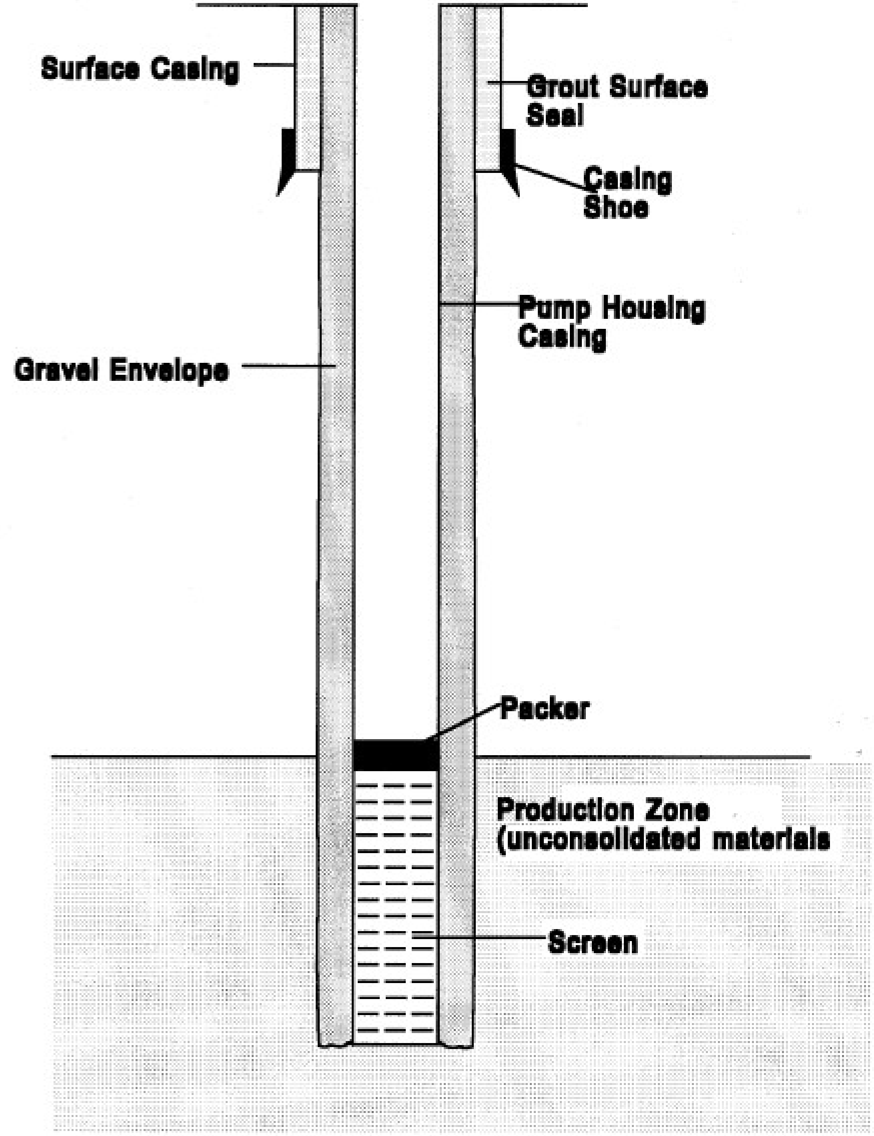


Figure 2 Gravel envelope well.

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 to 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.

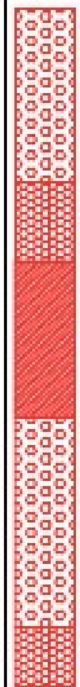
Drilling log

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
....	....	....	....

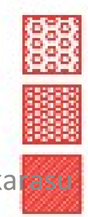
Drilling log

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

Well 2

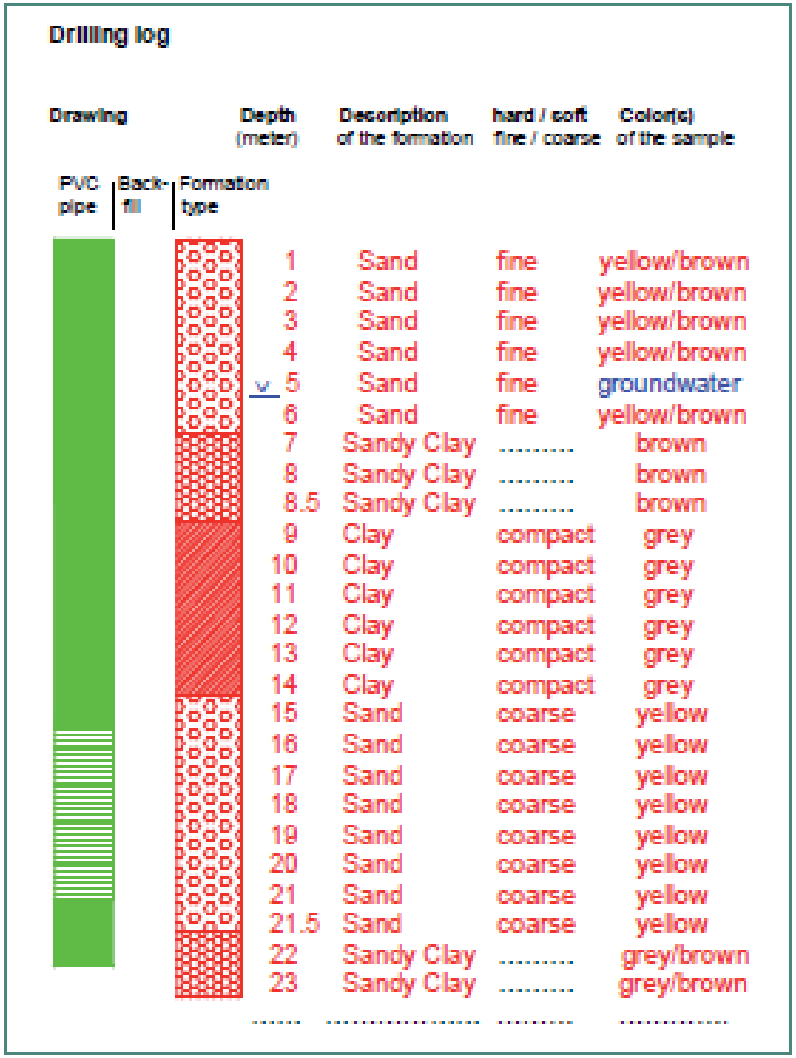
Latitude/longitude: 39° 32′29.7″/102° 40′02.5″, North American Datum of 1983
Land surface altitude: 4,310 feet, North American Vertical Datum of 1929
Date well completed: 8/20/2008
Log prepared by L.R. Arnold

[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

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	groundwater
6	Sand	fine	yellow/brown
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8	Sandy Clay	....	brown
8.5	Sandy Clay	....	brown
9	Clay	compact	grey
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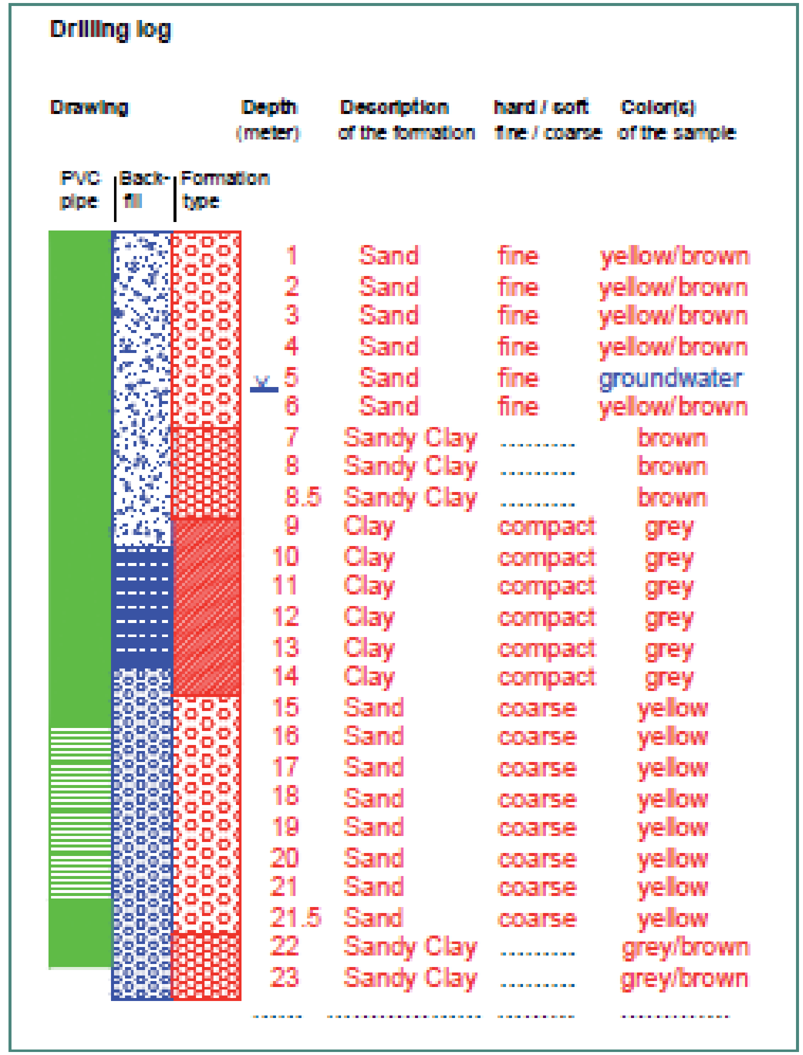
23	Sandy Clay	....	grey/brown
......	....	....	....



Drilling log

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......	....	....	....

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

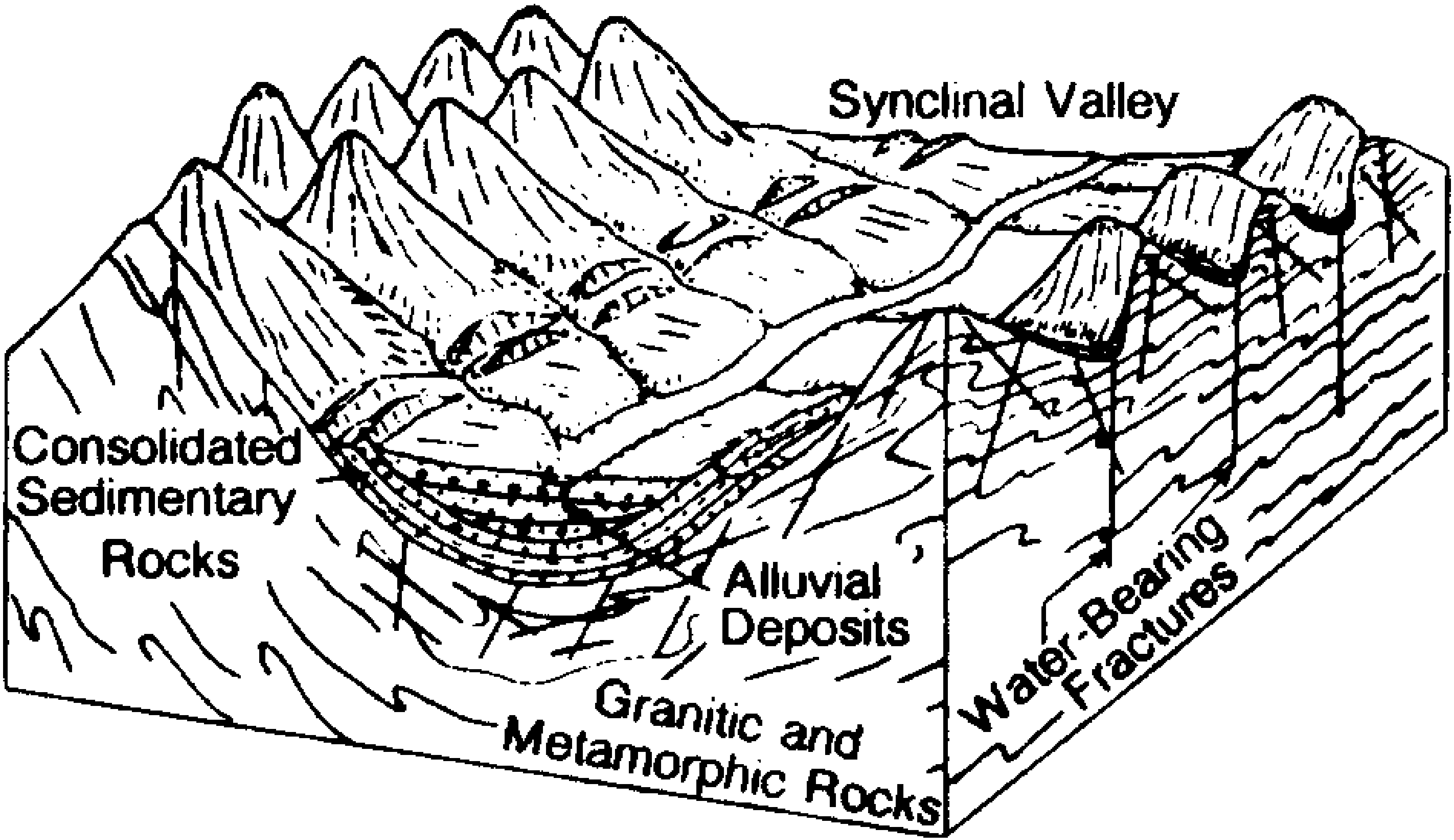
Gravel pack

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.

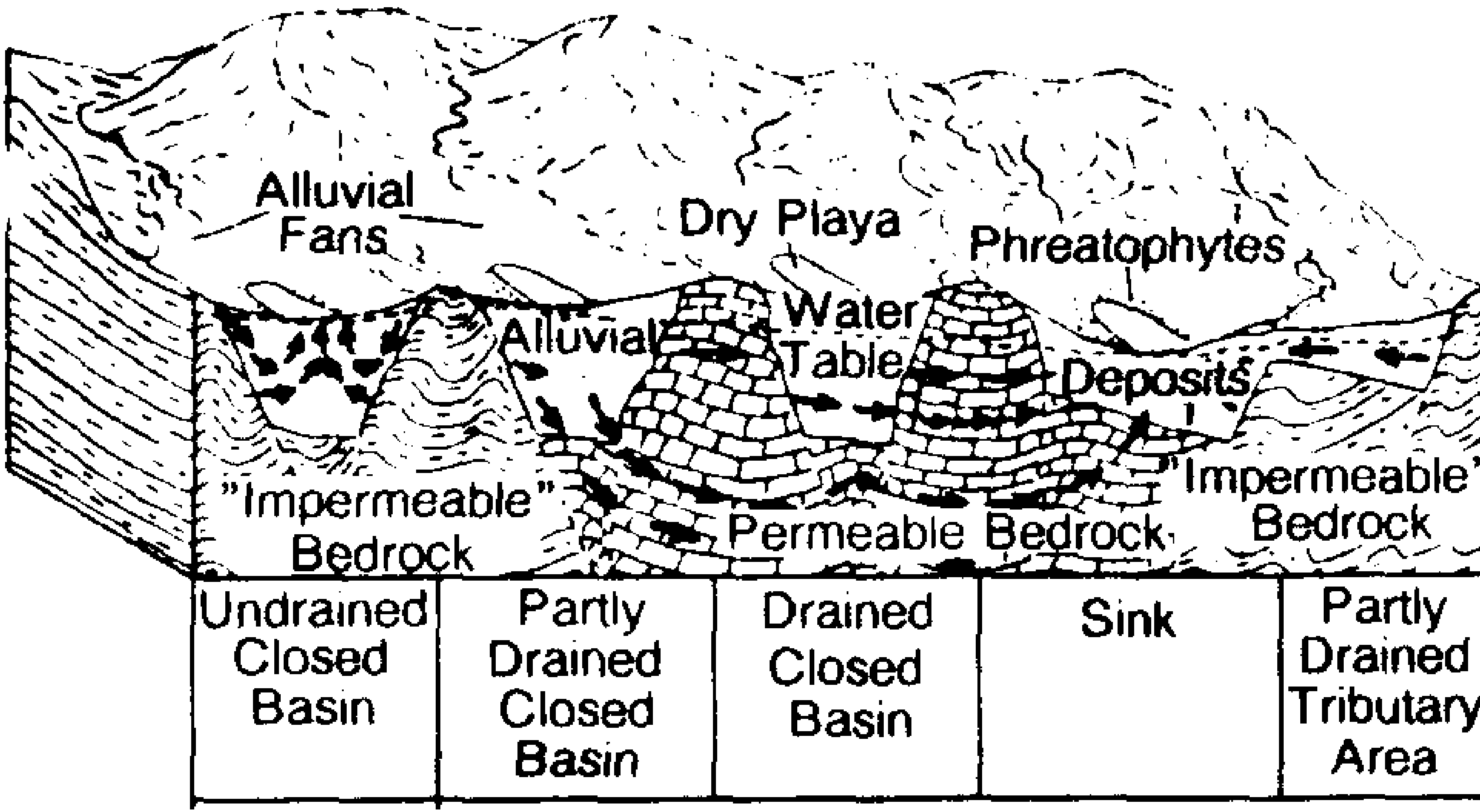
- Resistivity logging or electrical logging, optical / acoustic logging, gamma ray logging, are some of the other types of bore hole geophysical surveys to study the characters of subsurface lithology
- It is also possible to conduct pump test within the bore hole using proper equipments like, electric motor pump and water level indicator
- 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.

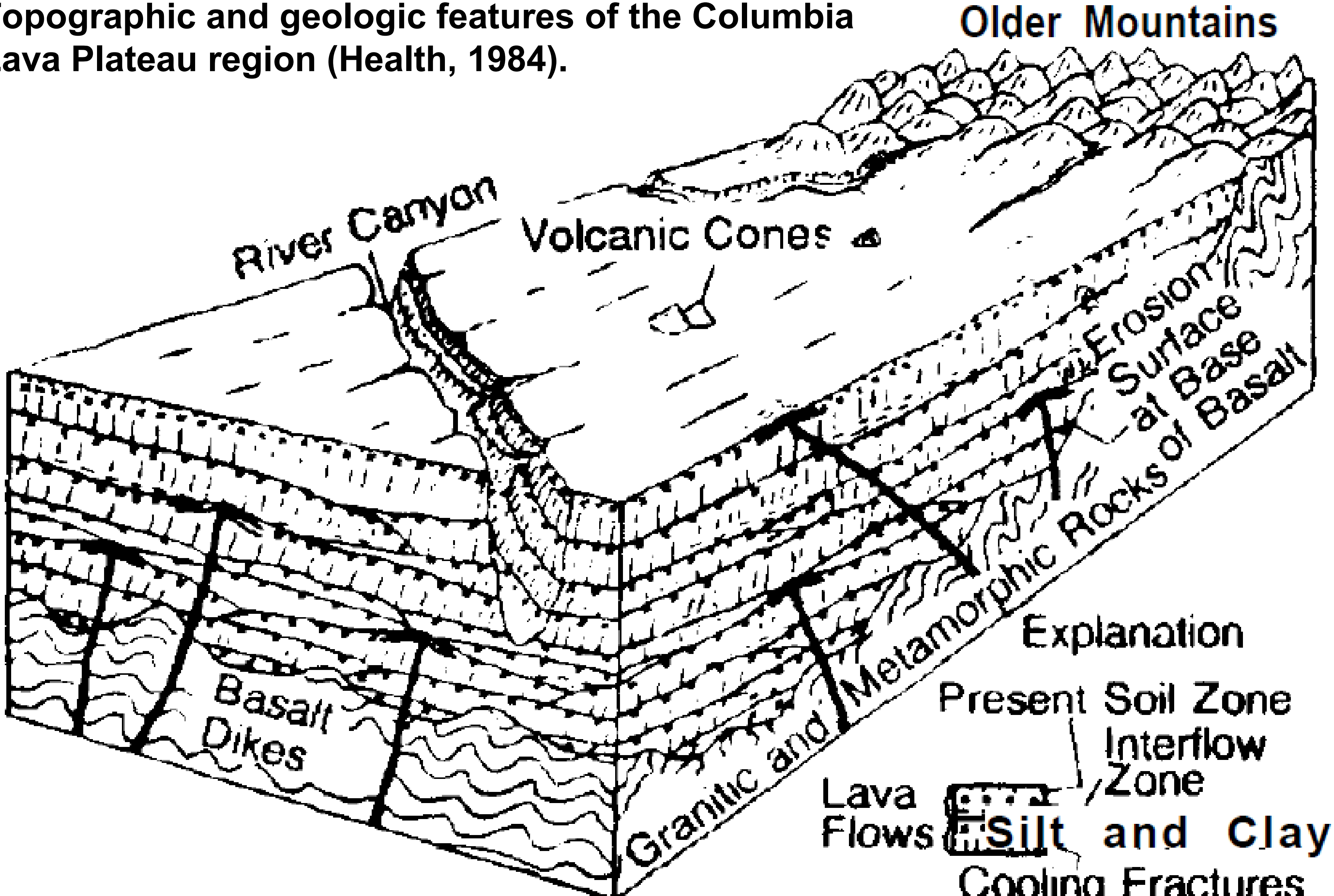
Aquifers / formations derived out of combination of data collected through surveys



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


Alluvial Fans
Dry Playa
Phreatophytes
Alluvial
Water Table
Deposits
"Impermeable" Bedrock
Permeable Bedrock
"Impermeable" Bedrock
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).



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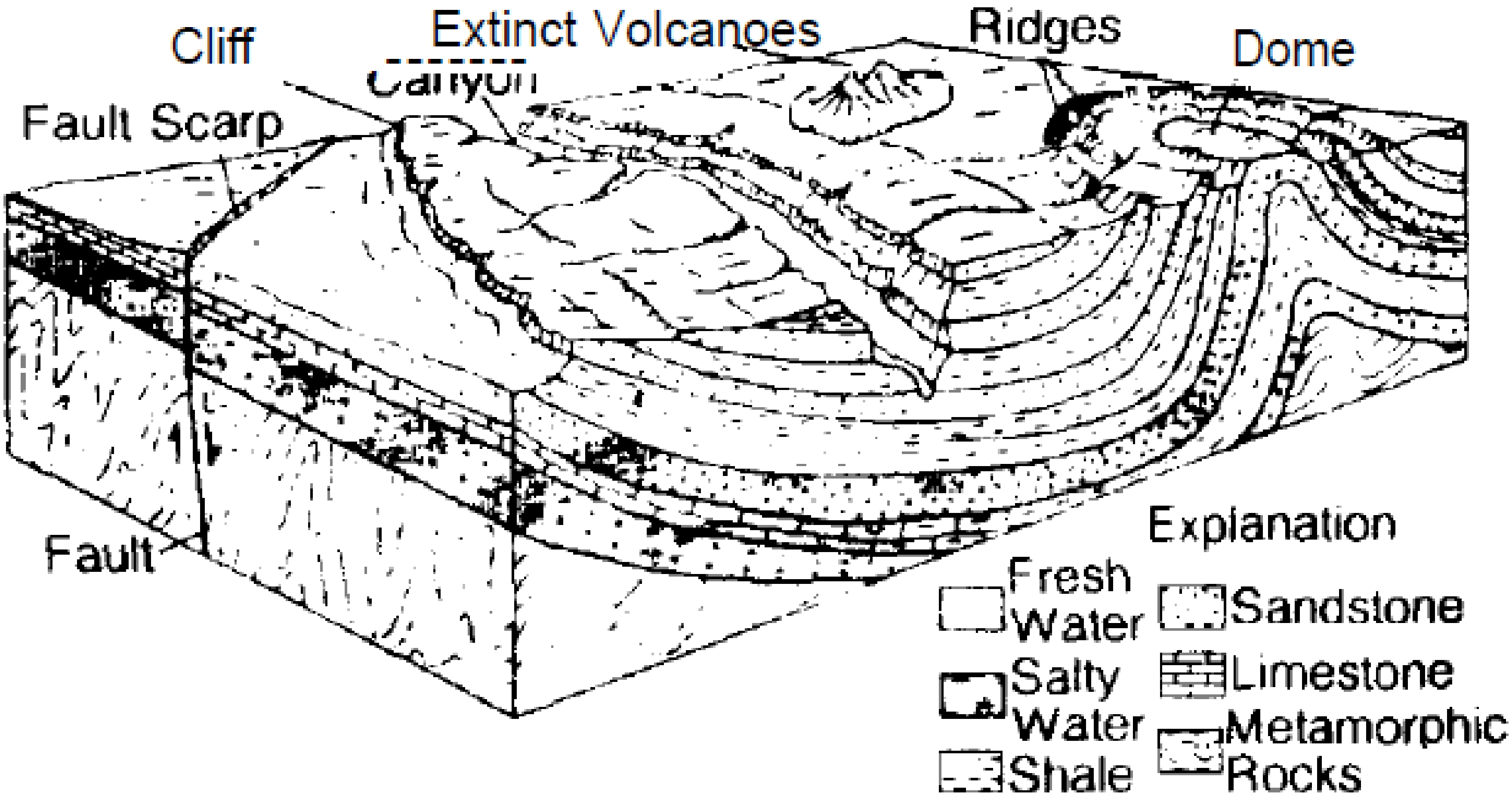
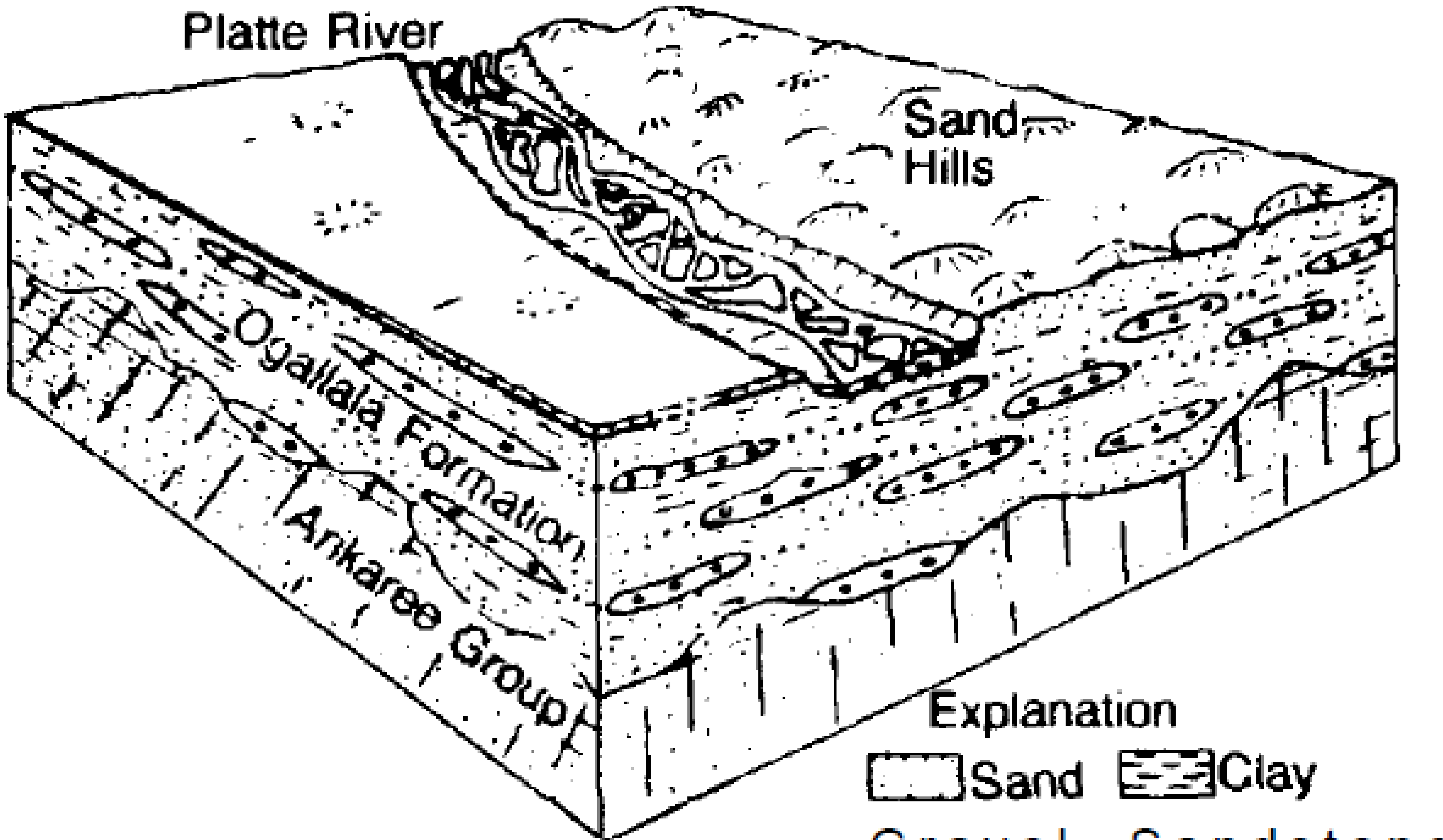


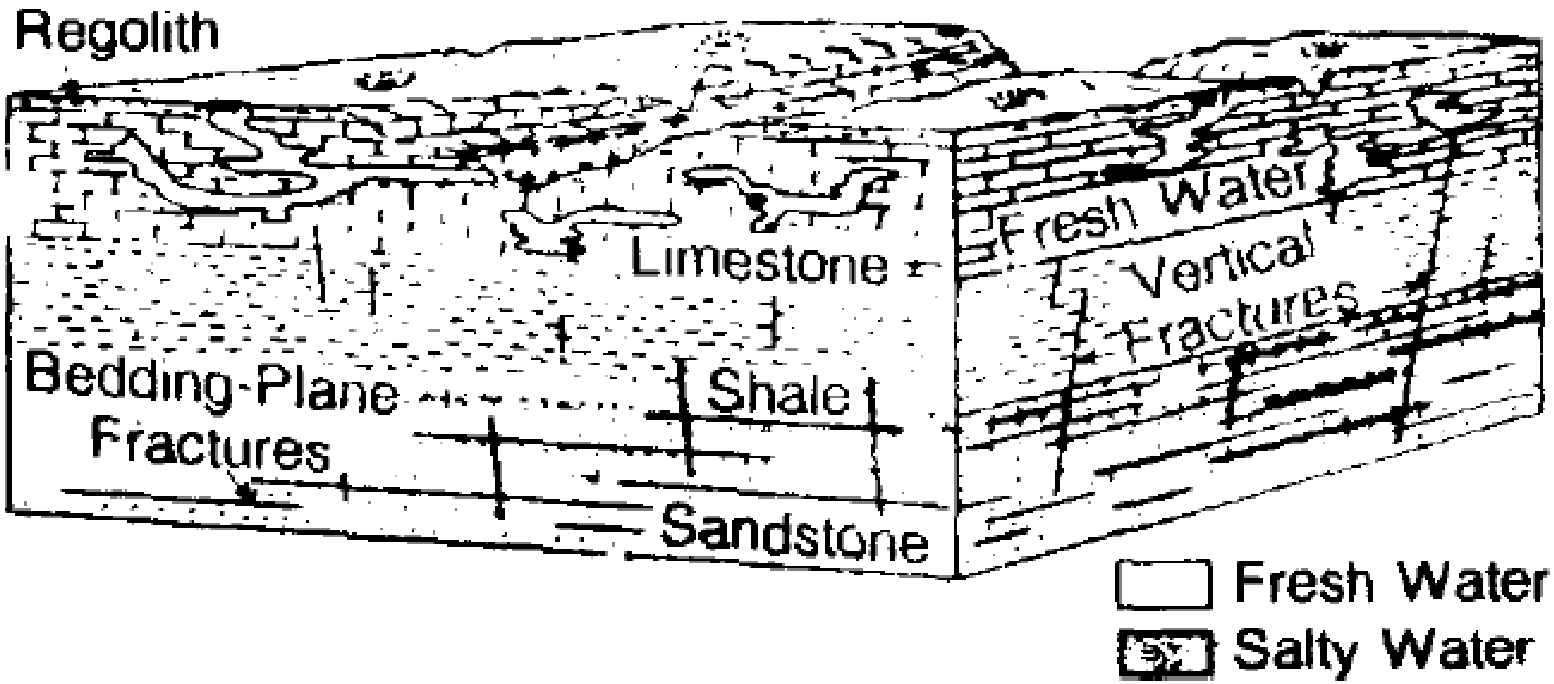
(b)

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



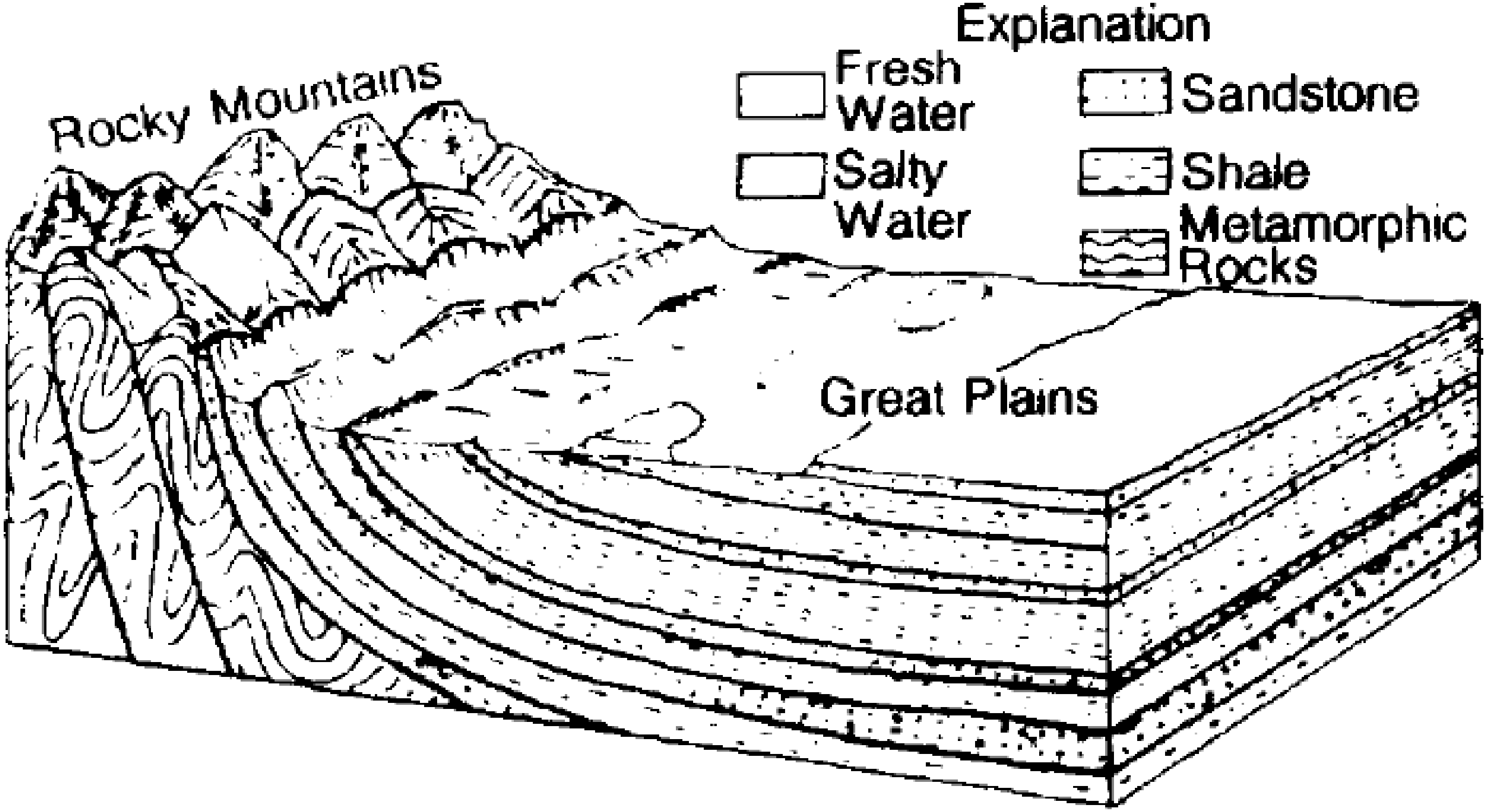
(b)

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).

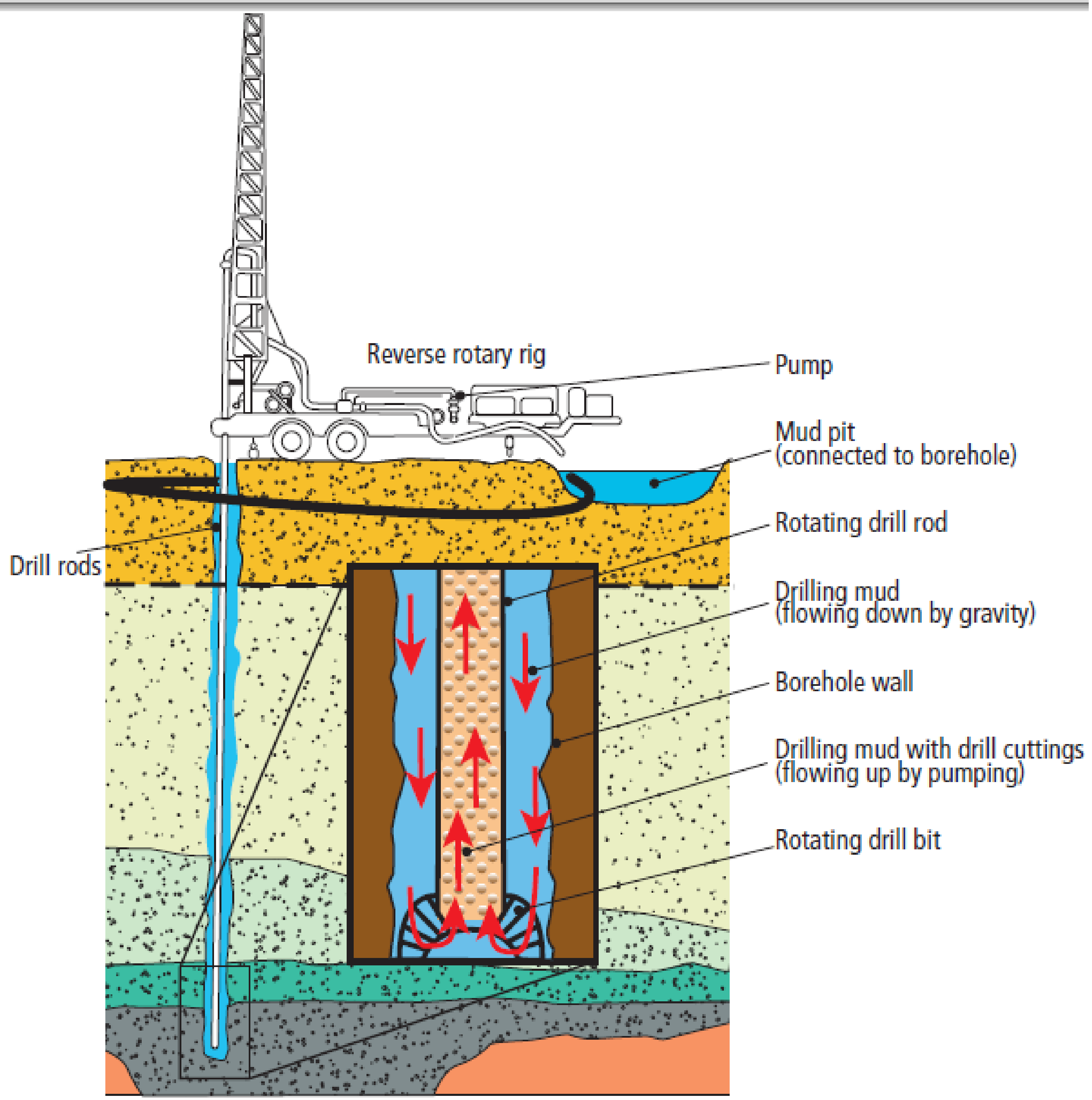


Figure 2. Principles of reverse rotary drilling. (adapted from Driscoll, 1996. Johnson

- 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

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 be placed varies by county.

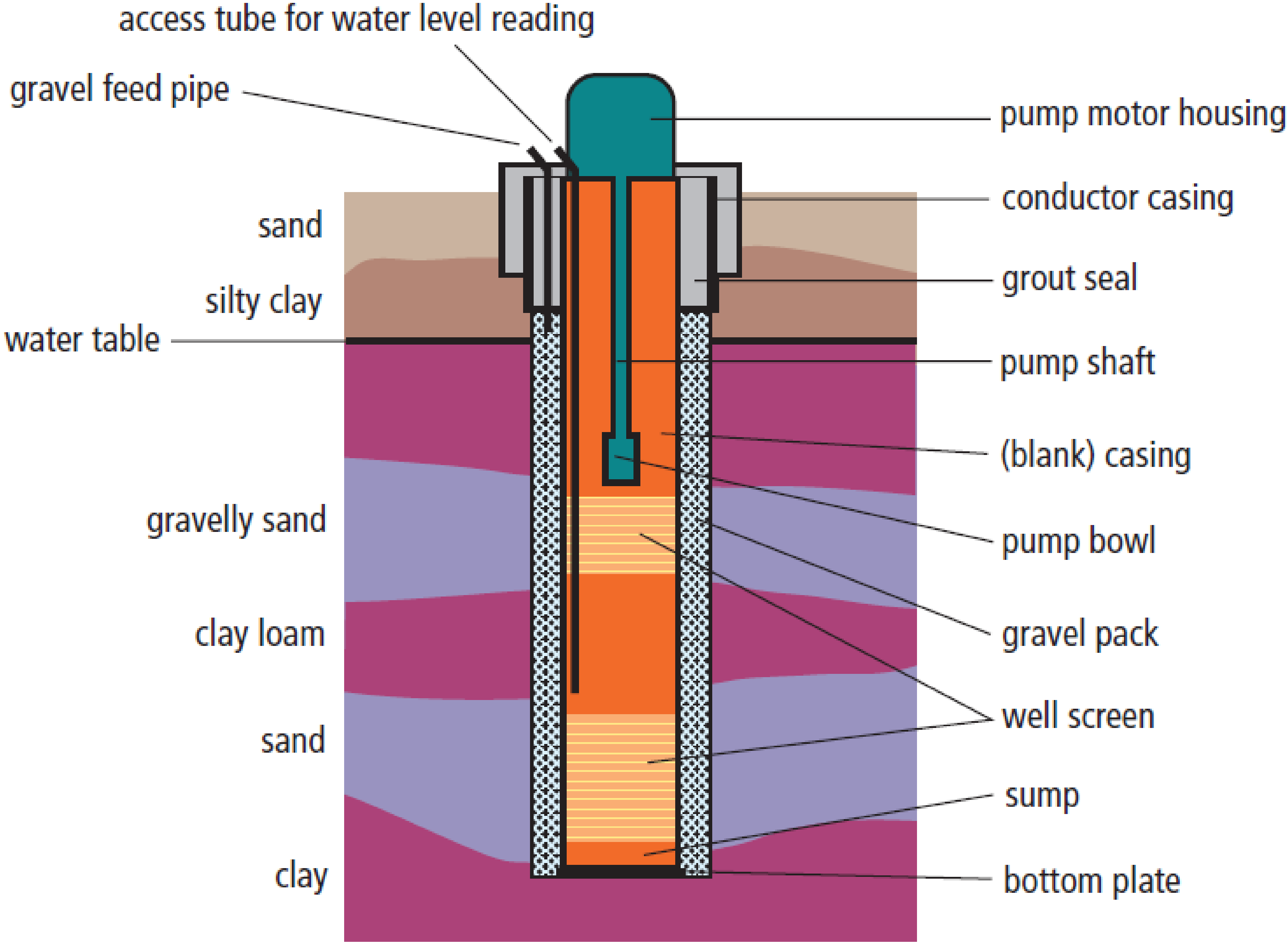
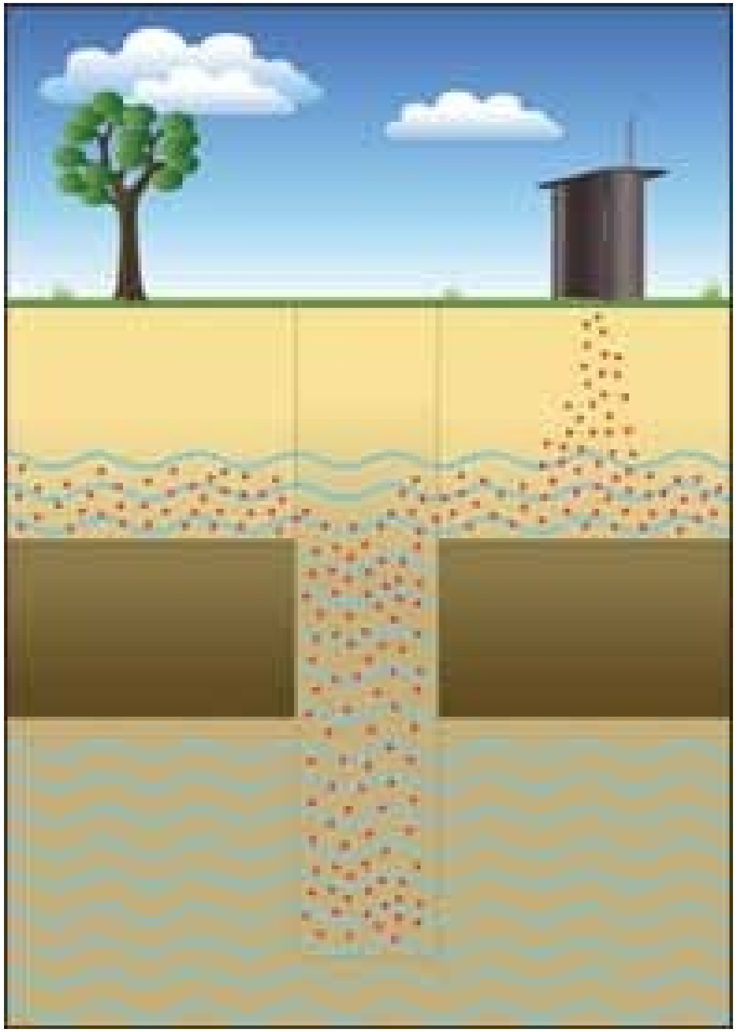


Figure 1. Components of a well.

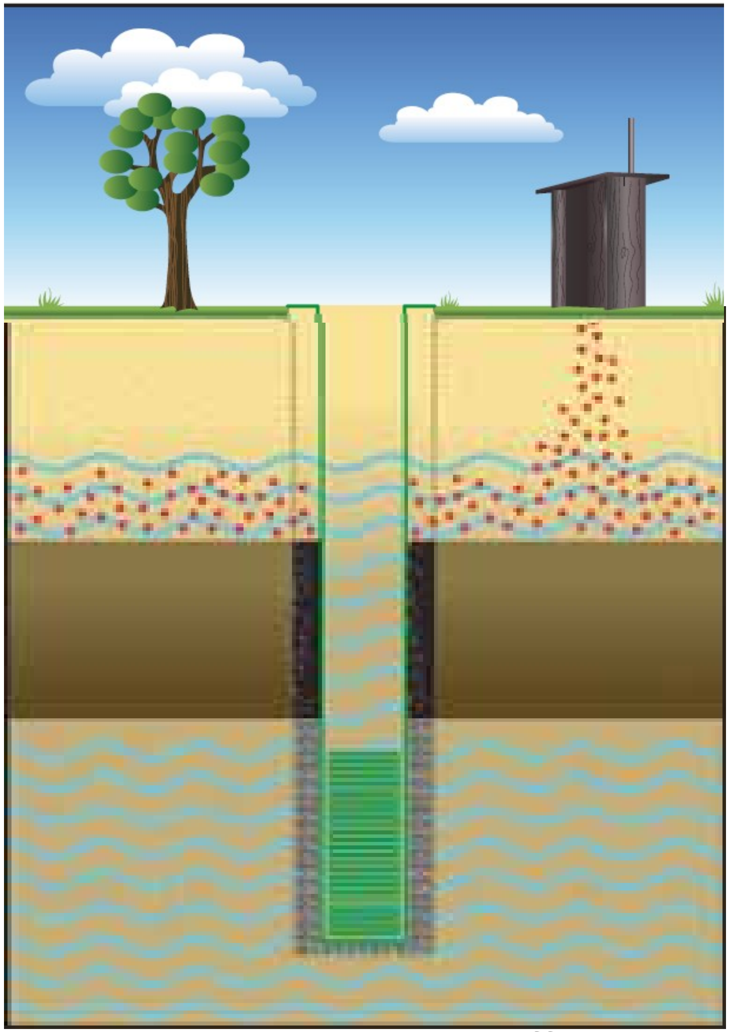
- In alluvial aquifers, which commonly contain alternating sequences of coarse material (sand and gravel) and fine material, the latter construction method is much more likely to provide clean, sediment-free water and is more energy efficient than the installation of a continuous screen.
- Hardrock wells, 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

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
  - 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.
- In 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 and rock conditions found during the drilling process.

The **screen** plays a critical role in the performance of the well since it filters 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.

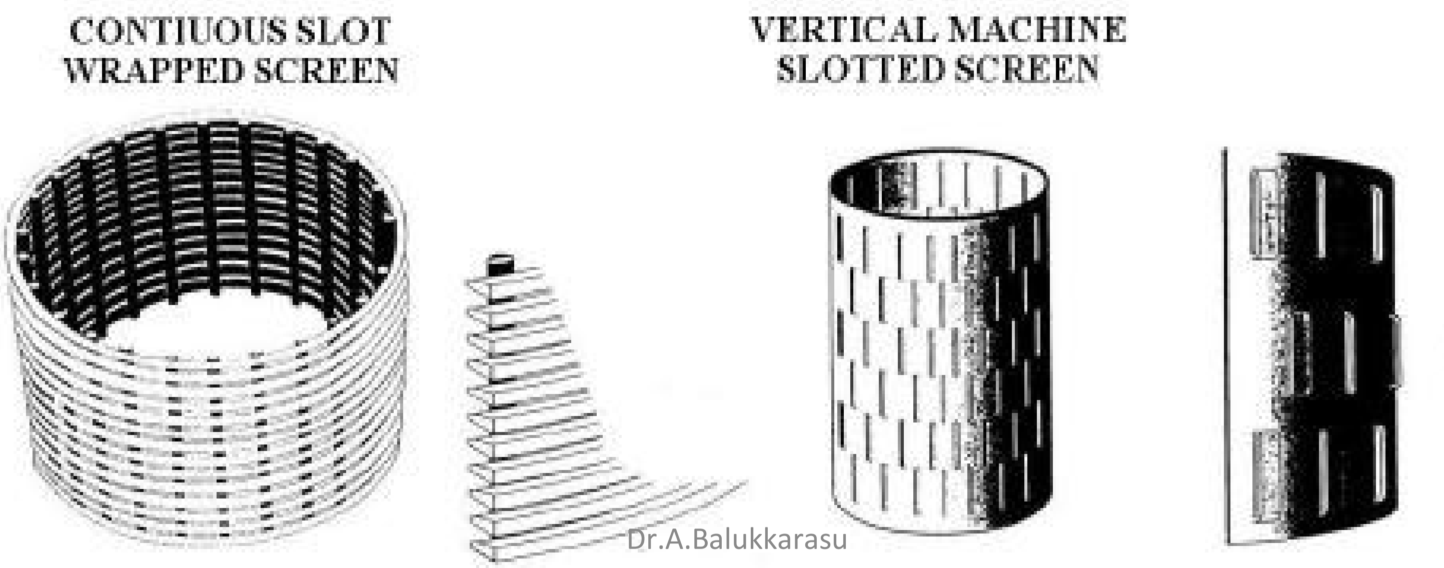
Casing

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

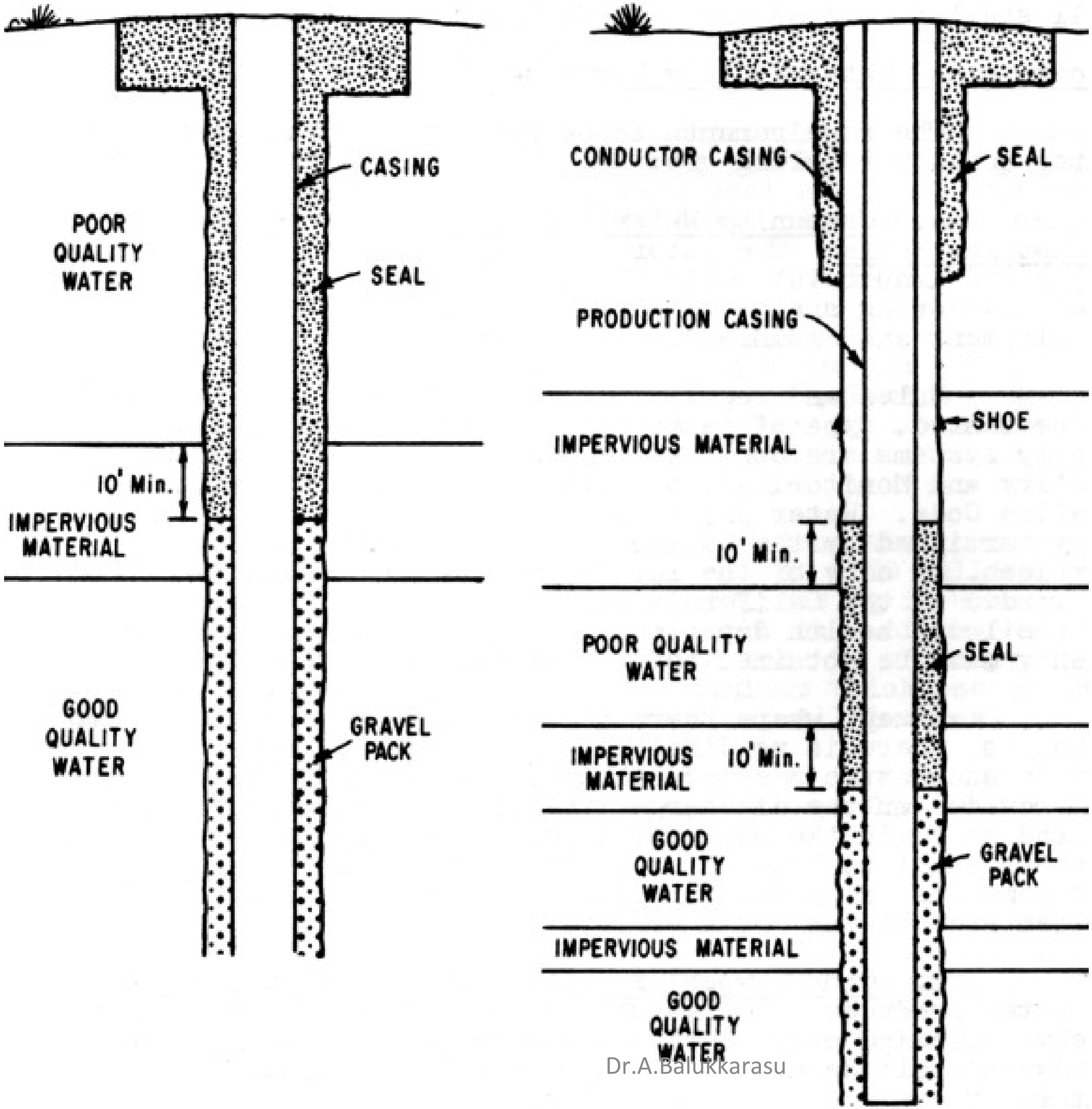
Gravel is sometimes placed outside the screen to support the aquifer materials (called *formation stabilizer) or to* increase near bore permeability and to assist in filtering aquifer materials (called *artificial filter). Regardless of function,* the common term for the practice is *gravel pack. The 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.

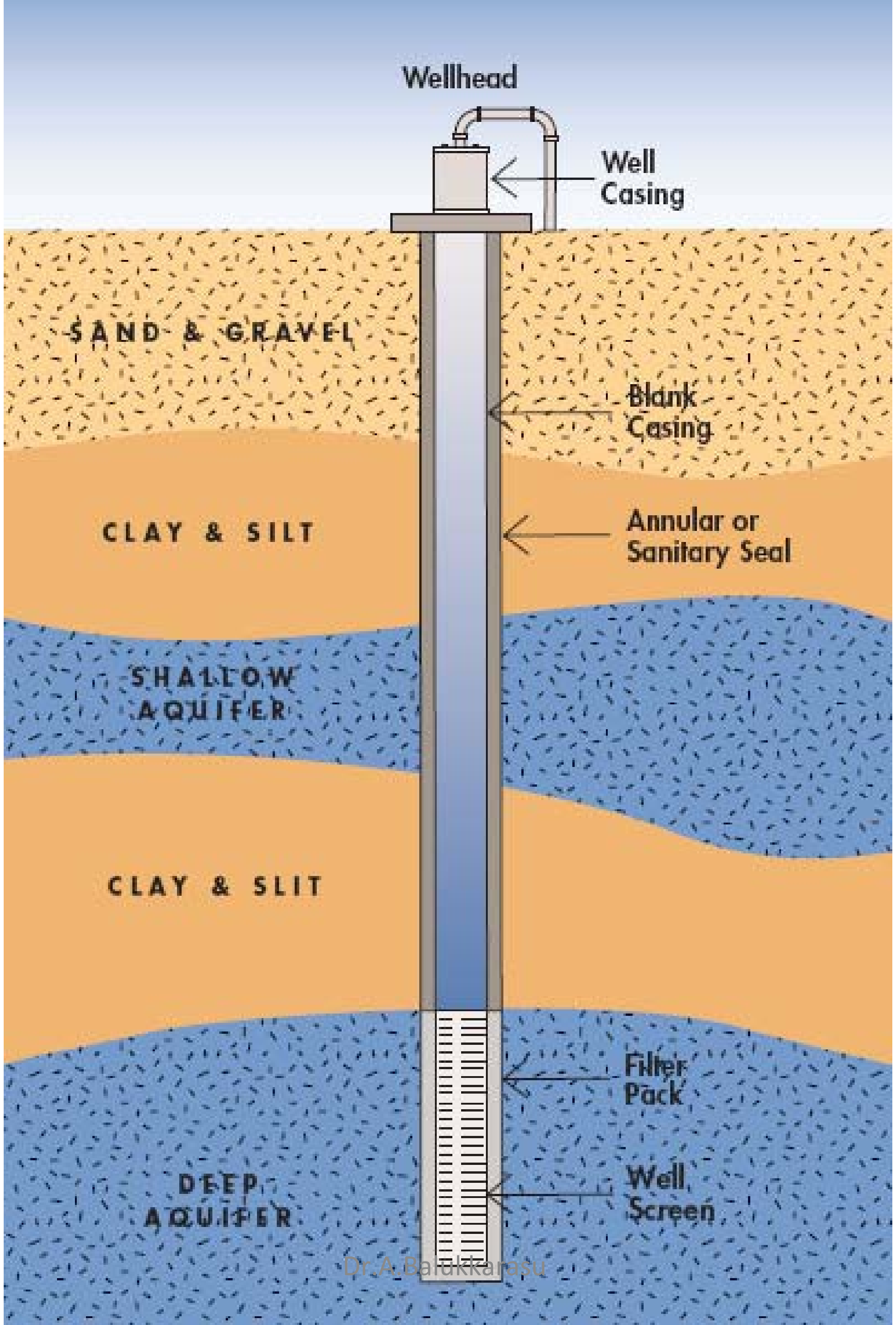
- For high yield wells a “gravel pack” is sometimes used to fill up the space between the well screen and the drilled hole.
- Placing the gravel in the well next to the screen can be a tricky business, but the highly permeable gravel can really help make the well efficient.
- Selecting the size of gravel 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, most contractors will use a special adaptor 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

- 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).*

MATRIX NUMBER 1

General Hydrogeologic Conditions & Well Design Requirements

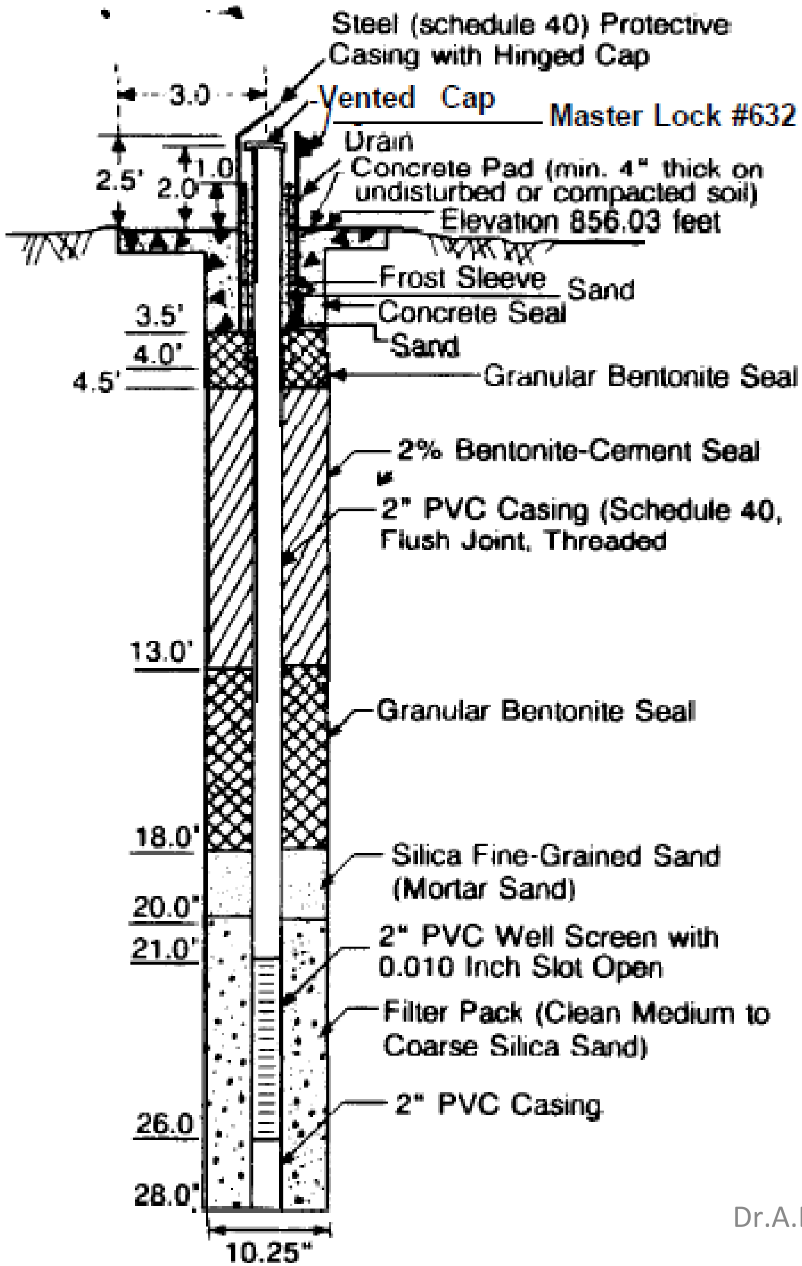
Unconsolidated; saturated; invasion of formation by drilling fluid permitted; casing diameter 2 inches or less; total well depth 0 to 15 feet.

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.

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



Well Development

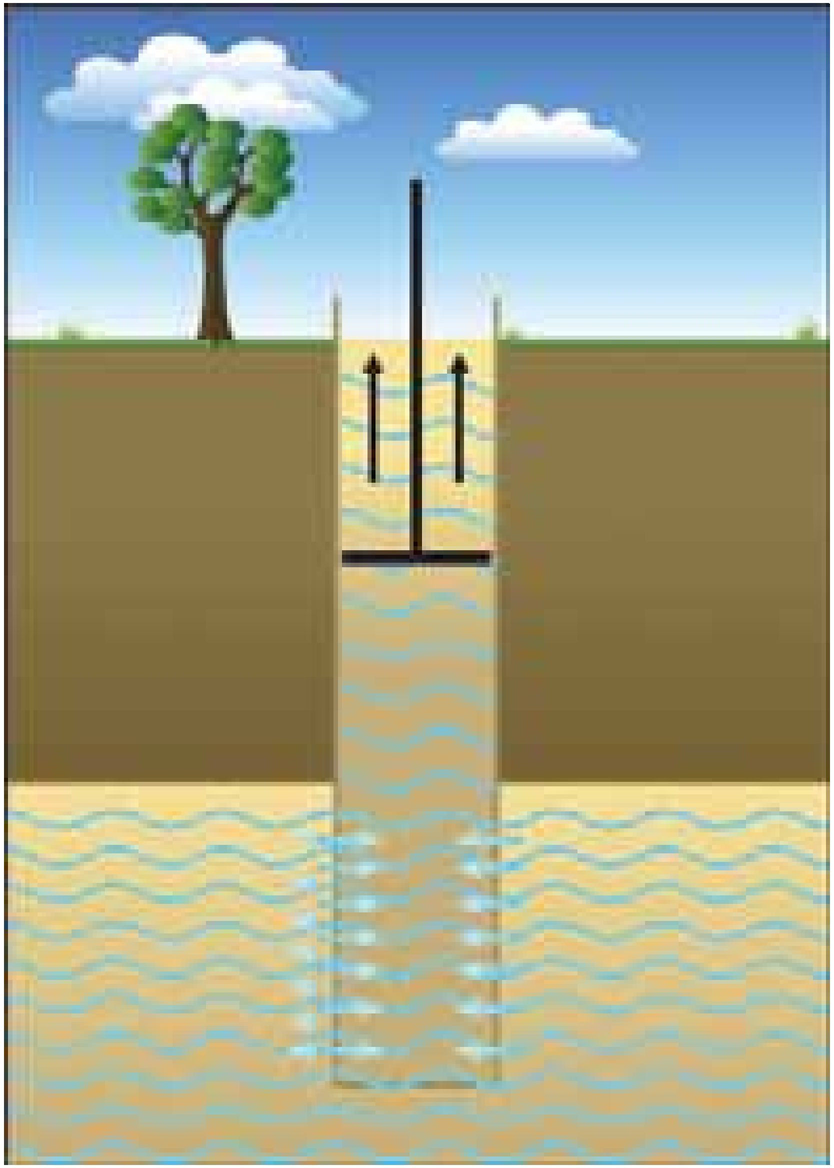
Removing fines and drilling fluid additives from the well and the surrounding aquifer, and settlement of the gravel pack.

- ‘Well development’ is necessary to maximize the yield of the well and optimize the filter capacity of the gravel pack.
- This is achieved by *removing the fines and drilling fluid additives, and settlement of the gravel pack.*

- **Factors affecting well development**
  - Type of geologic material
    - Install the well intakes at the prescribe settings
    - Uniformly distribute and maintain proper height of a filter pack above the well intakes
    - Place the bentonite seals in the intended location and
    - Emplace a secure surface seal

Methods of well development

- Surging with a surge Mock / surge block / plunger
- Bailing
- Pumping, discontinuous pumping, over pumping and backwashing through the pump till water becomes clearer
- Airlift pumping and
- 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

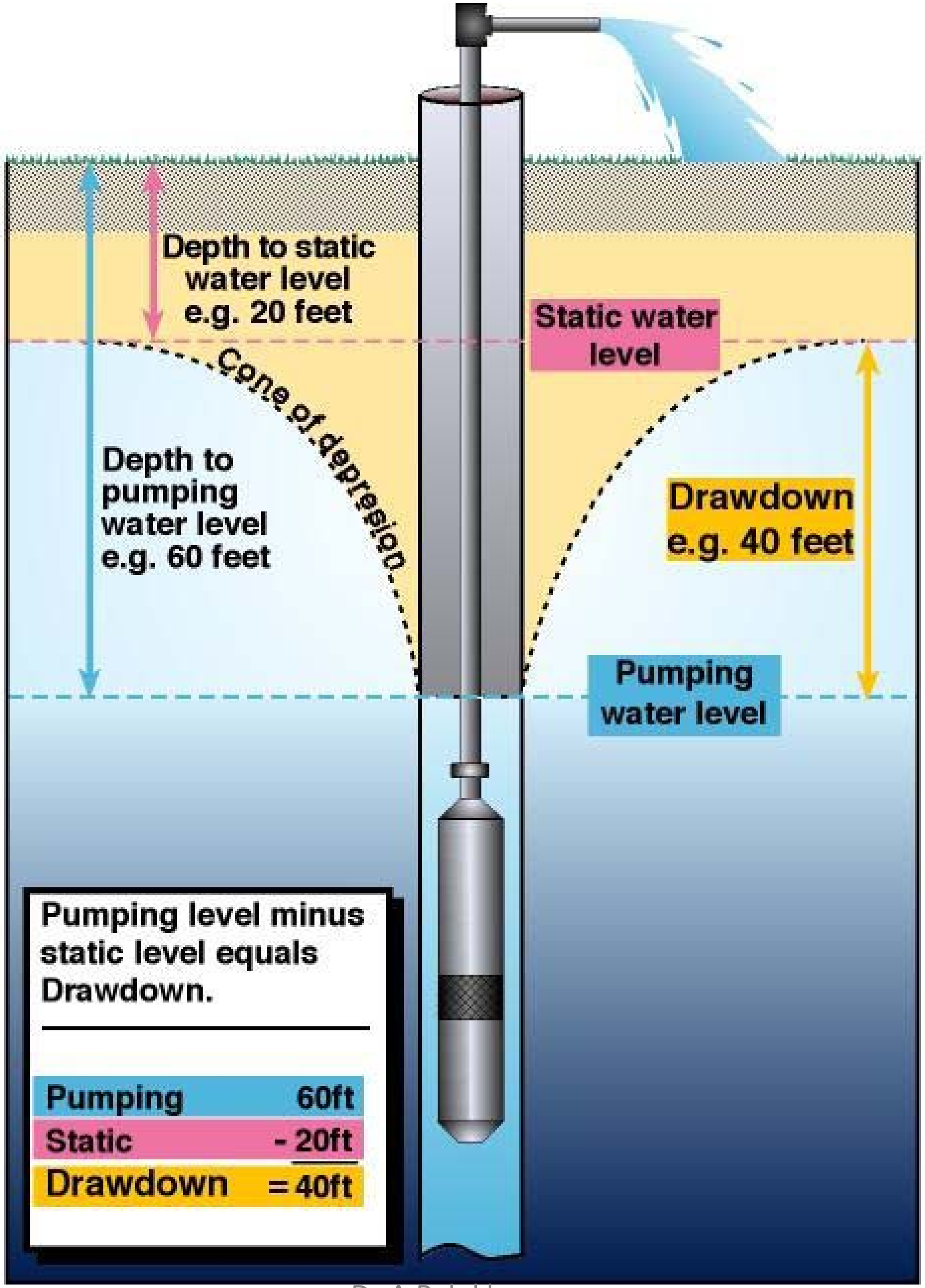
Well development by hand

Re-development by airlifting

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, 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.
- 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.

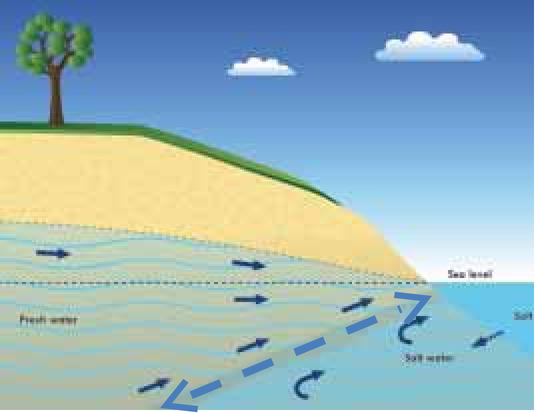

Depth to static
water level
e.g. 20 feet
Static water
level
Cone of depression
Depth to
pumping
water level
e.g. 60 feet
Drawdown
e.g. 40 feet
Pumping
water level
Pumping level minus
static level equals
Drawdown.
Pumping 60ft
Static - 20ft
Drawdown = 40ft

Theory of Up-coning

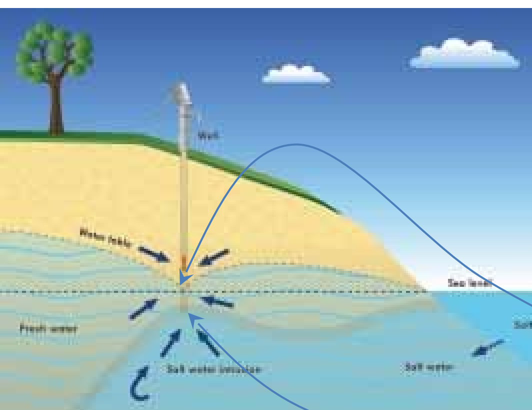
- In coastal aquifers, where the fresh water lies above saline water, and is pumped by a well, the interface rises below the well due to drawdown of the groundwater table around the well.

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

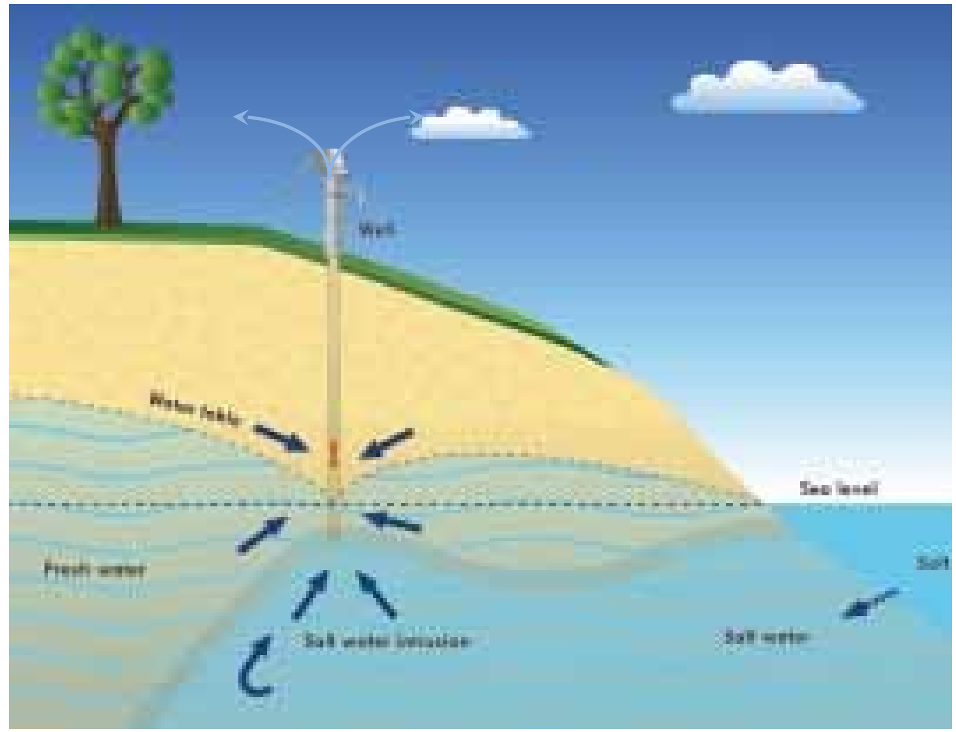
- This phenomenon is known as up-coning. If the top of the conical mound reaches the well, saline water will begin to mix with fresh water, and degrade the quality of the well water [Fig.1].



Fresh water on top of salt water



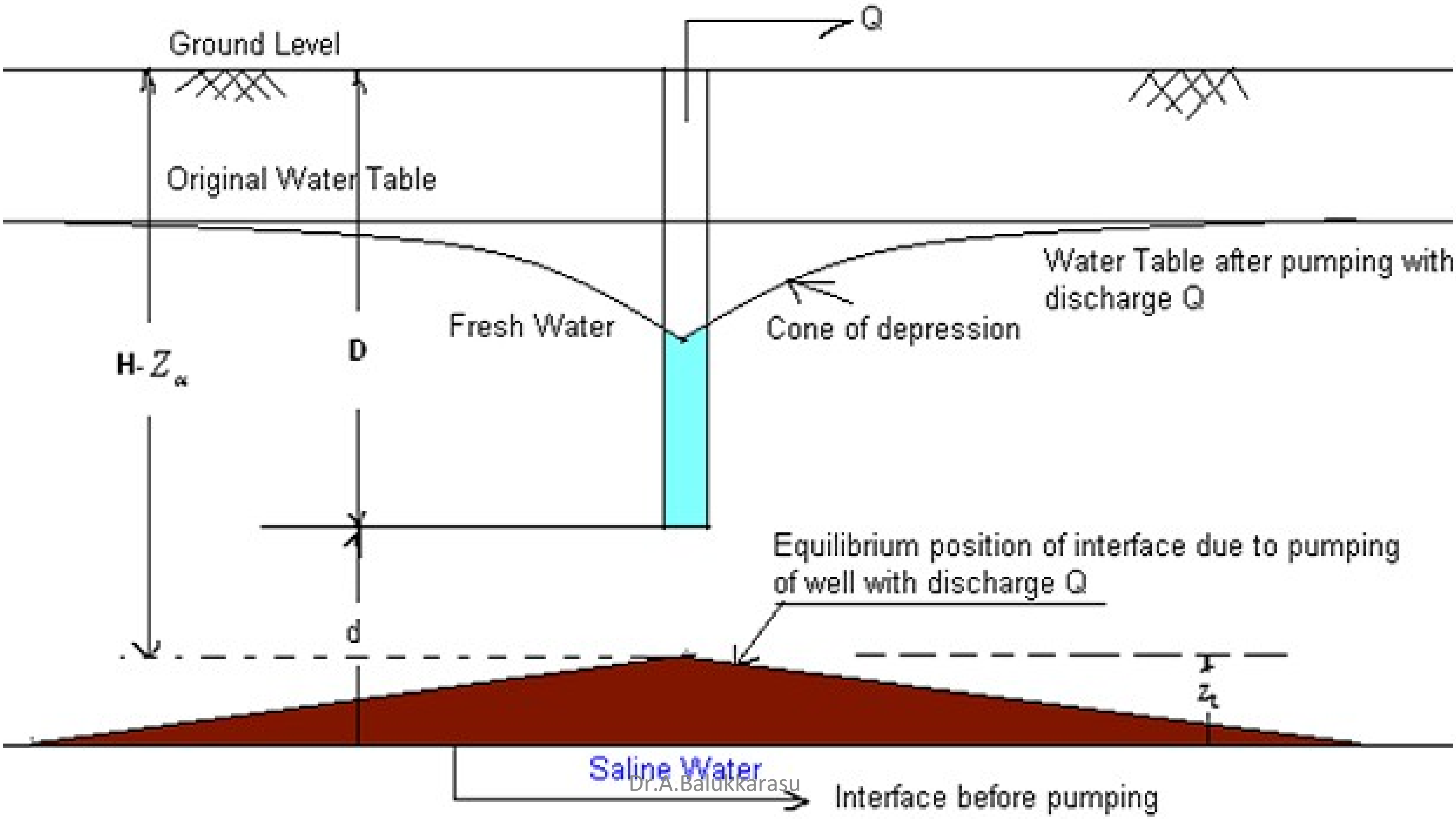
Salt water intrusion



On depressing the water table because of over exploitation / uncontrolled gw pumping – results into cone of Depression of water table – above.

Below, which Salt water intrusion occurs.

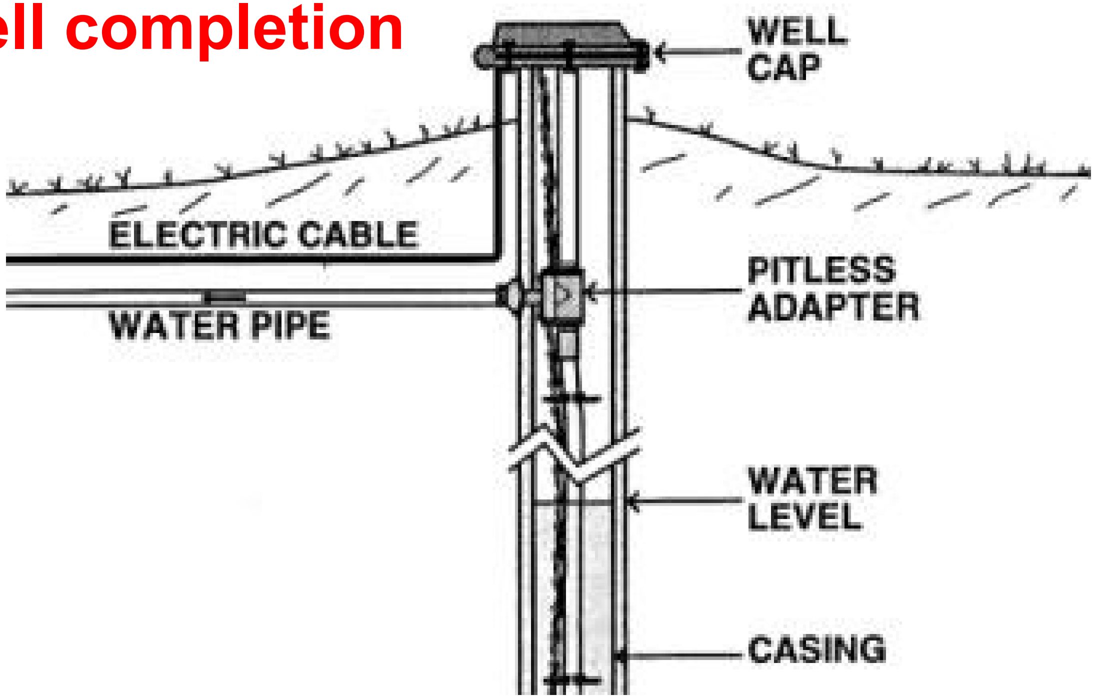
Figure 1: Up-coning of saline water beneath a pumped well



- 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.

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.

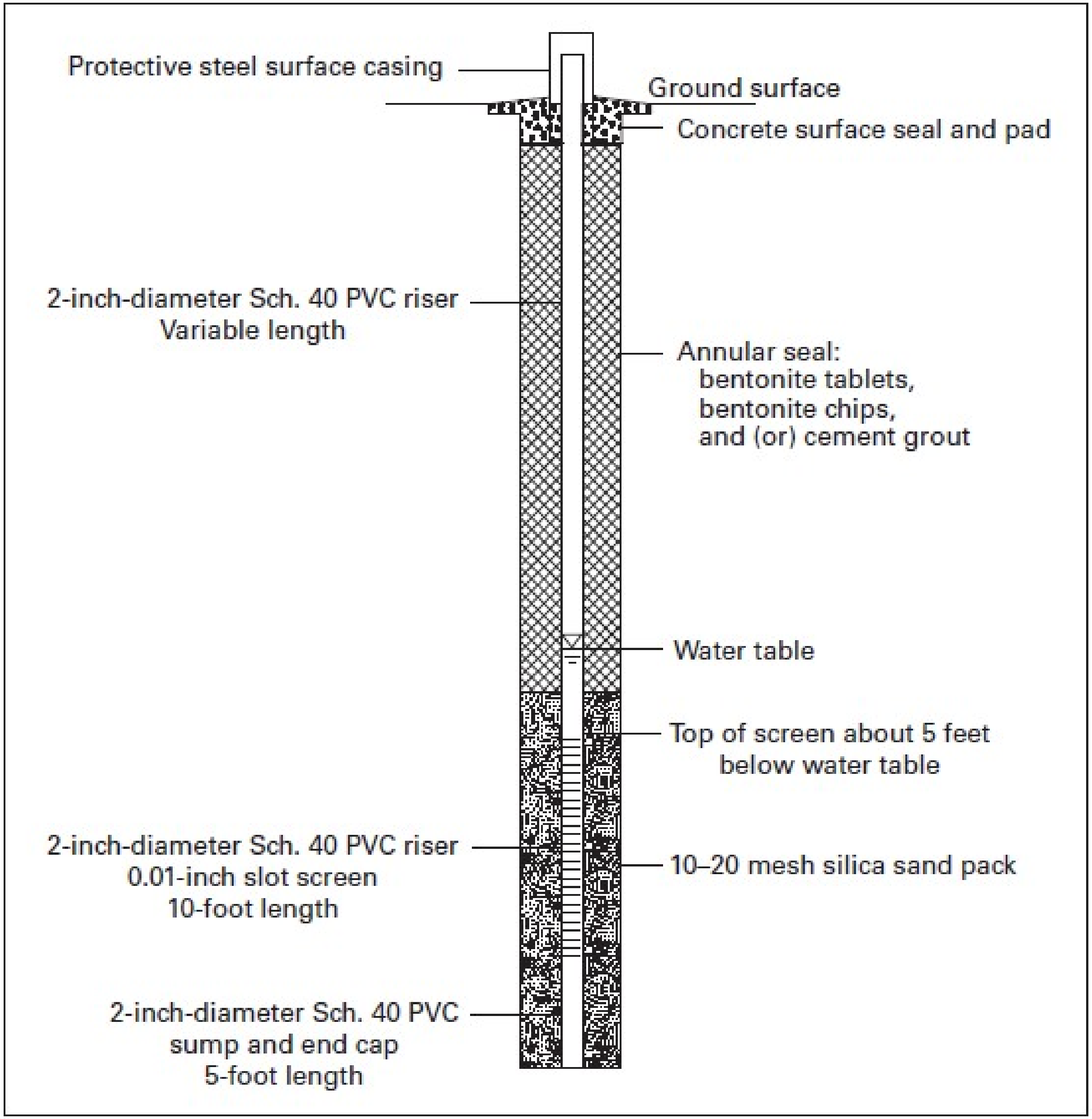


Figure 8. Schematic diagram of High Plains groundwater monitoring-well completions.

WELL PROTECTION / WELLHEAD PROTECTION

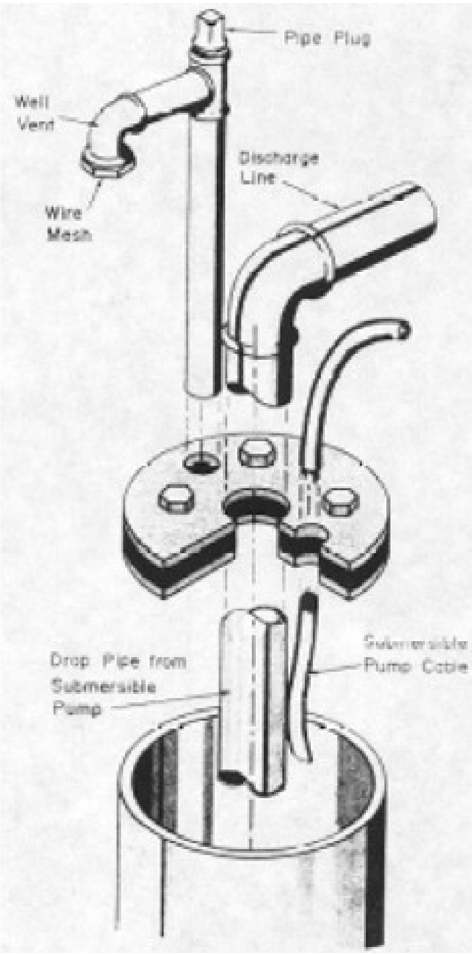
- Once the well is completed and developed, it is a good practice to conduct an *aquifer test (or pump test).*
- *For an aquifer test, the well is pumped at a constant rate or* with stepwise increased rates, typically for 12 hours to 7 days, while the water levels in the well are checked and recorded 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.
- 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.

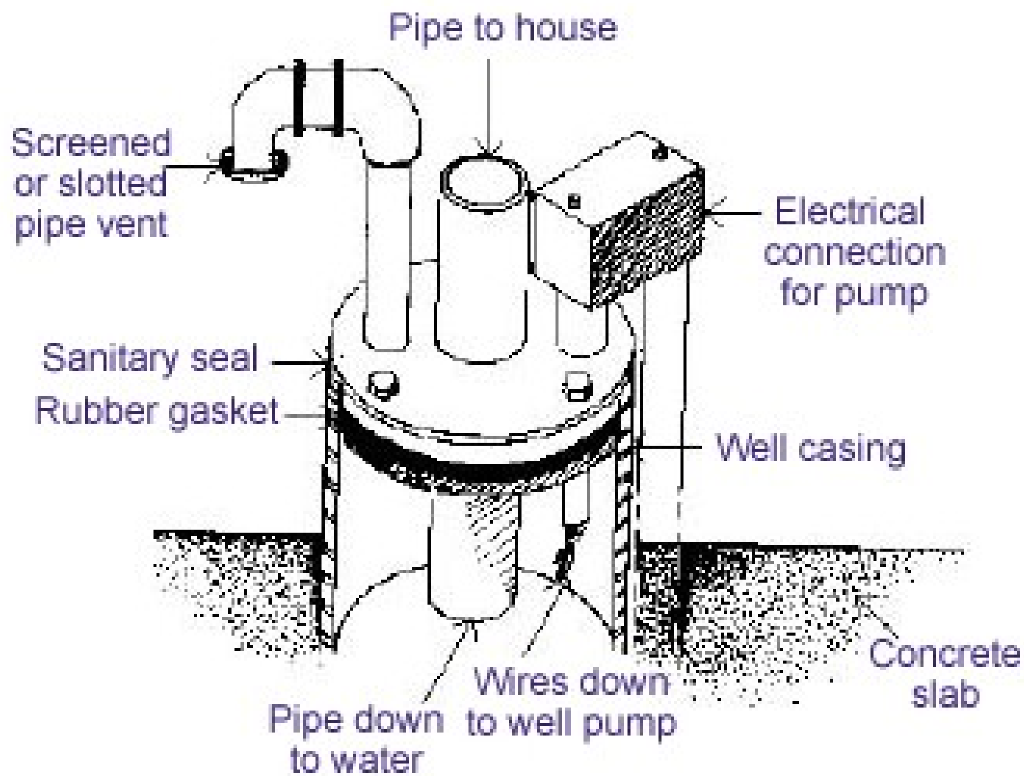
- The construction of the final well seal is intended to provide protection from leakage and to keep runoff from entering the wellhead

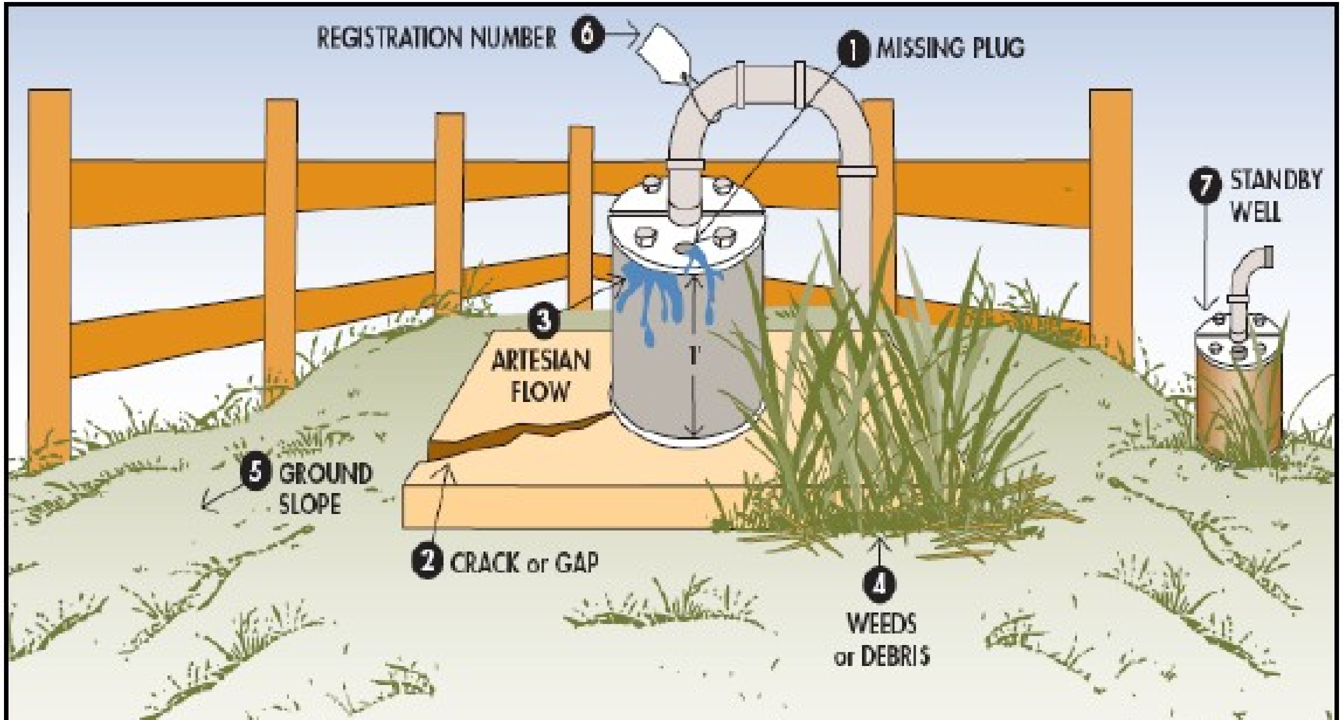
- It is also important to install backflow prevention devices, especially if the well water is mixed with chemicals such as fertilizer and pesticides near the well.

- 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
Wire Mesh
Discharge Line
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



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 permited as "standby wells" by the District.*)

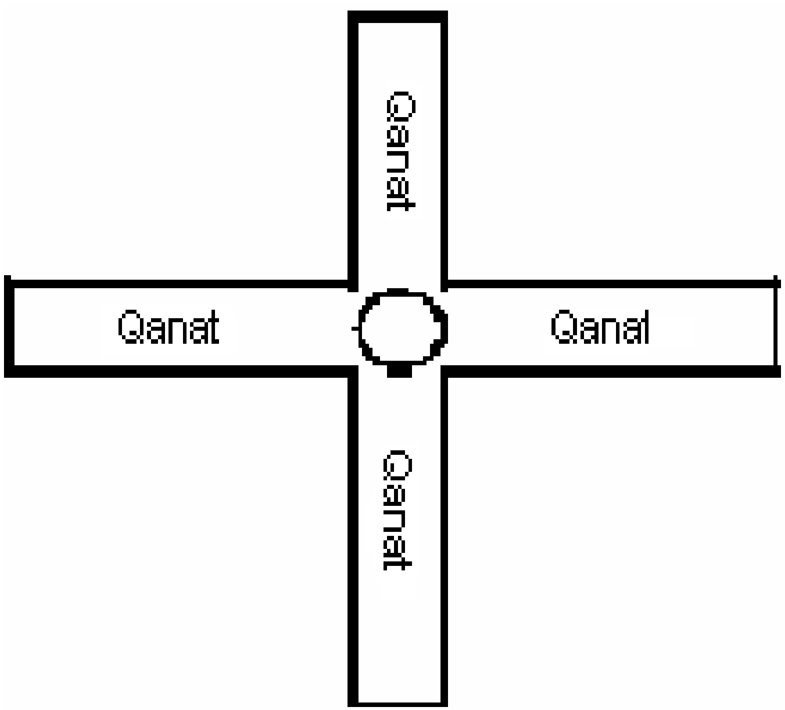
Figure 15: Guidelines for well inspection[48] (Santa Clara p. 5)

Guidelines for well inspection / maintenance

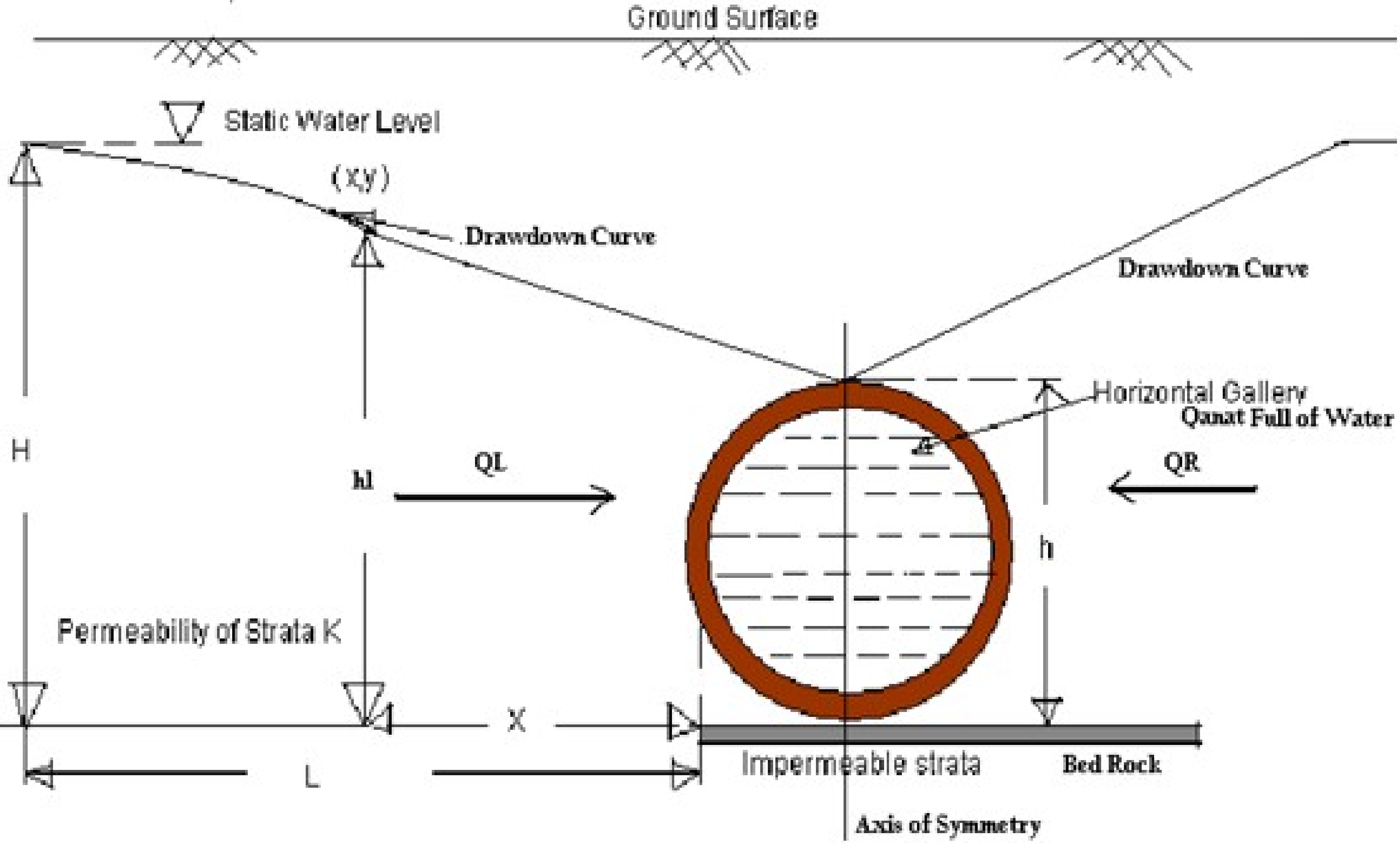
HORIZONTAL WELL – QANAT'S DESIGN

- 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 [6,7].
- 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 [Fig.2].

- The qanats may be pipes of permeable material of 0.5 to 1.5 m diameter, set at a depth of 1 to 5 m 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.

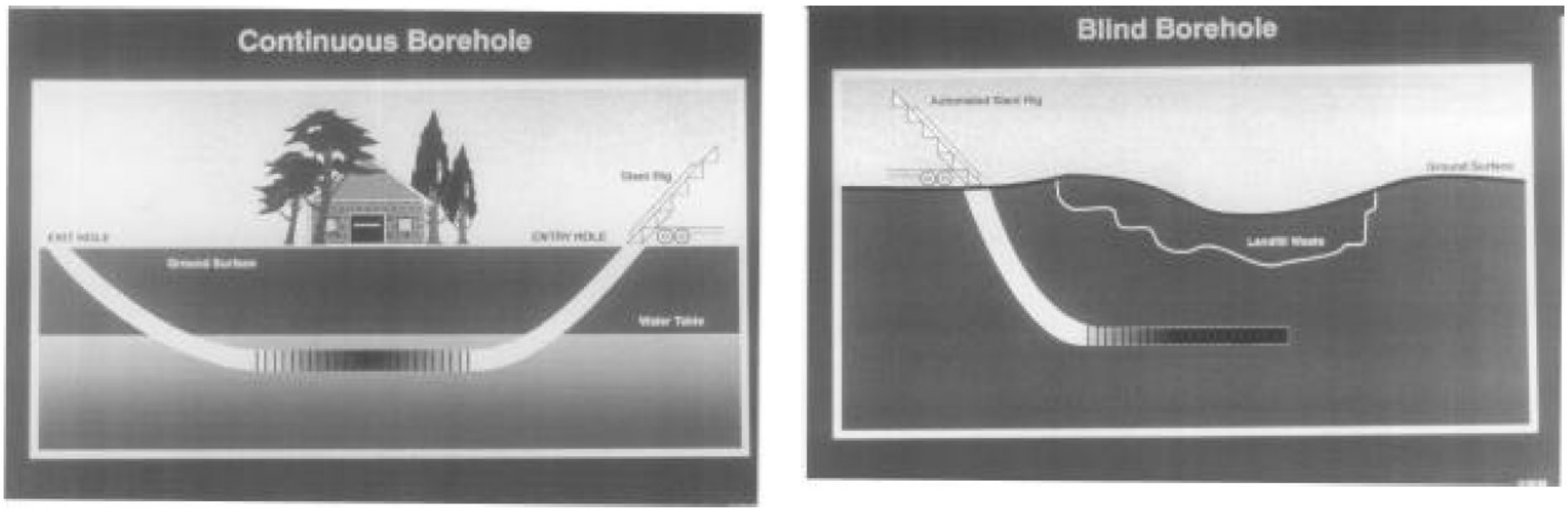
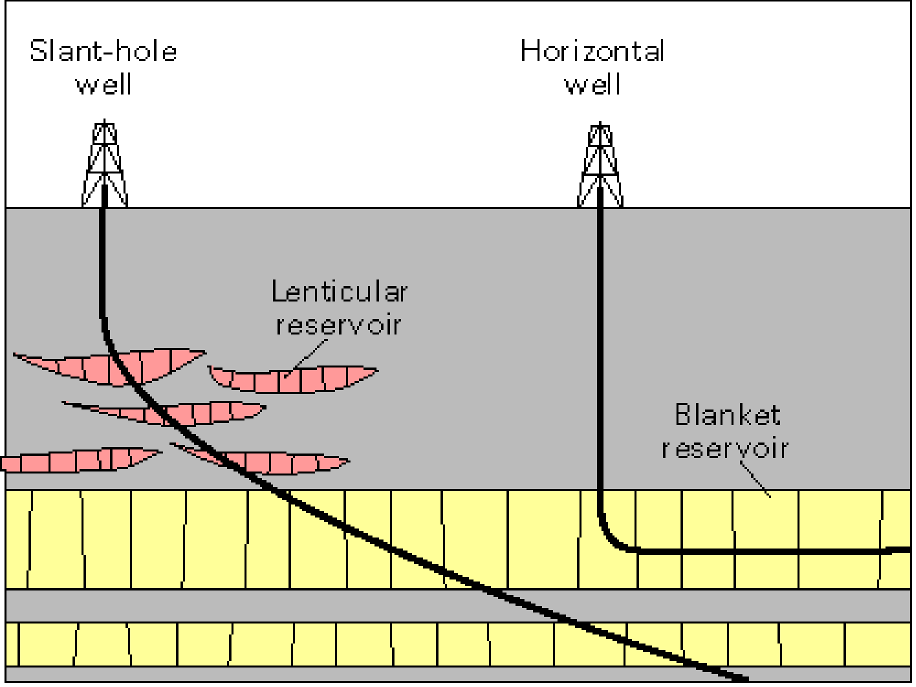


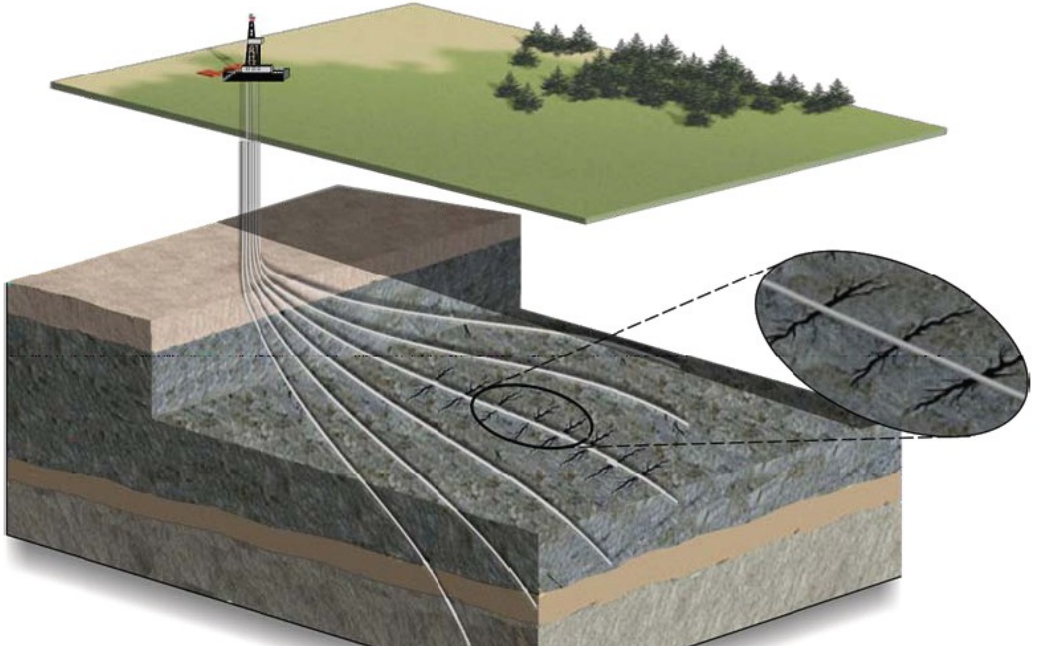
Figure 3. Horizontal environmental well types.

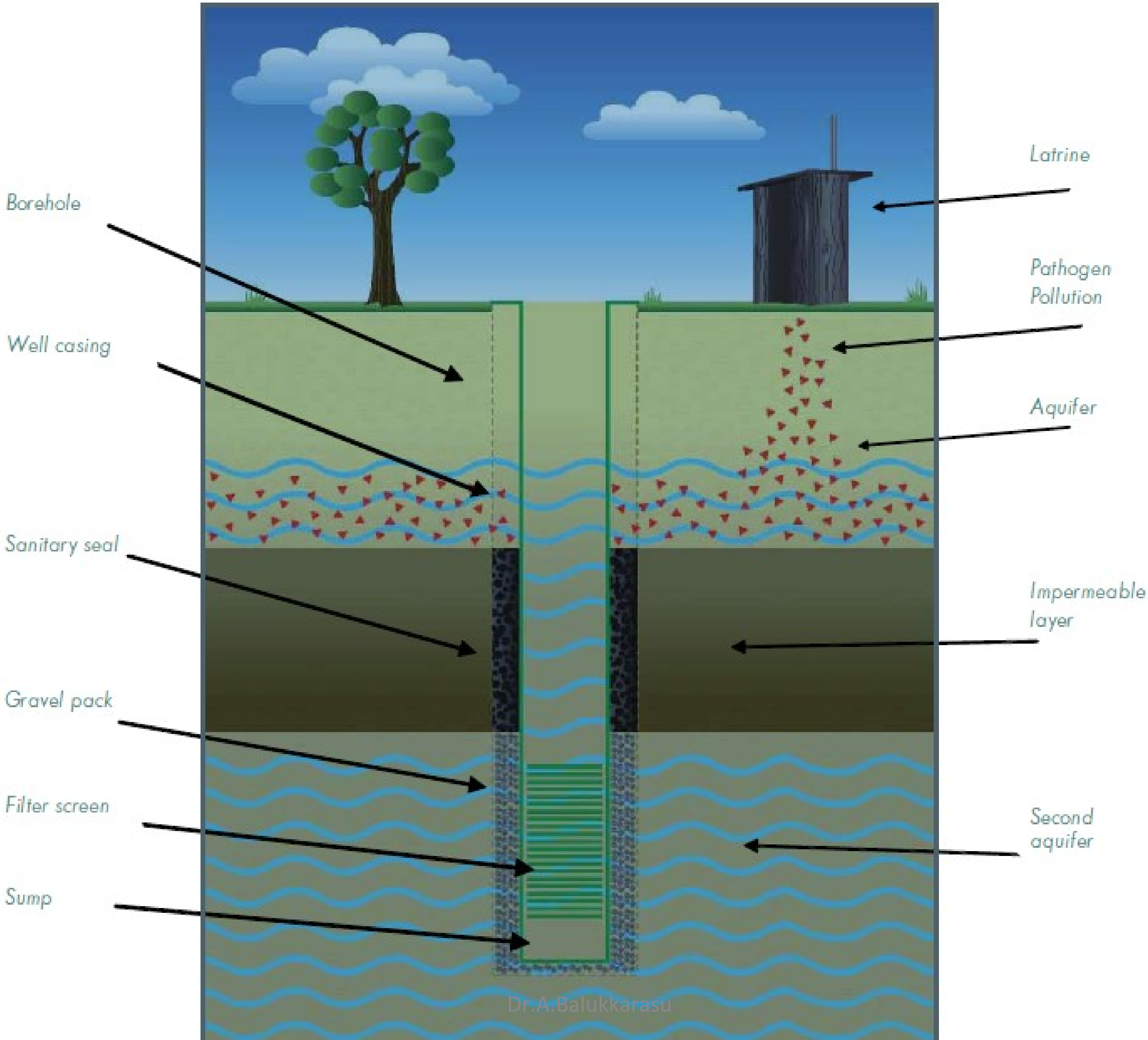
Horizontal environmental wells are designed to enhance access to soil and ground-water contamination and to increase the remediation efficiency compared to the baseline technology (vertical wells) by vastly increasing the per-well zone of influence.

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



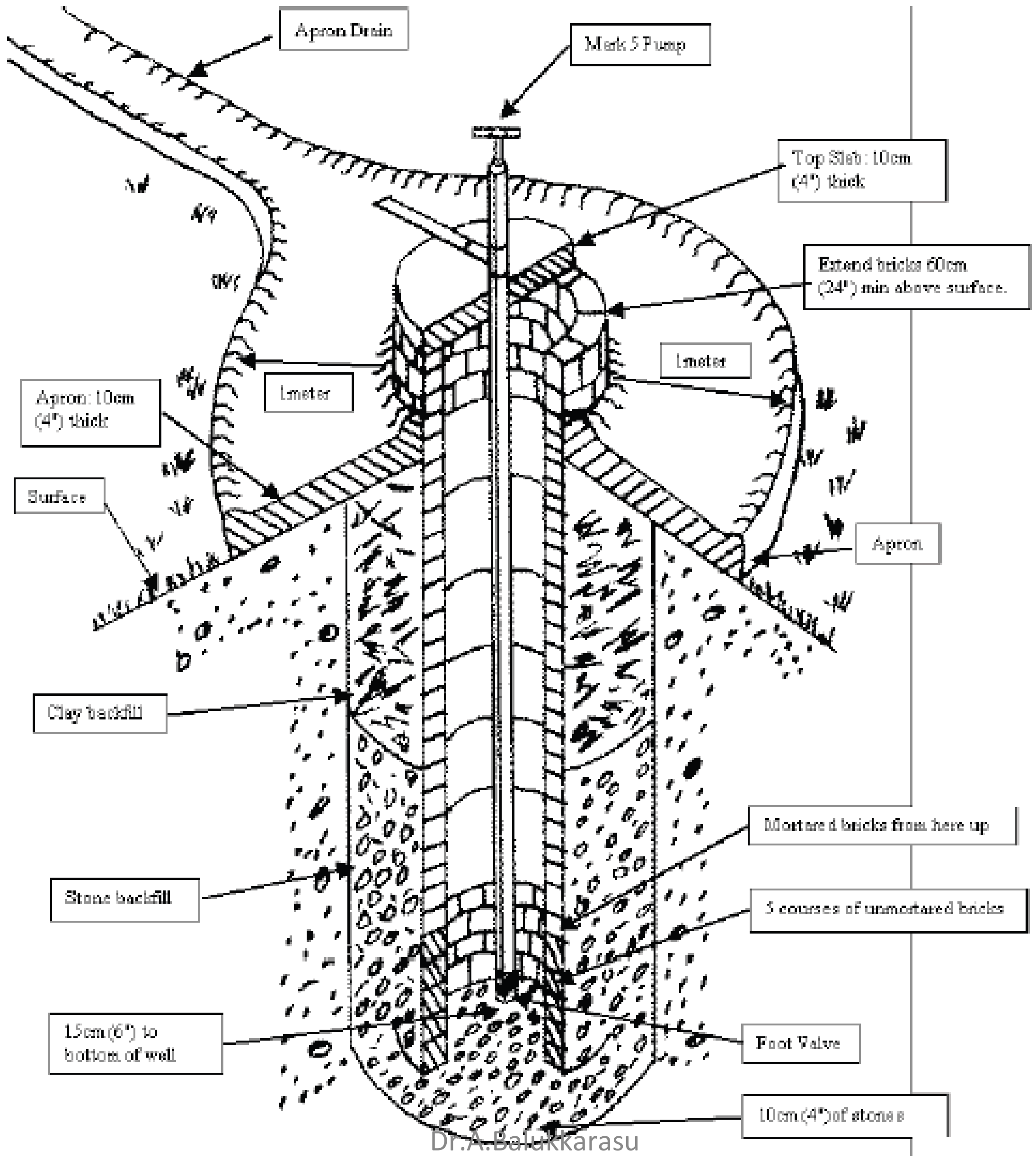

Borehole
Well casing
Sanitary seal
Gravel pack
Filter screen
Sump
Latrine
Pathogen
Pollution
Aquifer
Impermeable
layer
Second
aquifer

APPENDIX III

A typical protected shallow well fitted with a hand pump:

Dissected to show the internal components

(http://www.marionmedical.org/Manual/complete.htm)



Well Rehabilitation

- **Factors affecting well performance**

1. Aquifer properties, such as subsurface heterogeneity, and presence of low-permeability units or fractures
2. Contaminant properties, such as level of sorption to soil, of a separate non-aqueous phase, and partitioning to a separate non-aqueous phase
3. Adequacy of source removal and size of the plume itself
4. System design, such as pumping rate, location of extraction wells, and depth/length of screened interval.

Well rehabilitation objective is:

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

Methods are:

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

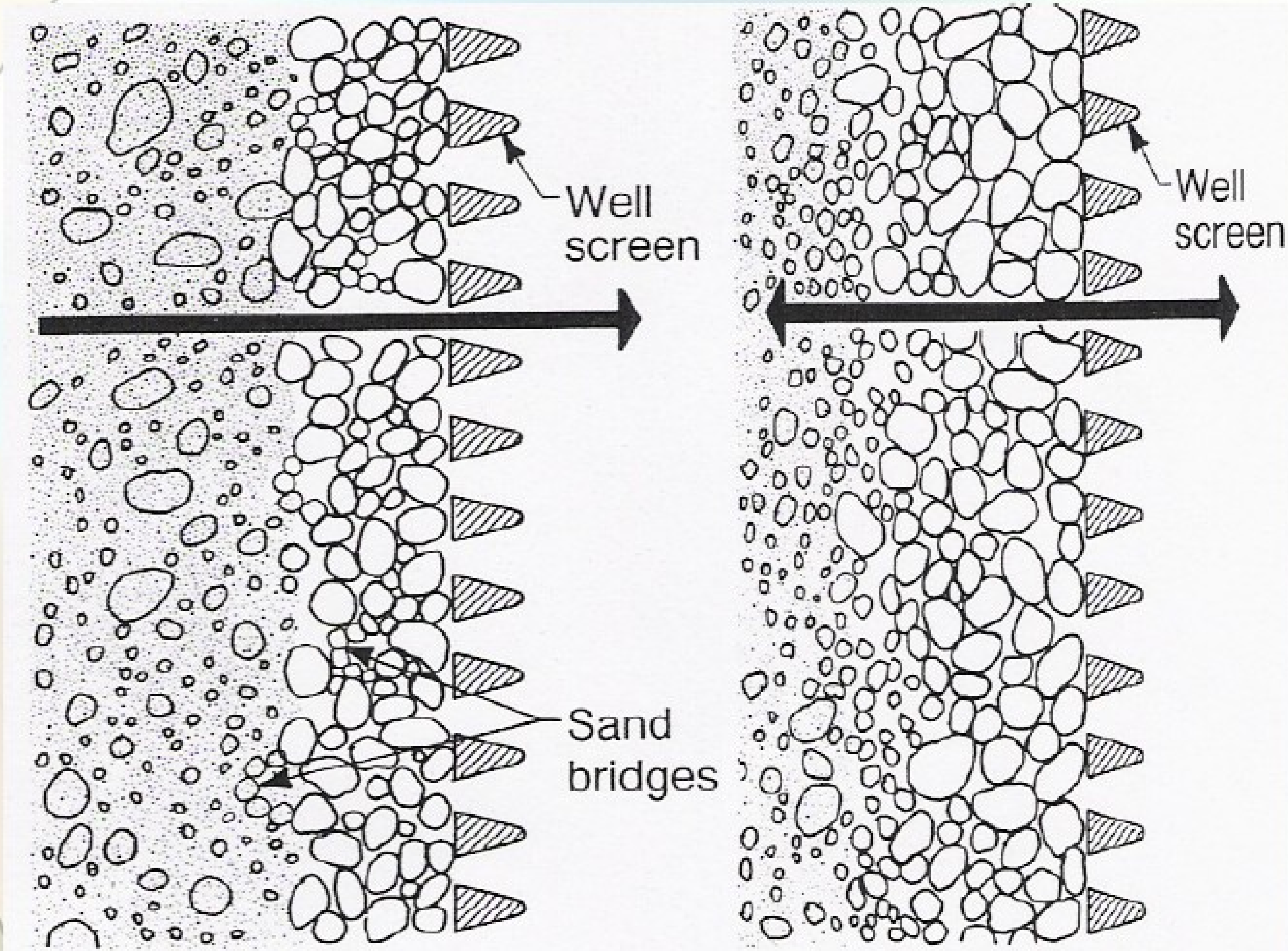
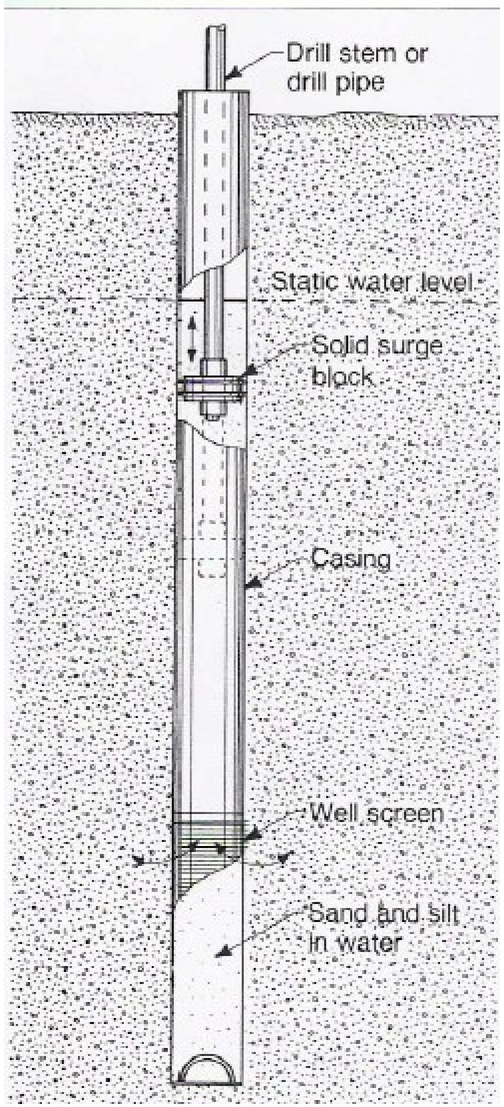
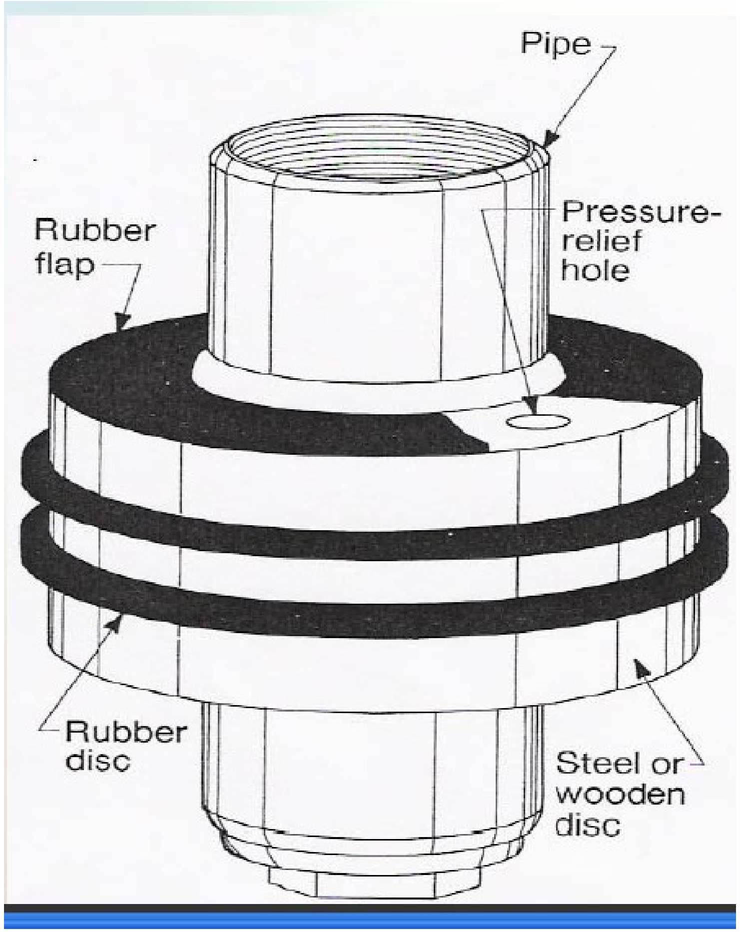
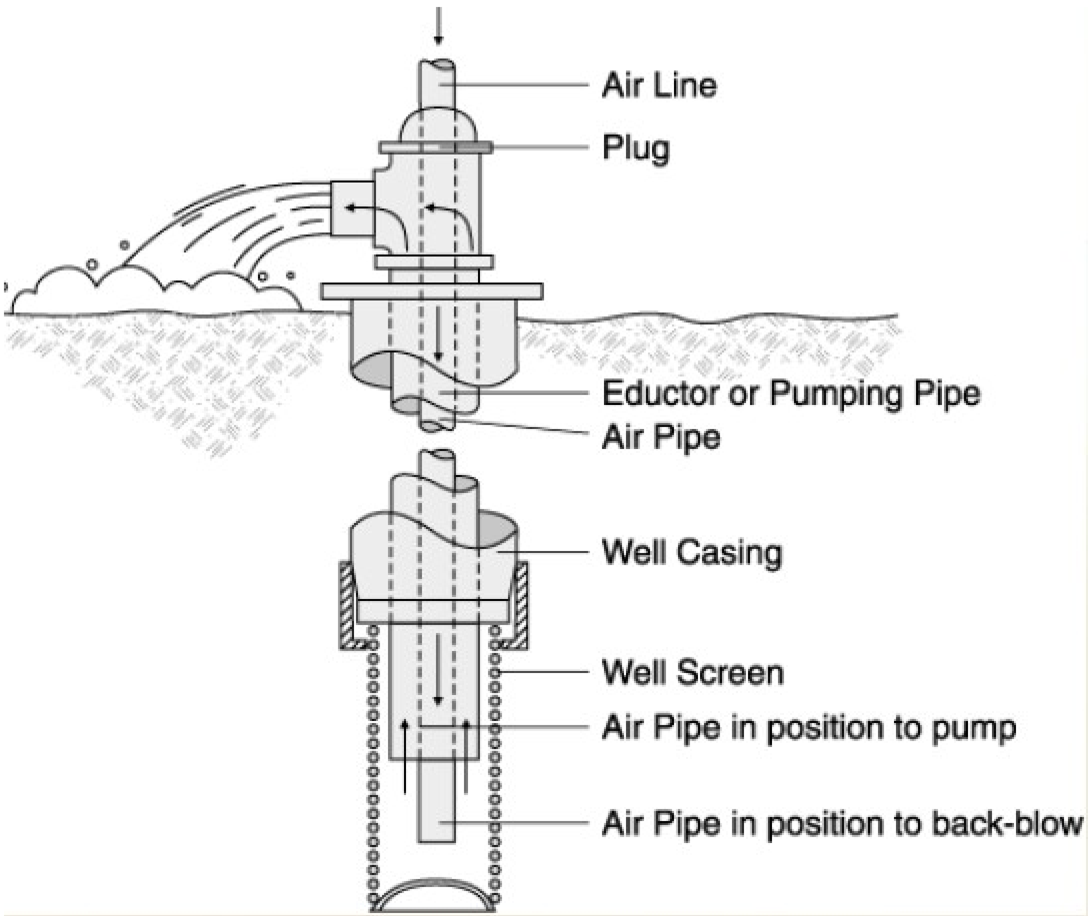


Figure 7: Back washing effect on breaking down bridge of particles.

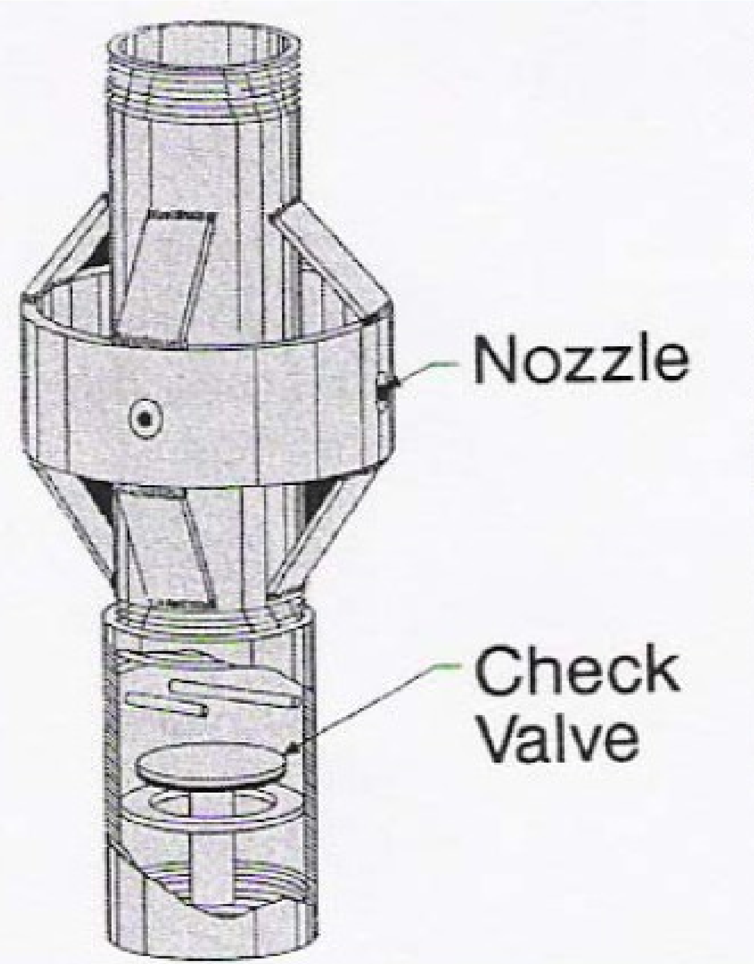


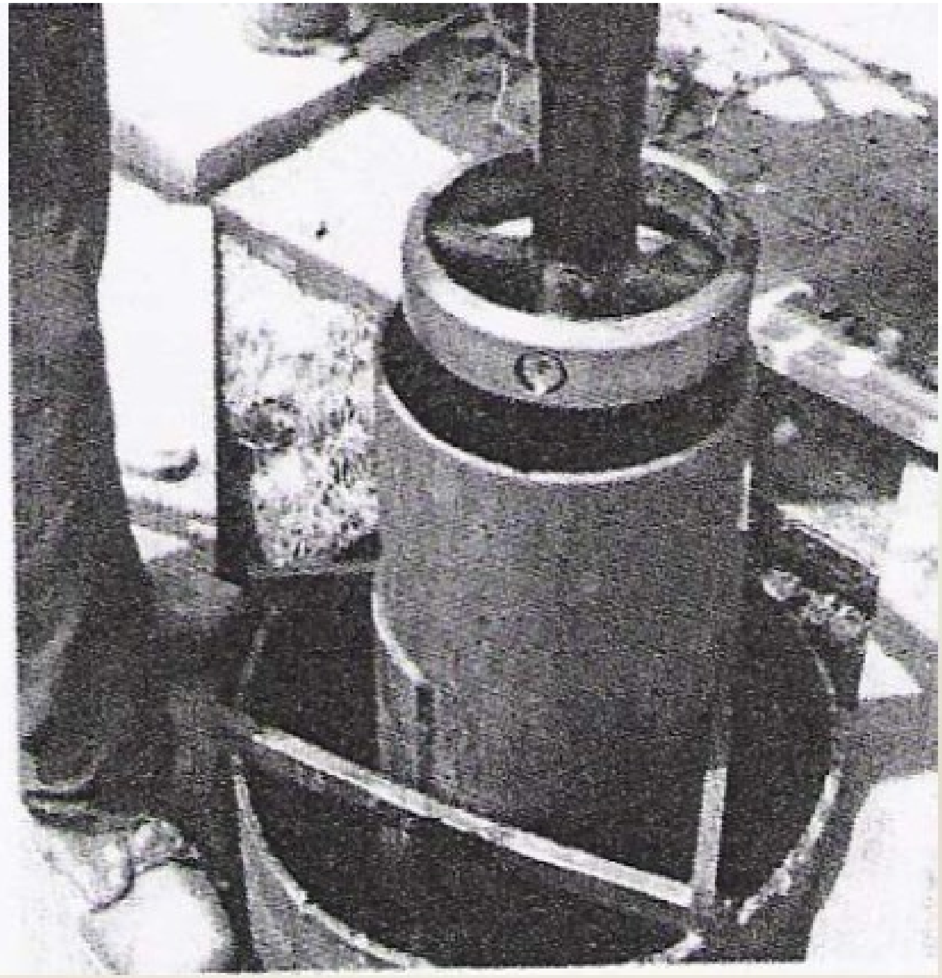


Mechanical surging by using solid surge block



e 9: Well redevelopment using airlift pumping and agitation





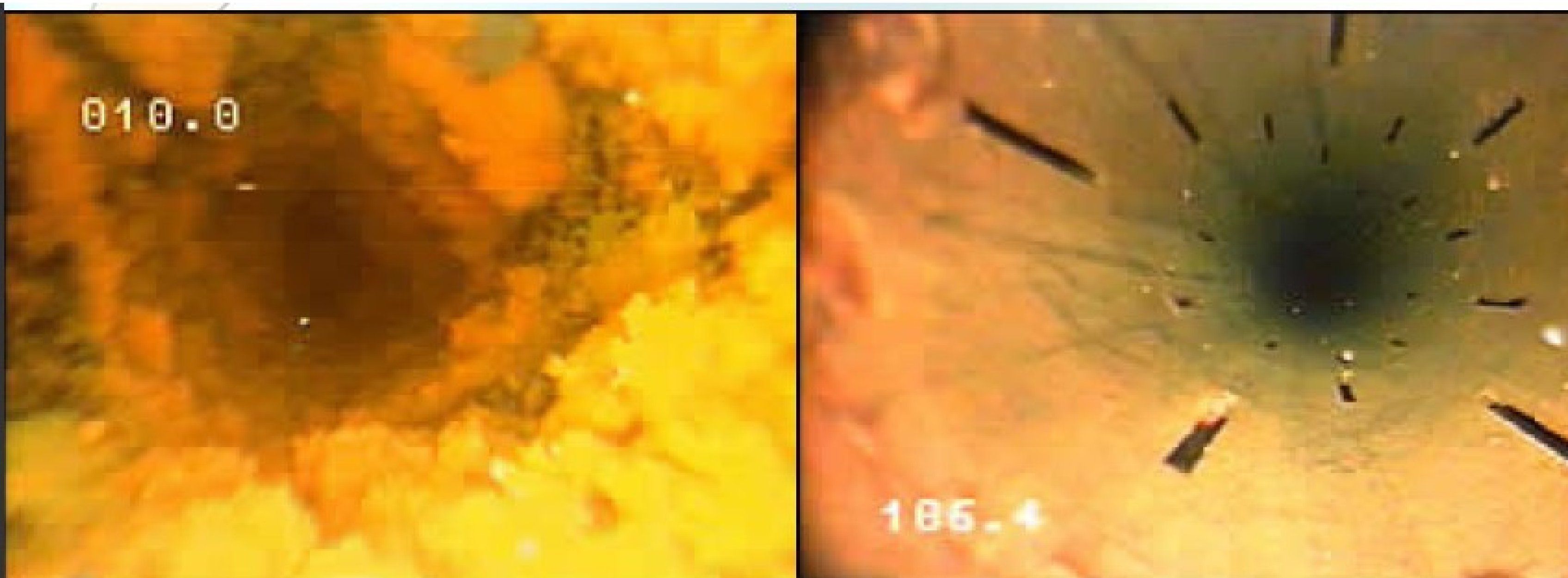
ıre 15: Four-nozzle jetting tool designed for jet development of well screens.

Re-development

- 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.*

AQUIFER DEVELOPMENT TECHNIQUES

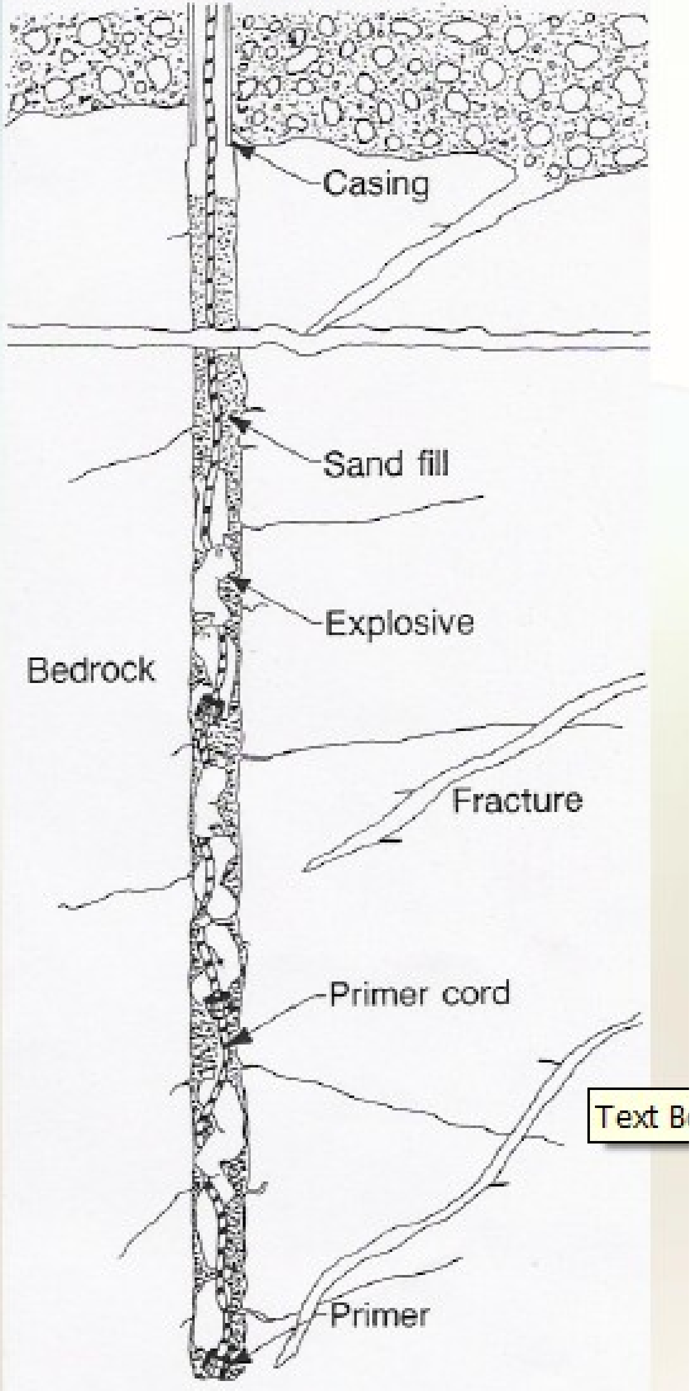
1 Use of acid
2 Use of explosives
3 Disinfection of wells by chlorination
4. Use of hydrochloric acid in carbonate lithology



Before: severe clogging of slots

After: open area restored

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



Placement of explosives in the well.

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.