CHAPTER 4

COLLECTION OF WATER

SALT WATER INTRUSION

A special type of underground water is fresh water found on islands or in the coastal regions near the sea. The fresh water permeates in the porous layer and floats over sea water as an underground lens. The fluctuation of fresh water is downward and upward within this lens.

Fresh water in contact with salt water adjacent to a coast line is given in Figure 1. This figure illustrates the initial equilibrium (when there is no drawdown).

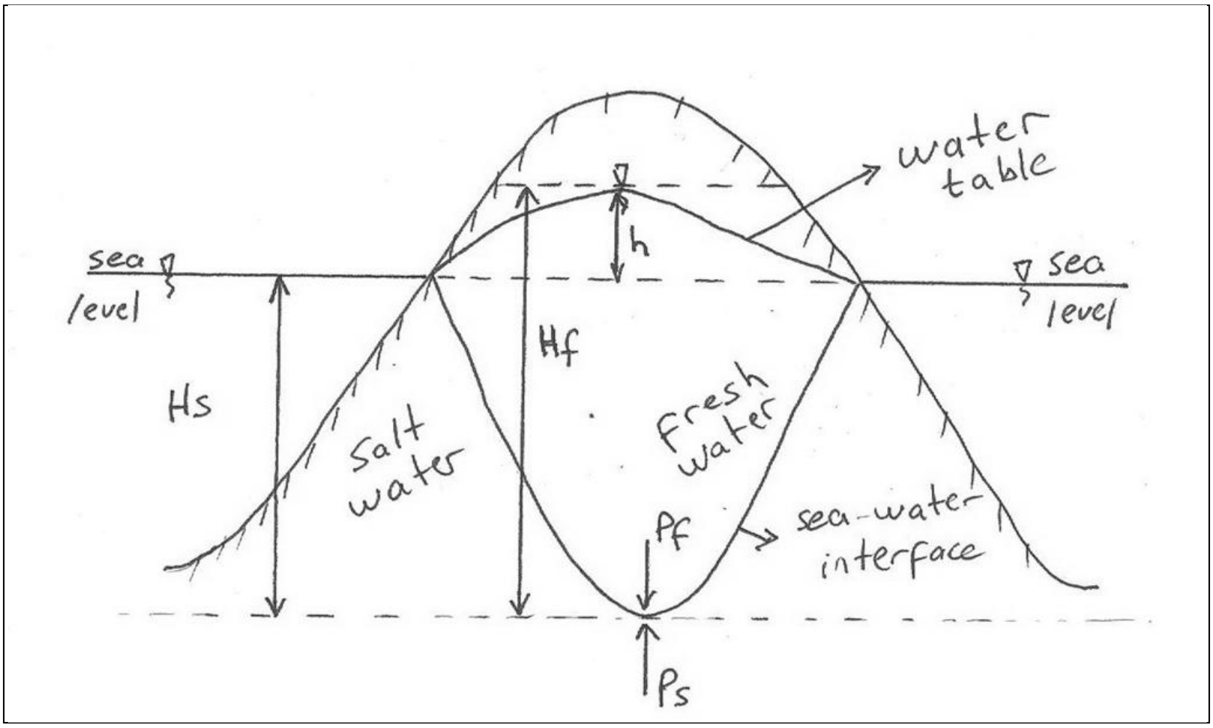


Figure 1: Fresh water in contact with salt water adjacent to a coast line (initial equilibrium)

where
H_f = thickness of fresh water (m)
H_s = height of salt water above the bottom of fresh water lens (m)
H = height of the groundwater table above sea level (m)

The pressure due to salt water must balance the pressure due to fresh water at the bottom of fresh water. So, according to initial equilibrium (Figure 1):

Pressure due to fresh water (P_f) = Pressure due to salt water (P_s)

$P_f = P_s$

and then

$$\rho_f . g . H_f = \rho_s . g . H_s$$

$$\rho_f . g . (H_s + h) = \rho_s . g . H_s$$

These equations show the static condition when there is no drawdown.

ρ_f = density of fresh water (kg/m^3)
ρ_s = density of salt water (kg/m^3)
g = acceleration due to gravity (m/sec^2)

If pumping is done, the thickness of the fresh water lens will be reduced and situation in Figure 2 will occur. This figure shows the final equilibrium after drawdown of d.

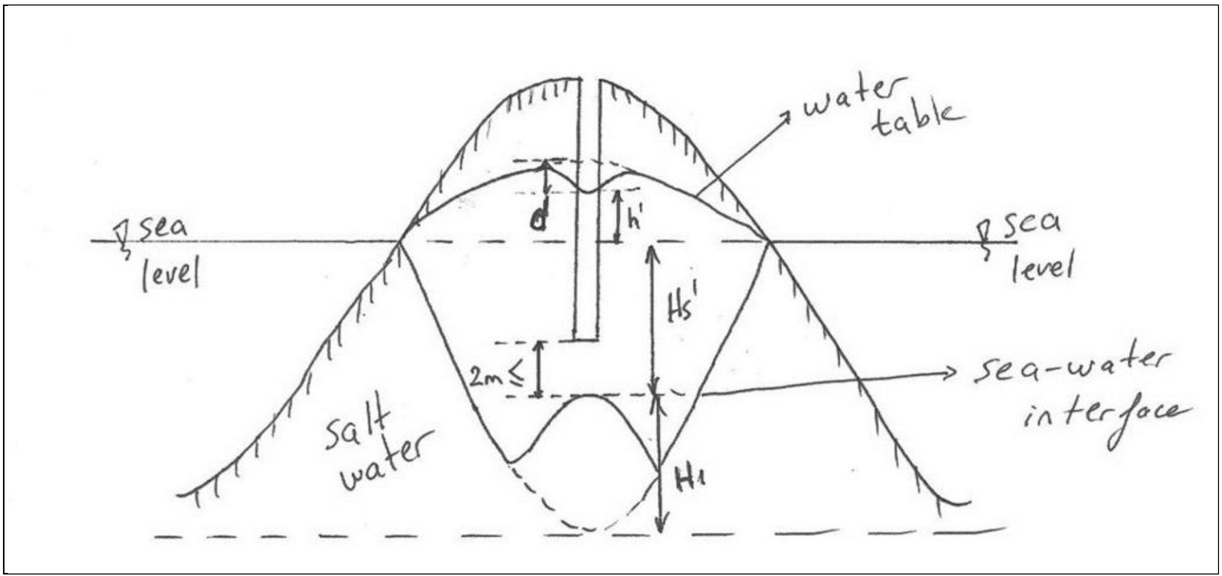


Figure 2: Final equilibrium after drawdown d.

In Figure 2, H_1 is the height of rise of the sea-water interface.

Final equilibrium will be

$$\rho_f . g . H'_f = \rho_s . g . H'_s$$

WELLS

Assumptions [1]:

- The aquifer is bounded on the bottom by a confining layer.
- All geologic formations are horizontal and of infinite horizontal extent.
- The potentiometric surface of the aquifer is horizontal prior to the start of the pumping.
- The potentiometric surface of the aquifer is not changing with time prior to the start of the pumping.
- All changes in the position of the potentiometric surface are due to the effect of the pumping well alone.
- The aquifer is homogeneous and isotropic.
- All flow is radial toward the well.
- Ground-water flow is horizontal.
- Darcy's law is valid.
- Ground water has a constant density and viscosity.
- The pumping well and the observation wells are fully penetrating, i.e., they are screened over the entire thickness of the aquifer.
- The pumping well has an infinitesimal diameter and is 100% efficient.
- In unconfined aquifers, pumping will result in drawdown of the water table.
- In confined aquifers, pumping will cause drawdown of the potentiometric surface.

Definitions:

Aquifer [2]:A water-bearing layer of rock, or of unconsolidated sediments, that will yield water in a usable quantity to a well or spring.

Confining Bed [2]:A layer of rock, or of unconsolidated sediments, that retards the movement of water in and out of an aquifer and possesses a very low hydraulic conductivity.

Unconfined aquifer [2]: An aquifer is considered unconfined if water only partially fills the aquifer materials and water freely rises and declines along the unsaturated/saturated zone boundary. These unconfined aquifers are often referred to as water-table aquifers and wells that are opened to these unconfined aquifers indicates the position of the water-table.

Confined aquifer [2]: A confined aquifer is generally defined when water completely fills the aquifer materials and is overlain by a confining bed. A common term for a confined aquifer is an artesian aquifer. The water level from a well that permits water solely from a confined aquifer to enter the well will stand at some point above the top of the confined aquifer but not necessarily above the land surface. The water level in a well open to a specific confined aquifer stands at the level of the potentiometric surface. If the potentiometric surface is above land, the well is often considered as a free-flowing artesian well.

Drawdown [1]: It is the lowering of water table caused by pumping of wells and defined as the difference between elevations of the current water table and water table before pumping began.

Cone of Depression [1]&[2]: It will form in the aquifer around a pumping well as the water level declines. As water is withdrawn from a well, the water level in the well begins to decline as water is removed from storage in the well. The head in the well will fall below the level of the surrounding aquifer and water begins moving from the aquifer into the well. The water level will continue to decline and the flow rate of water into the well will increase until the inflow rate is equal to withdrawal rate. Water from the aquifer must converge on the well from all directions and the hydraulic gradient must get steeper near the well. For this reason the resultant 3-D shape of water withdrawal is a called a cone of depression.

UNCONFINED STEADY FLOW IN WELLS

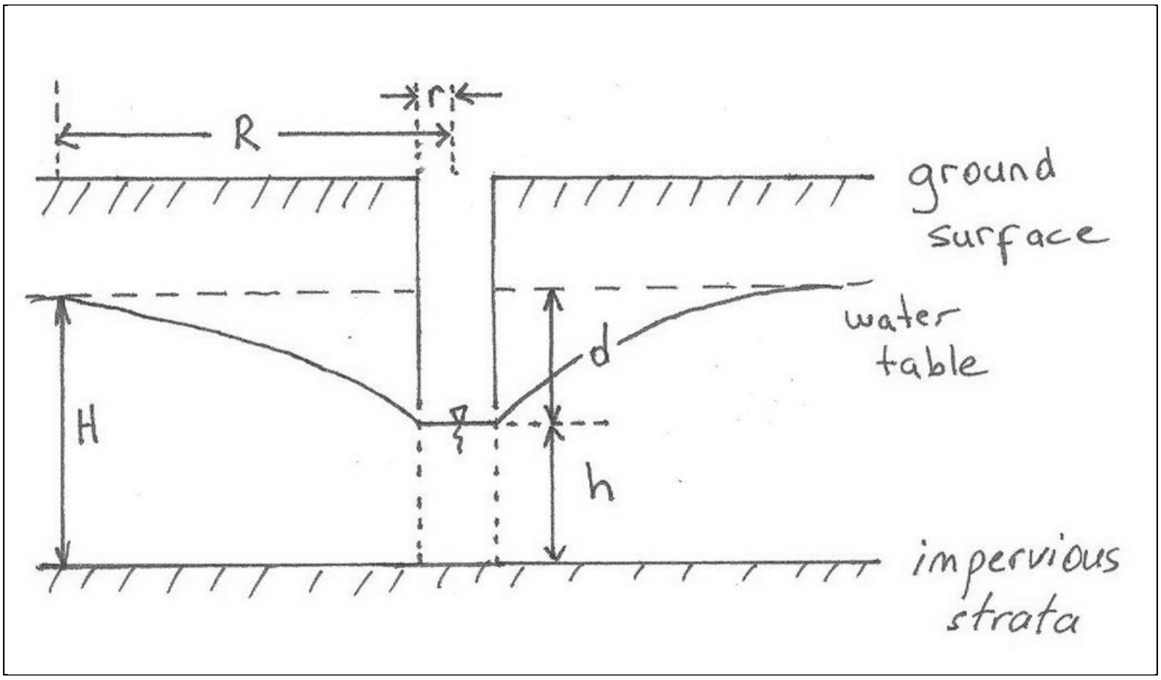


Figure 3: Schematic view of an unconfined aquifer after drawdown d.

The yield from an unconfined aquifer can be formulized as follows:

$$\boldsymbol{Q = \frac{k\pi(H^2 - h^2)}{Ln\frac{R}{r}}}$$

where
Q = yield from an unconfined aquifer (m^3/sec)
k = permeability coefficient (m/sec)
H = height of the water table (m)
h = height of the water in the well (m)
R = radius of influence (m)
r = radius of the well (m)

Radius of influence can be calculated empirically as:

$$\boldsymbol{R = 3000\, d \sqrt{k}}$$

where
d = drawdown from the well (m)
k = permeability coefficient (m/sec)

CONFINED STEADY FLOW IN WELLS

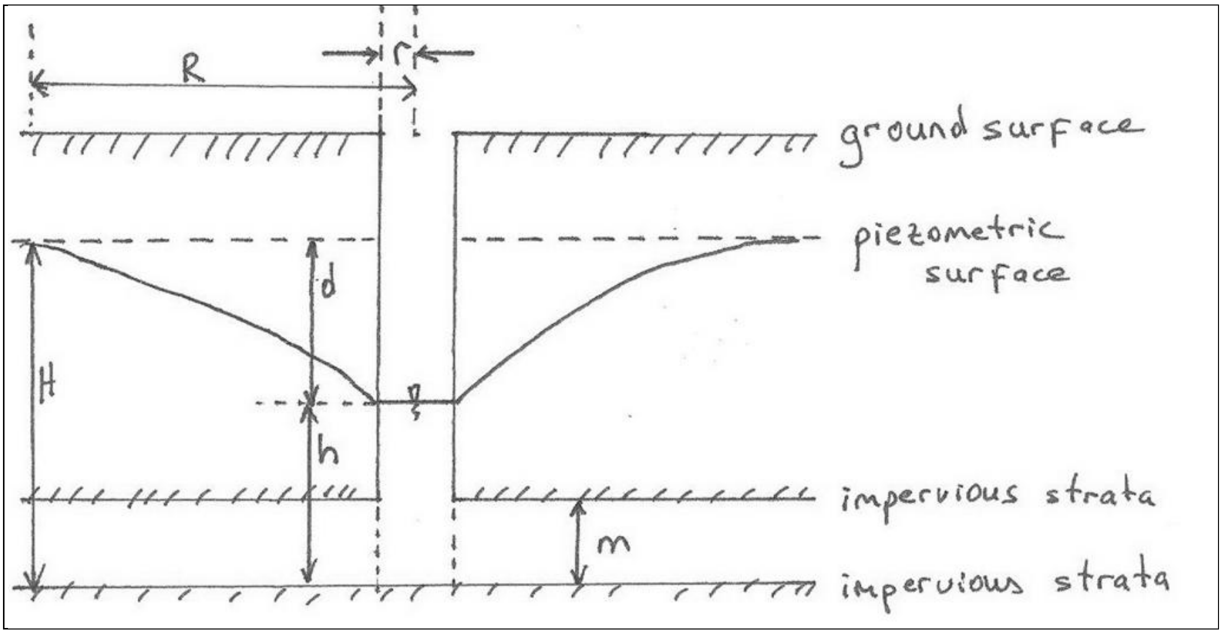


Figure 4: Schematic view of a confined aquifer after drawdown d.

The yield from a confined aquifer can be formulized as follows:

$$\boldsymbol{Q = \frac{2k\pi m(H-h)}{Ln\frac{R}{r}}}$$

where
Q = yield from an unconfined aquifer (m^3/sec)
k = permeability coefficient (m/sec)
H = height of the piezometric surface (m)
h = height of the water in the well (m)
m = thickness of the water bearing strata (m)
R = radius of influence (m)
r = radius of the well (m)

PUMPING TEST FOR SOIL PERMEABILITY (ONSERVATION WELLS)

A pumping test is used to determine the permeability of soil. Observation wells are sunk at varying distances from the test well to measure the drawdown.

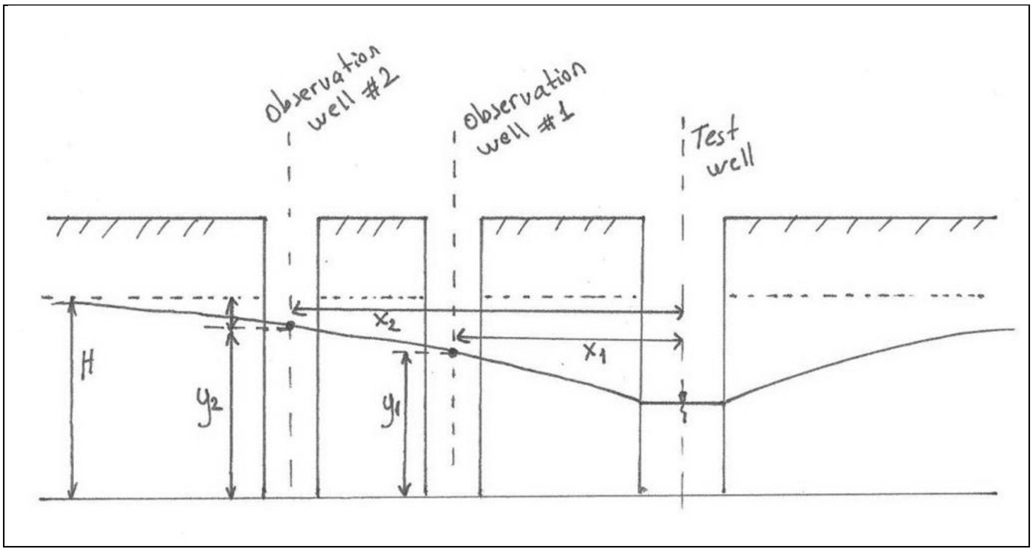


Figure 5: Observation wells for an unconfined aquifer.

For unconfined flow (Figure 5), k is calculated as:

$$\boldsymbol{K} = \frac{\boldsymbol{Q}.\boldsymbol{Ln}\frac{\boldsymbol{x_2}}{\boldsymbol{x_1}}}{\boldsymbol{\pi}(\boldsymbol{y_2^2} - \boldsymbol{y_1^2})}$$

where

Q = yield from an unconfined aquifer (m^3/sec)

x_i = horizontal distance from the test well i (m)

y_i = height of the water in the observation well i (m)

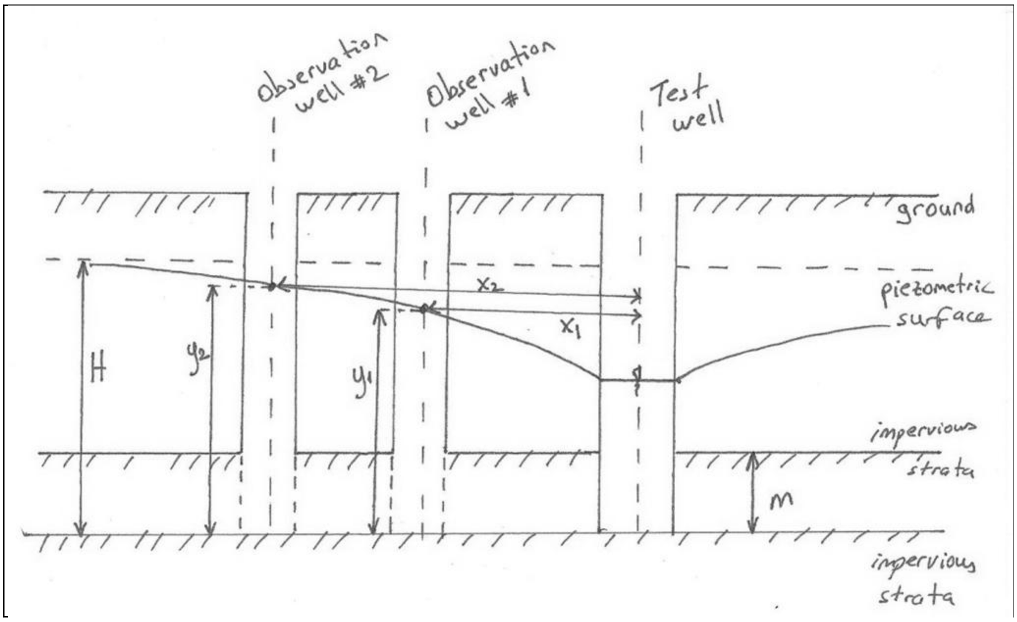


Figure 6: Observation wells for a confined aquifer.

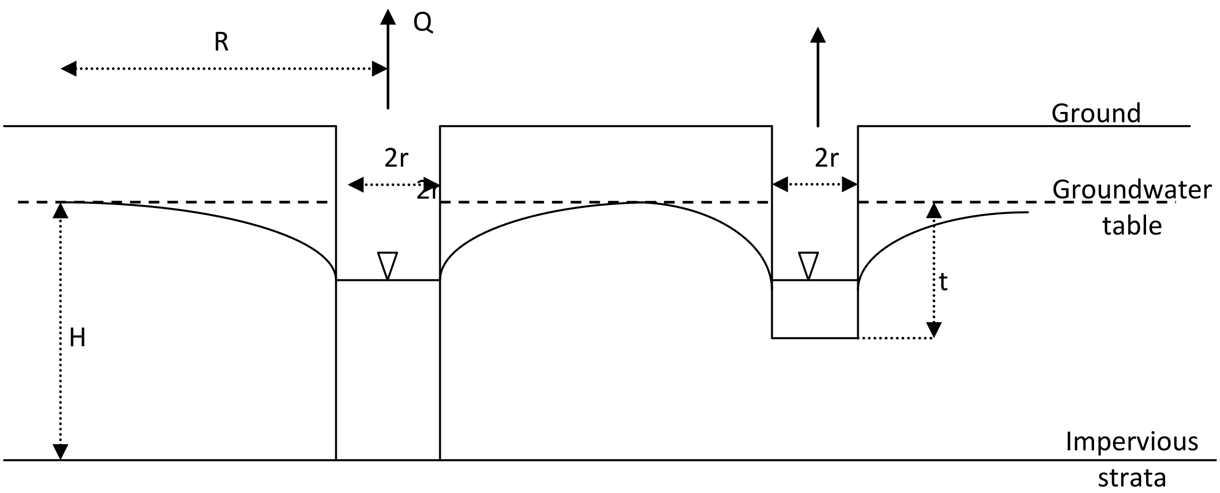
For confined flow, k is calculated as:

$$K = \frac{Q.Ln\frac{x_2}{x_1}}{2\pi m(y_2 - y_1)}$$

where
Q = yield from a confined aquifer (m^3/sec)
x_i = horizontal distance from the test well i (m)
y_i = height of the water in the observation well i (m)
m = thickness of the aquifer (m)

PARTIALLY IMMERSED WELLS

These wells are not driven in to the bottom of impervious strata. If the water bearing strata is too thick or hard, those wells will be used because of technical and economical.



To calculate the yield from a partially immersed well, we use:

$$\frac{q}{Q} = \left(\frac{t}{H}\right)^{1/2}\left(\frac{2H - t}{H}\right)^{1/4}$$

where
Q = yield of a well which is driven to the bottom of impervious layer and having the same radius as partially immersed well (m^3/sec)
q = yield of a well which is driven t meters (not up to impervious strata) (m^3/sec)

STAGNATION POINT

In a sloping piezometric surface the flow net does not consist of radial flow lines and concentric equipotential lines as the cone of depression does not remain symetrical.

For confined aquifer:

$$Q = \frac{2\pi km(H-h)}{Ln\frac{R}{r}}$$

Flow through unit depth of aquifer:

$$q = \frac{Q}{m}$$

The distance of point of stagnation:

$$X = \frac{q}{2\pi V_u}$$

And $V_u = k.i$

OPTIMUM FLOW FOR CONFINED & UNCONFINED WELLS

Qmax = permissible capacity of well = A *x* Vmax

$Vmax = \frac{\sqrt{k}}{30}$ for dug wells

$Vmax = \frac{\sqrt{k}}{30}$ for other wells

A = side area of the well and calculated as

$A = 2\pi rh$ for unconfined wells and

$A = 2\pi rm$ for confined wells.

As a result Qpermissibe can be calculated as

For unconfined wells:

$$Q = 2\pi rh(Vmax)$$

For confined wells

$$Q = 2\pi rm(Vmax)$$

Q optimum can be found either by numeric solution or graphical approach.

<u>Numerical solution</u>:

When $Q_{yield} = Q_{permissible}$ then Q optimum will be equal to that value. This equality is solved by trial & error.

Graphical solution:

Plot the values of Q yield and Q permissible. X-axis will be flow and Y-axis will be H. The intersection point will be Q optimum.

TYPES OF WATER WELLS

Wells can be classified as shallow and deep. Wells up to 35 m depth are classified as shallow wells. A shallow well receives water from the subsoil overlying an impervious stratum. It may be contaminated by the surface water percolation through the soil from nearby areas.

A deep well (more than 35 m) receives water from an aquifer below an impervious strata. Chances of such a well becoming contaminated are remote.

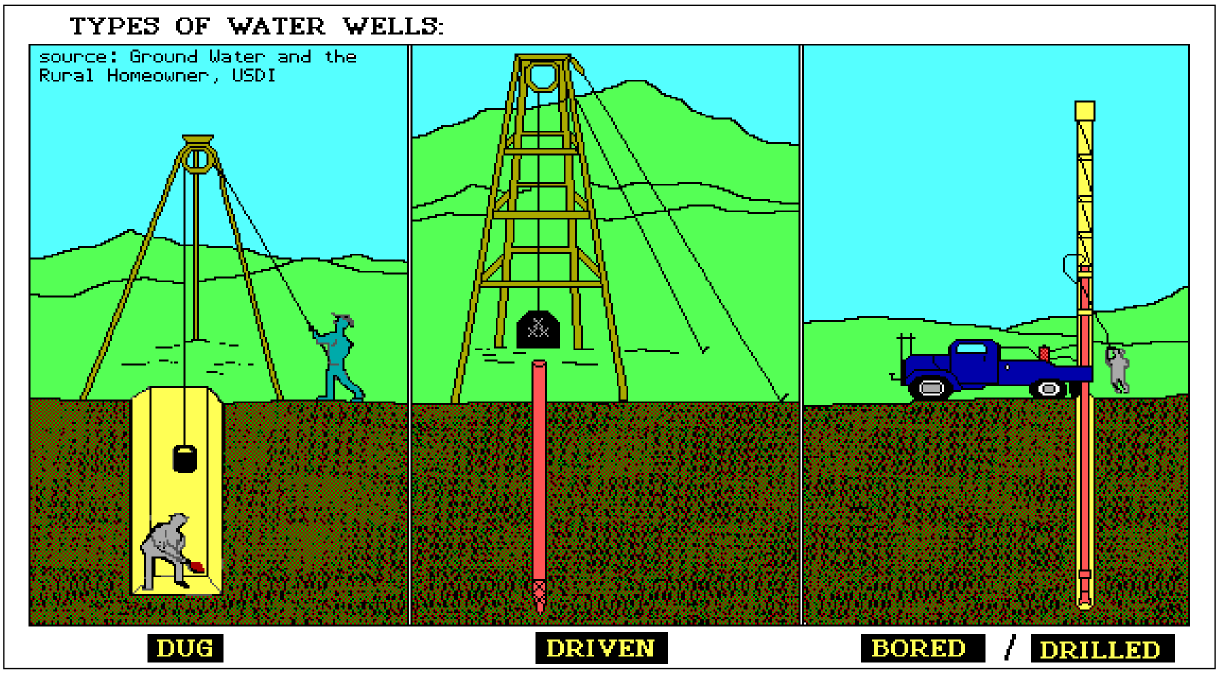


Figure 7. Types of wells according to their construction method [3].

Dug Wells:

Historically, dug wells were excavated by hand shovel to below the watertable until incoming water exceeded the digger's bailing rate. The well was lined with stones, brick, tile, or other material to prevent collapse, and was covered with a cap of wood, stone, or concrete [3]. Depths may vary between 5 to 15m. Diameter of the well may be between 1 and 5m.

Bored Wells:

An earth auger rotated, by hand or power, bores the hole and carries the earth to the surface. Casing is usually steel, concrete or plastic pipe. Bore hole diameter ranges from 5 to 75 cm. Bored wells can be up to 300m deep. The soil should be cohesive so that the sides of the hole do not cave in. A concrete or metal casing is inserted in the hole and cemented in place before the strainer is installed [3].

Driven Wells:

They are constructed by driving assembled lengths of pipe into the ground with percussion equipment or by hand. Normally 5 cm or less in diameter and less than 15m deep. They can only be installed in areas having relatively loose soils, such as sand or gravel. Usually a screened well point is attached to the bottom of the casing before driving. Relatively simple and economical to construct. Poses a moderate to high risk. Easily contaminated from nearby surface sources[3].

Drilled Wells:

They are constructed by either percussion or rotary-drilling machines. Drilled wells that penetrate unconsolidated material require installation of casing and a screen to prevent inflow of sediment and collapse. They can be drilled more than 300m deep. To prevent contamination by water draining from the surface downward around the outside of the casing, the space around the casing must be sealed[3].

Methods to Drill Wells:

1) Percussion method (soft clay to hardest rock)

2) Hydraulic rotary (hard rock)

3) Core drill (hard rock)

4) Water jet borings (soft, unconsolidated alluvial deposits)

INFILTRATION GALLERRIES

- They are used to collect groundwater located not deeper than 6-7m.
- They are horizontal tunnels or perforated pipes constructed through water bearing strata (aquifer).
- They are laid in a direction nearly normal to the direction of groundwater flow.
- Perforated pipes are enclosed in gravel pebbles to prevent entrance of sand or other fine grained materials into the pipe.
- They can be constructed:
    a) Adjacent to a river or artificial recharge basin from which water may be obtained by seepage.
    b) Into the sides of hills and mountains.
    c) At right angles to artificially built valleys between hills.
- Groundwater enters into galleries from one side or two side depending on the characteristics of groundwater.

ONE SIDED GALLERIES

If the groundwater table has a slope, i.e, not horizontal.

Unconfined aquifer:

Yield equation for unconfined one sided aquifer

$$\boldsymbol{Q = \frac{kL(H^2 - h^2)}{2R}}$$

Confined aquifer (galleries usually are constructed in unconfined aquifers):

Yield equation for confined one sided aquifer

$$\boldsymbol{Q = \frac{kmL(H - h)}{R}}$$

TWO SIDED GALLERIES

If the groundwater table does not have slope, i.e, horizontal.

Unconfined aquifer:

Yield equation for unconfined two sided aquifer

$$\boldsymbol{Q = \frac{kL(H^2 - h^2)}{R}}$$

Confined aquifer (galleries usually are constructed in unconfined aquifers):

Yield equation for confined two sided aquifer

$$\boldsymbol{Q = \frac{2kmL(H - h)}{R}}$$

Design Criteria for Galleries:

1. The velocity of water ranges between 0.2 - 0.4 m/sec.
2. They are designed for half-full flow. Minimum diameter is taken as 10 cm.
3. On perforated pipelines, manholes are placed at every 50-100m for maintenance and inspection purposes.
4. The bottom of manholes are 40 - 60cm below the drainage pipe to collect sand present in water.
5. They are laid with a certain slope to provide flow with gravity

REFERENCES:

[1] http://www.cv.nctu.edu.tw/~wwwadm/chinese/teacher/Ppt-pdf/04Groundwater%20Flow%20to%20Wells.pdf

[2] http://www.ncwater.org/Education_and_Technical_Assistance/Ground_Water/Hydrogeology/

[3] http://pubs.usgs.gov/gip/gw_ruralhomeowner/gw_ruralhomeowner_new.html