LNCT GROUP OF COLLEGES
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Department of Civil Engineering

B.TECH – 6TH SEM

WATER RESOURCES AND IRRIGATION ENGINEERING

CE-603 (A)

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UNIT-II
GROUND WATER AND WELL IRRIGATION

Introduction

As established in this lessons, an enormous amount of water is stored within the ground. A small portion of that is in an unsaturated state but that below the water table, also called ground water, can be easily extracted for useful purpose, depending on the type and location within which the water exists. It has been roughly estimated that of the global water resources, about 0.6 percent exists as ground water, out of which about half can be economically extracted with the present drilling technology. In fact, the ground water is the largest source of fresh water on earth excluding the polar icecaps and glaciers. Hence, ground water has been extracted on all regions of the world for different purposes and about nearly one fifth of all the water used in the world is obtained from ground water sources.

Evidence of extraction of water from dug wells has been found in the archeological remnants of Mohenjodaro. In many of the cities established during the medieval ages in India, the main source of water was dug wells, though people were dependent on surface water bodies like rivers or, lakes, or ponds, if that happened to be nearby. It is only during the past century that tube wells became popular as an easily operatable source of extraction of ground water. Gradually with easy access to electricity deep tube wells have become a common source of water. However, establishment of tube well extraction of water involves knowledge about the movement of water through the geological formations, which has been discussed in Lessons 2.5 and 2.6. Water may have to be extracted from formations ranging from sand, silt, clay, fractured rocks of different compositions etc., A well may be dug to extract water from a confined or an unconfined aquifer. Digging of more than one well in close vicinity affects each others' yield as the drawdown of one influences the other. This may be quantitatively estimated by theories of ground water flow applied to the radial flow of water to each well. In this lesson, these theories are discussed, which would be helpful in designing such wells.

Steady flow and unsteady flows

Imagine a farmer using a deep tube or a dug well as a source of water for irrigating his field. The well may be fitted with a ***submergible pump*** or a ***centrifugal pump*** to draw out water and discharge at the head of a channel leading to the fields. As long as the pump is not in operation, the water in the well remains at a steady at a level, at that of the water table (Figure 1).

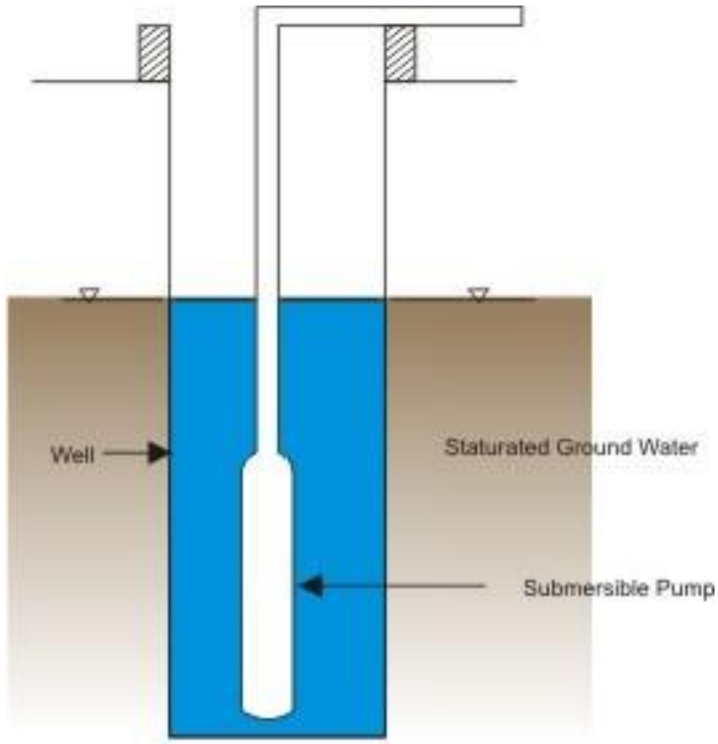

FIGURE 1. PUMP NOT STARTED

When the pump is just started, it starts drawing out water from the well and the level of water in the well decreases. The water table surrounding the well also gets lowered (Figure 2).

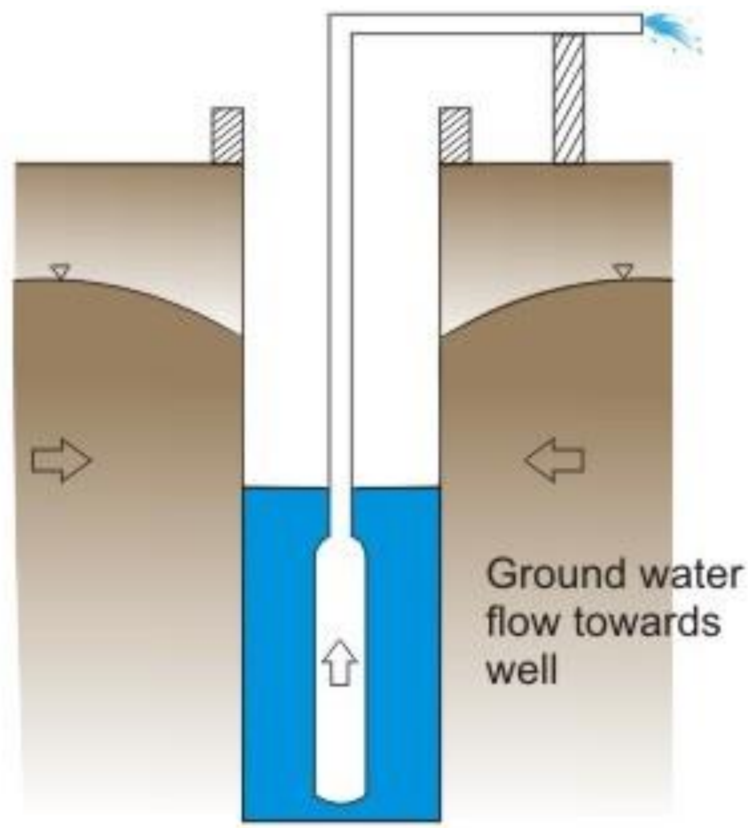

FIGURE 2. PUMP JUST STARTED

The water table gets lowered and forms a conical depression much like that shown in Figure 3.

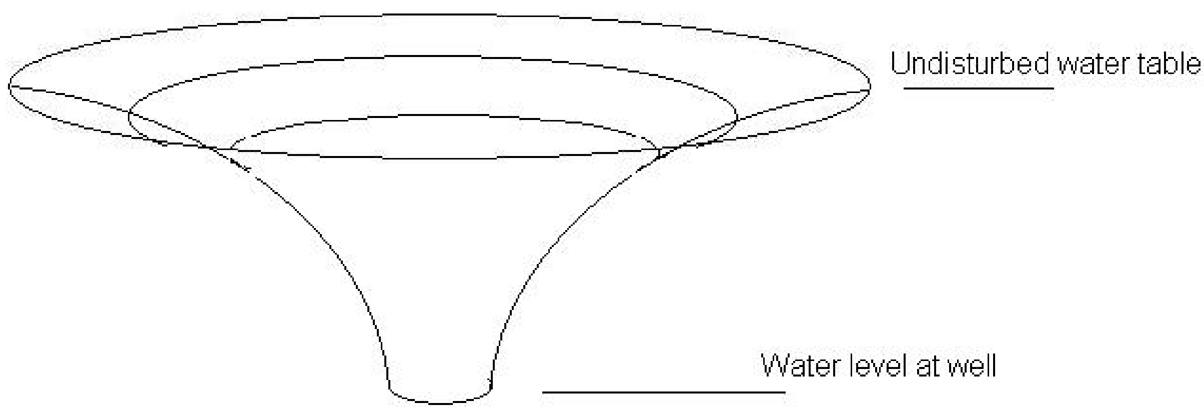

FIGURE 3. Cone of depression

It may be observed that the surface of the water table, shaped now in the form of a cone, is steepest where it meets the well. Farther away from the well, the surface is flatter and beyond a certain distance, called the radius of influence, the surface of the cone is almost as flat as the original water table.

As pumping continues (at the rated capacity of the pump), the water table gets lowered further until it becomes steady. At this position the water surface is called the draw down curve (Figure 4).

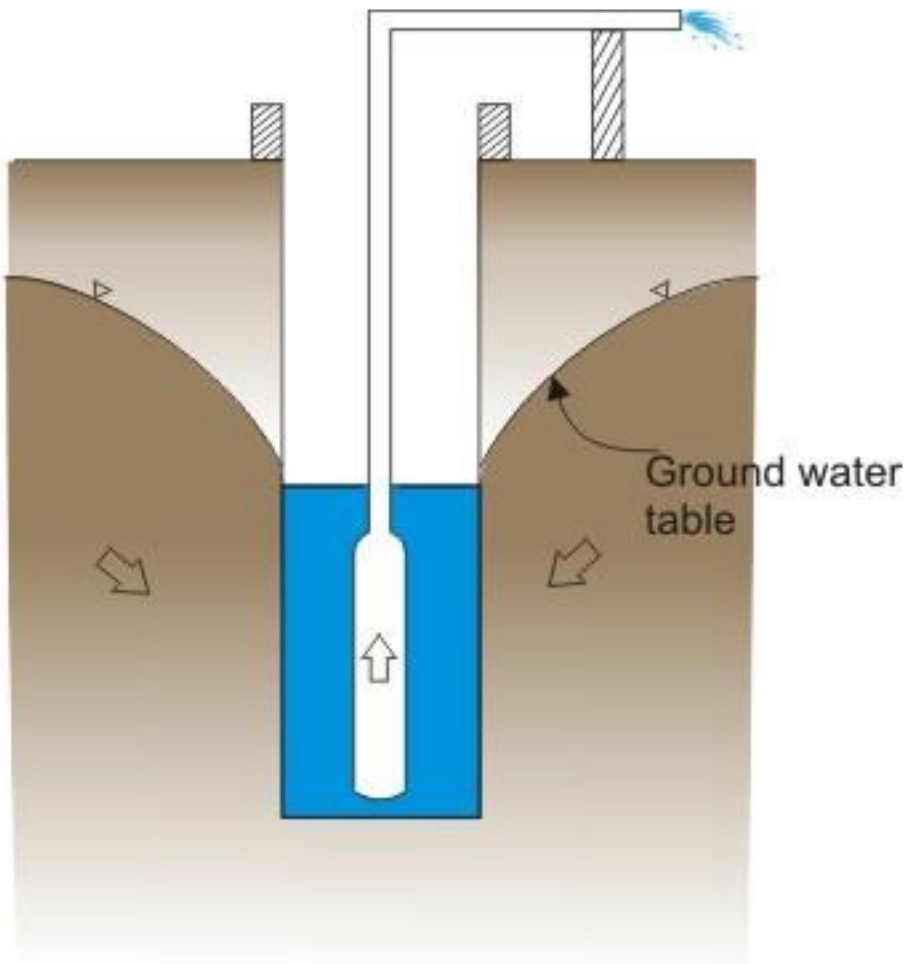

FIGURE 4. STEADY STATE DRAWDOWN

In must be observed that the water that is being pumped up from the well is being replenished by water traveling through the saturated formation towards the well. Further, if the capacity of the pump amount of water being in thrown from aware would be a lowered still.

Figures 1 to 4 depict a well that is drawing water from an unconfined aquifer. Corresponding figure of a steady state draw down curve in a confined aquifer would be as shown in Figure 5.

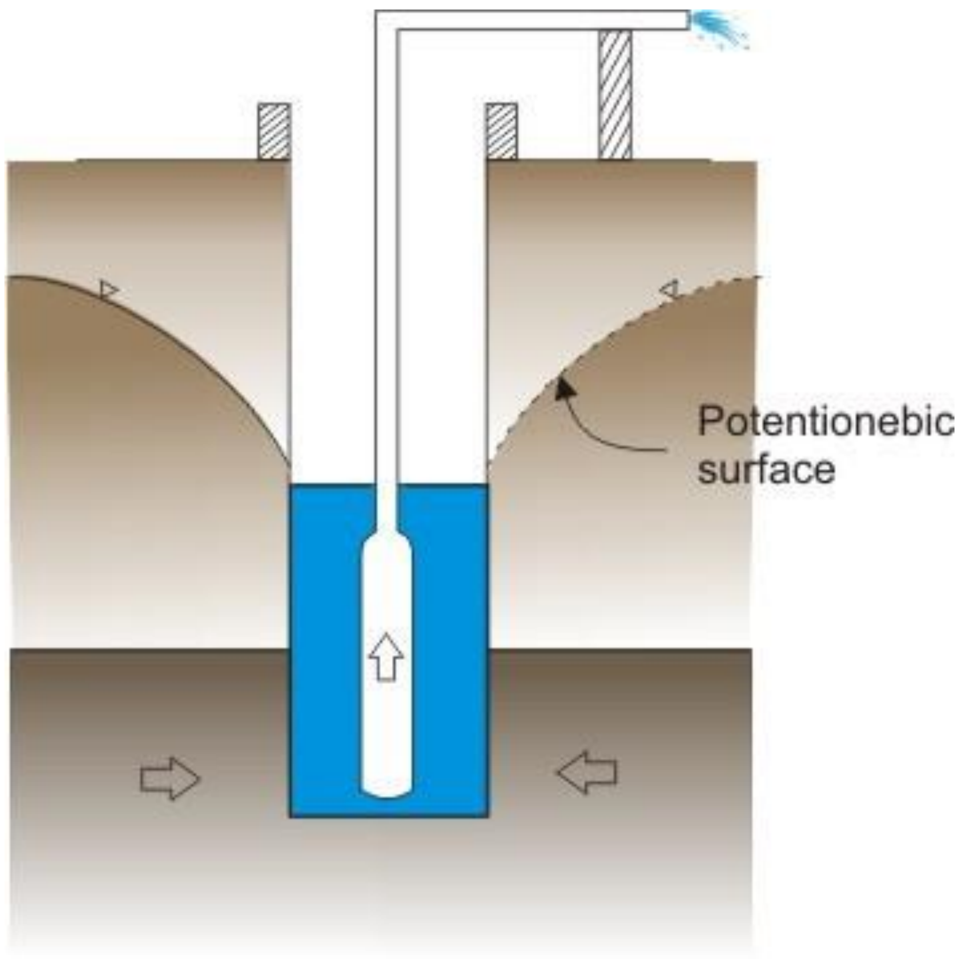

FIGURE 5. STEADY STATE POTENTIONETIC SURFACE FOR CONFINED AGNIFER

The following sections explain the mathematical relation between the water pumped and the location of the draw down. It must be remembered that the flow towards the wells is actually taking place radially. Hence, we shall be predominantly using the ground water flow equations using the cylindrical coordinates (r, θ, z, w) in contrast to the ones using Cartesian coordinates (x, y, z) as used in the previous lessons.

Steady and unsteady flow situations may further be classified as being confined or unconfined, depending on the relative positions of ground water conveying strata and the water table. The following sections describe each of these conditions individually.

Steady Flow to a Well: Confined Aquifer

Consider the case of a pumped well completely penetrating a confined aquifer (Figure 6). The corresponding steady state piezometric draw down surface is also shown for the assumed constant pumped discharge Q.

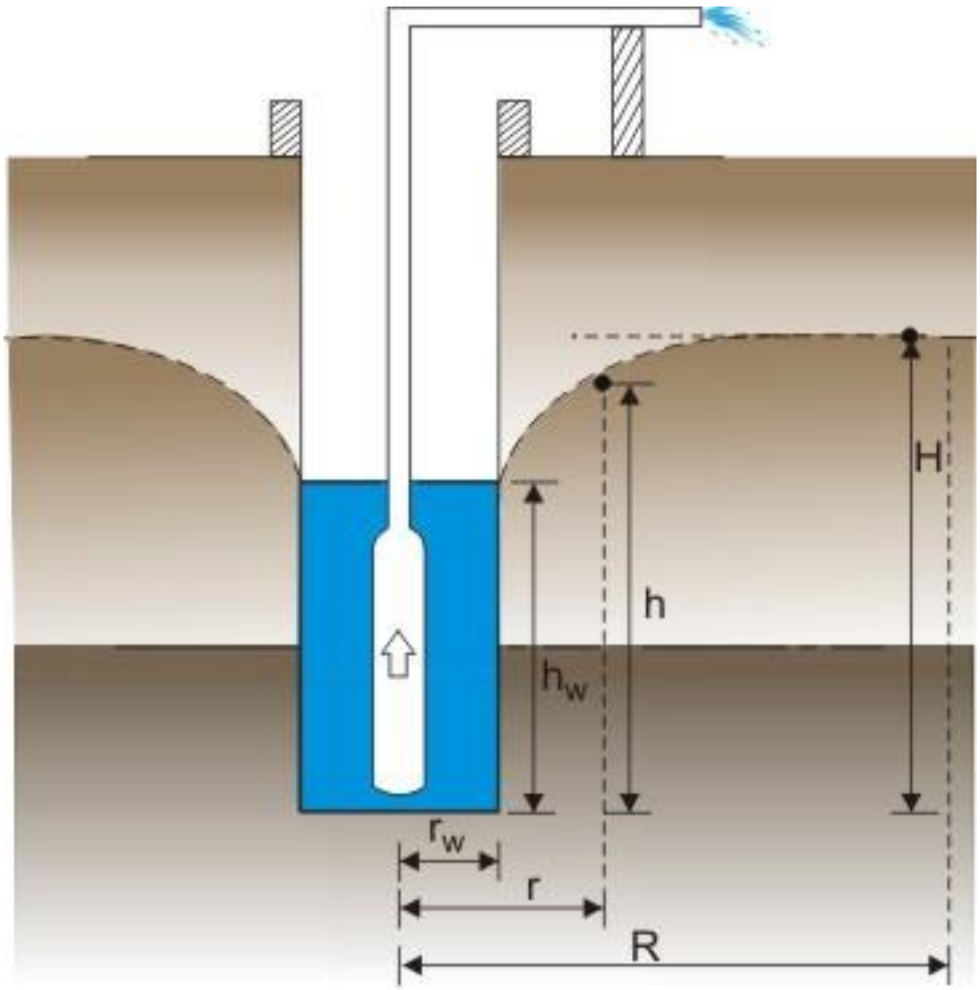

FIG 6. Definition of terms

The well is assumed to have a redius r_w and the radius of influence is thought to be R where the potentiometric surface is nearly equal to the original undisturbed value H, measured from a datum. At the well, the depth of water is designated by $\boldsymbol{h_w}$**,** which is also measured from a common datum. In general, at a certain radius r measured from the center of the well, the potentiometric surface stands at a height 'h' measured above the datum. The yield from the well Q may be expressed in terms of Darcy's law as,

$$Q = K\, i\, \mathrm{A} \tag{1}$$

Where ***K*** is the coefficient of permeability of the formation, ***i*** is the hydraulic gradient that is, the slope of the potentiometric surface at the well bound and **A** is the surface area of the well through which the flow is converging into the well from the aquifer. Thus,

$$Q = K \left.\frac{dh}{dr}\right|_{r=r_w} \left(2\pi r_w\, b\right) \tag{2}$$

In the above equation, ***b*** is the Thickness of the aquifer.

Naturally, the same amount of water also travels through the aquifer at a radial distance *r* from the center of the well. Thus, yield would also be

$$Q = K \frac{dh}{dr}\left(2\pi r\, b\right) \tag{3}$$

The above expression is true if the aquifer thickness ***b*** is assumed to be constant throughout. The above equations give us a value of the yield, *Q*, of the well but for that a measure of the gradient of the potentiometric surface is essential. This may be done by inserting a piezometer penetrating into the aquifer and noting the water level there (Figure 7).

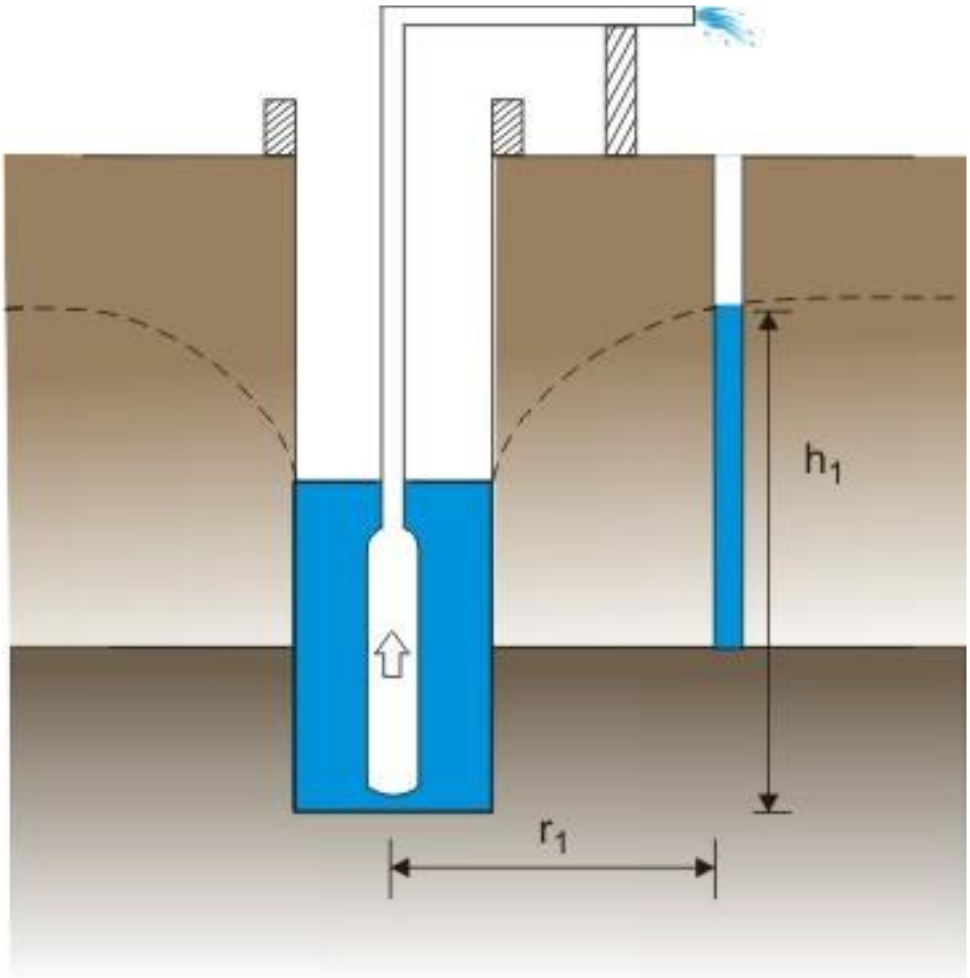

FIGURE .7 WATER VISE IN PIEZOMETER

Integrating (3) between the limits of $\boldsymbol{r_w}$ and $\boldsymbol{r_1}$, one obtains the following expressions:

$$h_1 - h_w = \frac{Q}{2\pi k b} \ln \frac{r_1}{r_w} \tag{4}$$

$$h_1 - h_w = \frac{2.3Q}{2\pi T} \ln \frac{r_1}{r_w} \tag{5}$$

Where ***T = Kb*** denotes the transmissibility of the aquifer.

This equation is known as equilibrium equation and can be used to determine variation of the potentiometric head radially outward from the well. The drawdown ***S*** at a radial distance ***r*** from the well (Figure 8) is given by

$$S = H_1 - h_1 = \frac{2.3Q}{2\pi T} \ln \frac{R}{r_1} \tag{6}$$

Where ***H*** is the undisturbed initial potentimetric surface and *R* is the radius of influence. If the drawdown ***S*** at distance r from the well known it is possible to work out ***T*** or ***K*** as

$$K = \frac{2.3Q}{2\pi S_1} \ln \frac{R}{r_1} \qquad (7)$$

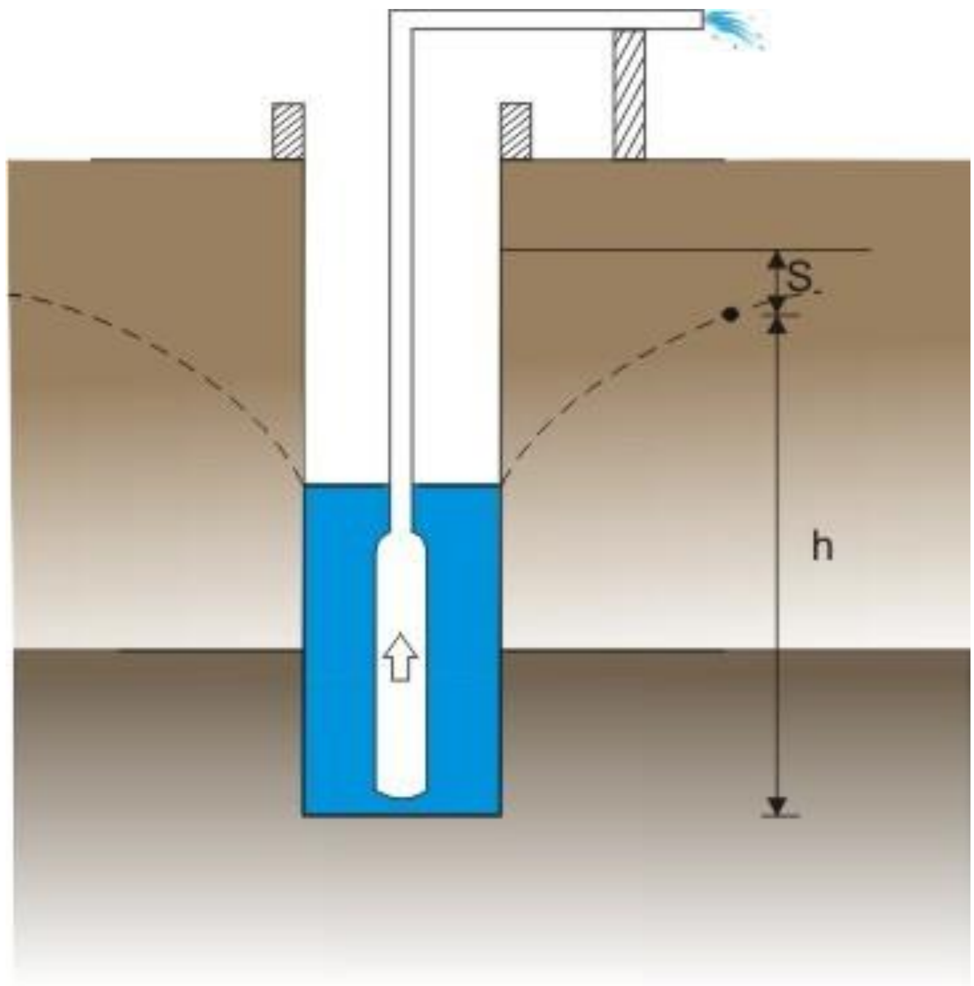

FIGURE .8 DEFINITION OF DRAWDOWN : S

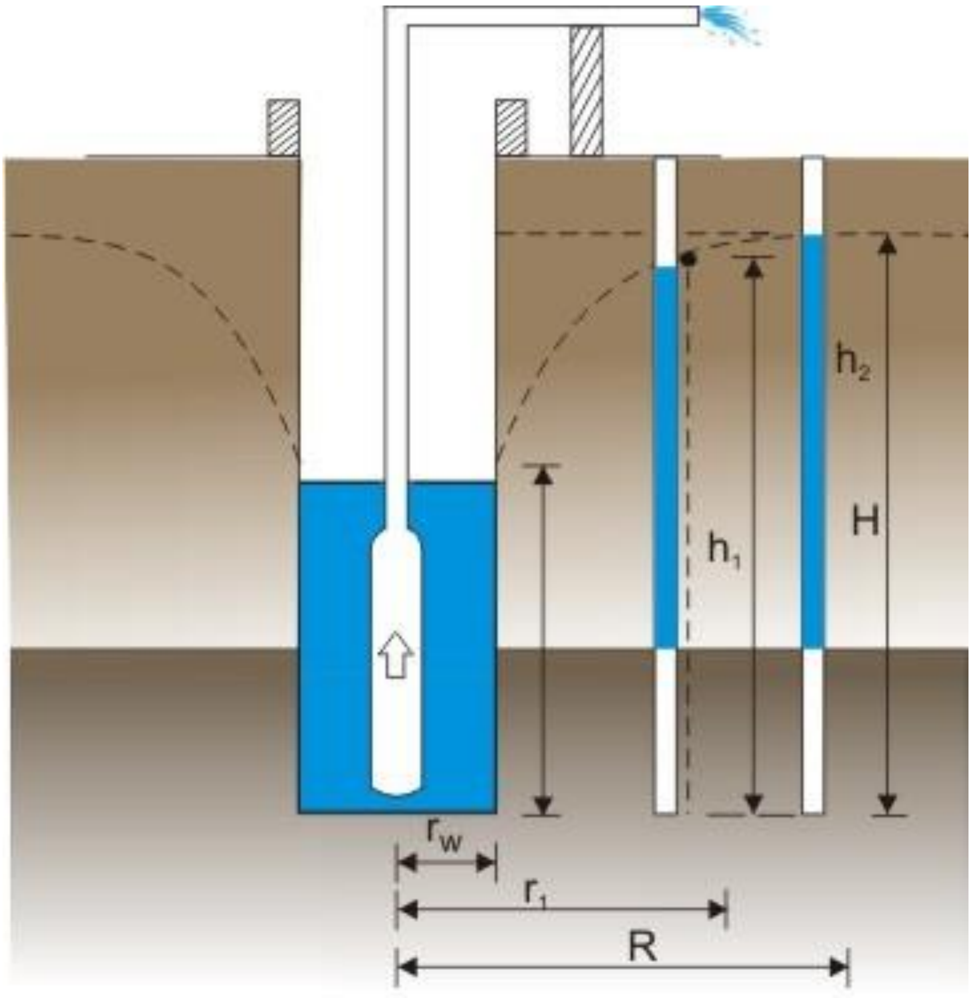

FIGURE . 9 DEFINITION OF TERMS

In case two piezometers are inserted near a well (Figure 9) and the piezometric head at these two places are given as h_1 and h_2, then the following expression is arrived at:

$$K = \frac{2.3Q}{2\pi b\,(h_2 - h_1)} \ln \frac{r_2}{r_1} \qquad (8)$$

This method of determining the permeability of an aquifer is known as Thiems method. Details about the method may be had from standard text books on ground water as the following:

Raghunath, H M (1998) ***Ground Water*****,** Second Edition, New Age International Publishers.

Steady Flow to a Well: Unconfined Aquifer

For the case of a pumped well located in an unconfined aquifer (Figure 10) the steady state discharge conditions are similar to that of confined aquifer.

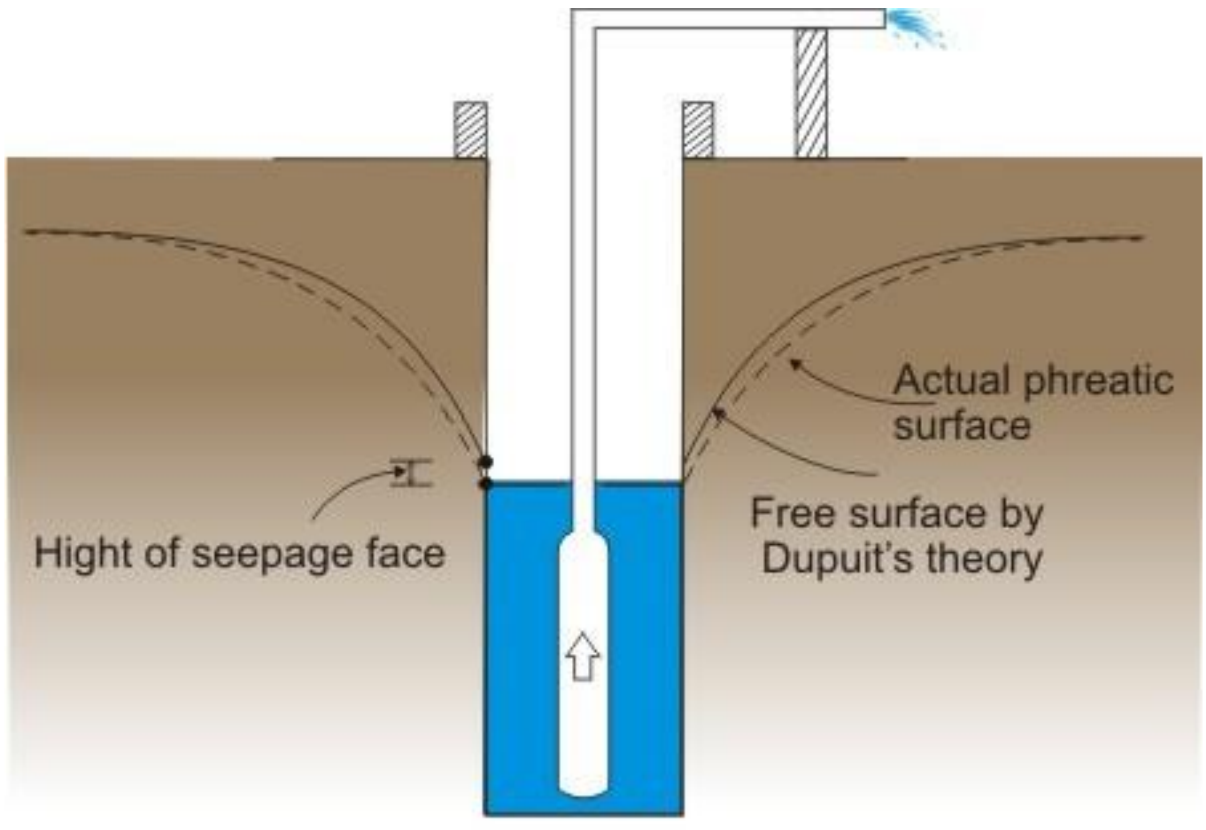

FIGURE .10 ASSUMPTION FOR DUPUIT'S THEORY

The flow at radial distance ***r*** from the well is given by the following equation under the simplifying assumptions made by Dupuit.

$$Q = 2\pi r K h_1 \left.\frac{dh}{dr}\right|_{r=r_1} \tag{9}$$

Where ***h*** denotes the height of the water take at a distance ***r*** above a datum, which may be the bedrock. Integrating between the limits of r_w and r_1

$$h_1^2 - h_w^2 = \frac{2.3Q}{\pi K}\ln\frac{r_1}{r_w} \tag{10}$$

By knowing the values of the water table at two places located at distances r_1 and r_2 from the centre of the well with corresponding heads h_1 and h_2 the value of the coefficient of permeability K can be worked out from the equation.

The water table head at any radial distance r can also be expressed in terms of H, the head at undisturbed initial water table before pumping as:

$$H^2 - h^2 = \frac{2.3Q}{\pi K} \ln \frac{R}{r} \qquad (11)$$

In the above expression, R is the radius of influence of the radial distances where the water table head is nearly equal to H.

Since (9) was derived with Dupuit's assumption (refer to Lesson 2.6), the actual free surface will be slightly higher than the predicted free surface. This is because the gradient of the cone of depression is larger towards the well where the curvature of streamlines is most marked. The free surface of water table will actually meet the periphery of the well at some height above the water level in the well as shown in Figure 10.

Unsteady flow to a well: Confined aquifer

When a well starts pumping out water at constant rate, the potentimetric surface gradually gets lowered. The unsteady state representation of the potential head in such a case is given by the following expression,

$$\frac{\partial^2 h}{\partial r^2} + \frac{1}{r}\frac{\partial h}{\partial r} = \frac{S}{T}\frac{\partial h}{\partial t} \qquad (12)$$

Where h is the potential head at a distance from the well at a time t; S is the Storativity and T is the Transmissivity. The boundary and initial conditions are defined as follows:

- The potential head is equal to H, the undisturbed potential head at $r \geq R$ and for all times, that is for $t \geq 0$
- At the well face, that is at $r = r_w$, the flux (or water getting discharged), Q, is related to the gradient of the potentiometric surface as,

$$r\left.\frac{\partial h}{\partial r}\right|_{r=r_w} = -\frac{Q}{2\pi T} \qquad (13)$$

- The initial condition that is at time $t = 0$, the following condition holds:

$$h\Big|_{at\ any\ r} = H \qquad (14)$$

A solution of (13), based on the boundary and initial conditions, was given by Theis as in the following equation. Interested readers may refer to text books on ground water for further details.

$$H - h = \frac{Q}{4\pi T}\left[-0.5772 - \ln u + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} - \frac{u^4}{4.4!} + \ldots\ldots\infty\right] \tag{15}$$

The unsteady state representation of the piezometric head, when the piezometric surface gradually gets lowered during of the well is given as:

$$u = \frac{r^2 s}{4T\,t} \tag{16}$$

In equation (15), ***H–h*** is the drawdown at any radial distance ***r***, measured from the centre of the well. The infinite series term in the equation is generally designated as ***W(u)***, and in textbooks on well hydraulics as Raghunath (1998), these are tabulated for ease of calculation. However, with the help of calculators, it is easy to evaluate the first three terms and for practical calculations, only the first three or four terms may be considered. If only the first two terms are taken, then the expression simplifies to:

$$H\text{-}\,h = \frac{Q}{4\pi T}\left[-0.5772 - \ln u\right] \tag{17}$$

$$= \frac{Q}{4\pi T}\left[\ln \frac{2.25Tt}{r^2 S}\right] \tag{18}$$

$$= \frac{0.183Q}{T}\left[\ln \frac{2.25Tt}{r^2 S}\right] \tag{19}$$

For values of ***u*** less then 0.05, the value of ***H-h*** evaluated by (19) is practically the same as that obtained by applying (15).

Unsteady flow to a well: Unconfined aquifer

As with confined aquifers, the decline in pressure in the aquifer yields water because of the elastic storage of the aquifer Storativity (***Ss***). The declining water table also yields water as it drains under gravity from the sediments. This is termed as specific yield (s_y). The flow equation has been solved for radial flow in compressible unconfined aquifers under a number of different conditions and by use of a variety of mathematical methods. It is not in the scope of the present text to discuss these methods. The interested reader may refer to textbooks on well hydraulics, for examples “Ground Water” by H.M. Raghunath, New Age International (P) Ltd, Publishers.

Determining properties of confined aquifer

The hydraulic properties of a confined aquifer are often required to be known and the equations discussed in Section 2.7.2 or 2.7.4 can be used if measurements of water levels at known value of the discharge rate.

If the observations correspond to equilibrium conditions, then two observation wells, data may be used along with equation (6), to yield

$$T = \frac{Q \log\left(r_2 / r_1 \right)}{2.73\left(h_2 - h_1\right)} \qquad (20)$$

Where ***T*** is the Transmissivity of the confined aquifer and h_1 and h_2 are the depth of piezometric heads at two observation wells located at radial distance r_1 and r_2 respectively from the pumping well centre.

Design of wells for water supply

A well is an intake structure dug on the ground to draw water from the reservoirs of water stored within. The water from the well could be used to meet domestic, agricultural, industrial, or other uses. The structure may be an open dug well, or as is common these days, may be tube-wells. The well may be shallow, tapping an unconfined reservoir or could be deep, penetrating further inside the ground to tap a confined aquifer located within aquicludes. In this lesson, we shall discuss the design of tube wells, a typical installation of which is given in Figure 11.

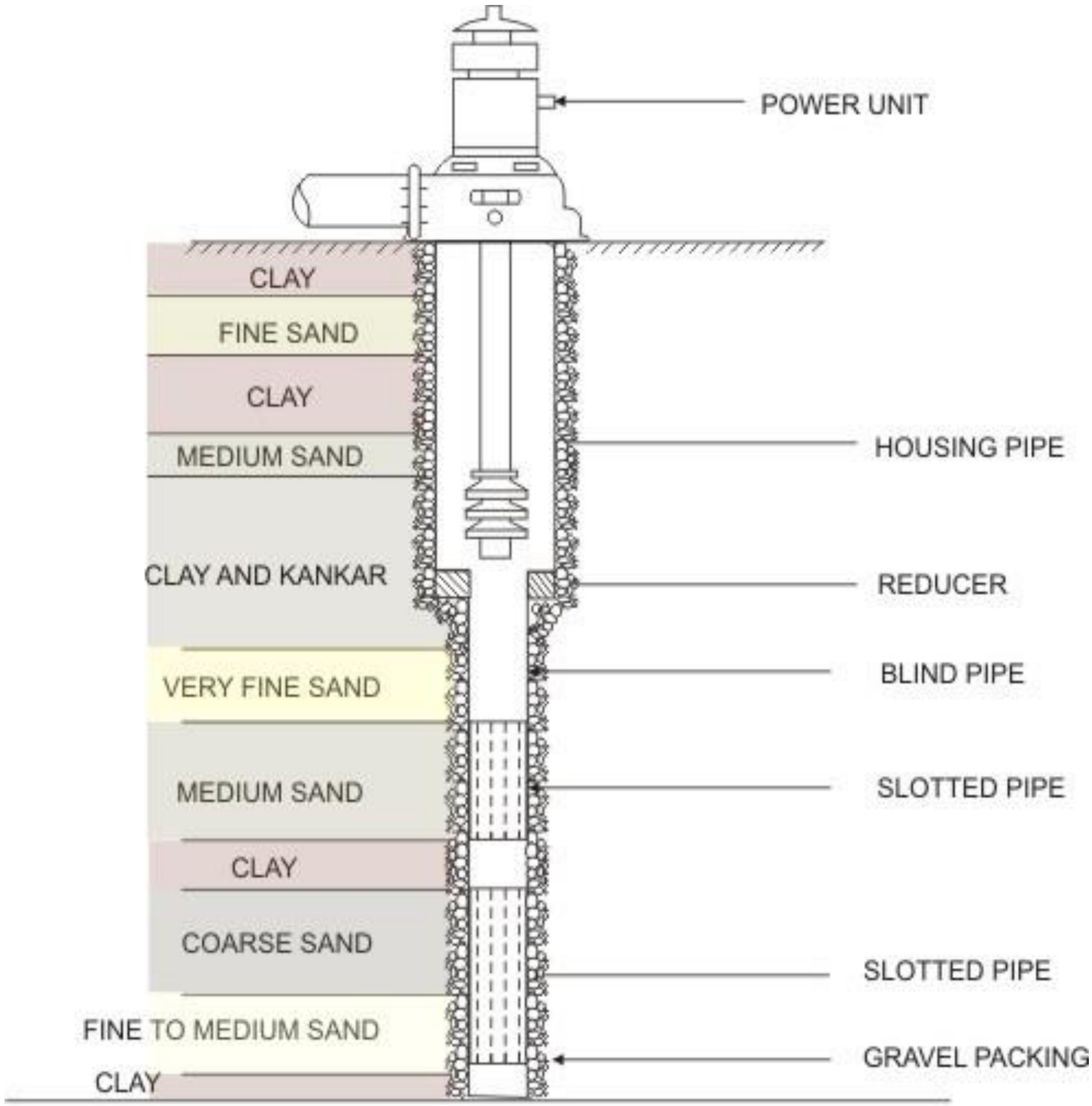

FIGURE . 11 TYPICAL INSTALLATION OF TUBE WELL

Design of a well involves selecting appropriate dimensions of various components and choosing proper materials to be used for its construction. A good design of tube well should aim at efficient utilisation of the aquifer, which it is supposed to tap, have a long and useful life, should have a low initial cost, and low mantenace and operation cost. The parameters that need to be designed for a well include the following:

- Well diameter
  The diameter of the well must be chosen to give the desired percentage of open area in the screen (15 to 18 percent) so that the entrance velocities near the screen do no exceed 3 to 6 cm/s so as to reduce the well losses and hence, the draw down. The velocity should be reasonably low as indicated, such that the five particles within the sand should not migrate towards the well strainer slots.

- Well depth

- Selection of strata to be tapped
  The samples during drilling are collected from various depths and a bore log is prepared. This log describes the soil material type, size distribution, uniformity coefficient etc. for the material available at different depths.

- Well screen design
  This includes fixing the following parameters for a well:
    - Well screen length
    - Well-screen slot size
    - Well-screen diameter
    - Well-screen material

In case of unconfined aquifers, where too thick and homogeneous aquifer is met, it is desirable to provide screen in the lower one third thickness. In case of confined aquifers where thick and nearly homogeneous aquifer is met, about 80 to 90 percent of the depth at the centre of the aquifer is advised to be screened. Where too thick and homogeneous aquifers are encountered it is common practice to place screen opposite the more permeable beds leaving about 0.3m depth both at the top and bottom of the aquifer, so that finer material in the transition zone does not move into the well.

The size of the well screen slots depends upon the gradation, and size of the formation material, so that there is no migration of fines near the slots. In case of naturally developed wells the slot size is taken as around 40 to 70 percent of the size of the formation material. If the slot size selected on this basis comes to less than 0.75 mm, then an artificial ground pack is used. An artificial gravel pack is required when the aquifer material is homogeneous with a uniformity coefficient less than 3 and effective grain size less than 0.25 mm.

The screen diameter is determined so that the entrance velocity near the well screen does not exceed 3 to 6 cm/sec.

The screen material should be resistant to incrustation and corrosion and should have the strength to withstand the weight of the well pipe. The selection of the screen material also depends on the quality of ground water, diameter and depth of the well and type of strata encountered.

Installation of tube wells

The entire process of installation of tube wells include drilling of a hole, installing the screen and housing pipes, gravel packing and development of the well to insure sand free water. Depending on the size of the tubewell, depth and formation to be drilled, available facility and technical know-how, different methods are used for the construction of tubewells. Two methods that are commonly used are explained below.

- ***Cable-tool percussion drilling***

  A rig consists of a mast, lines of hoist for operating the drilling tool and a sand pump (Figure 12).

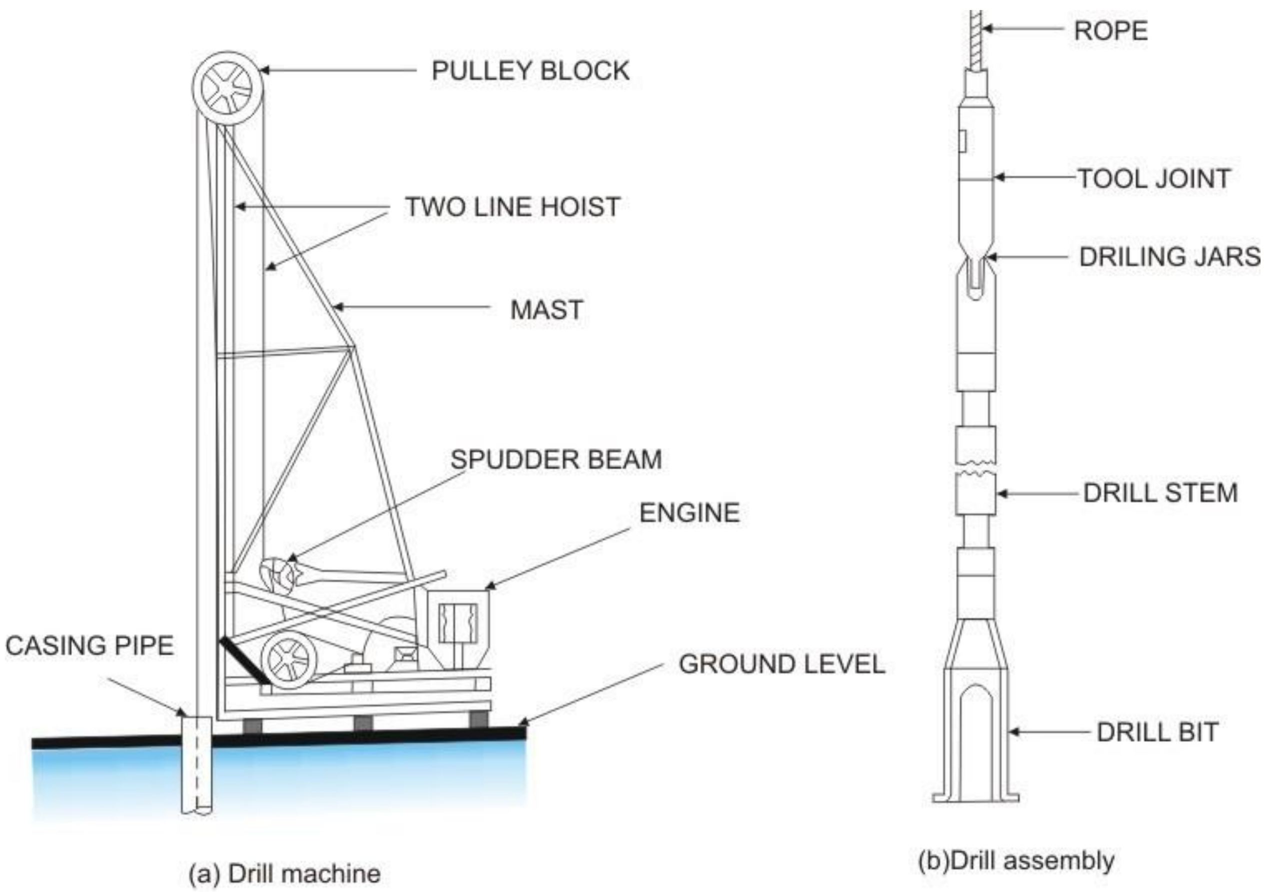

FIGURE .12 CABLE TOOL PERCUSSION DRILLING

The cutting tool is suspended from a cable and the drilling is accomplished by up and down movement (percussion) of the tool. A full string of drilling tool consists of four components:

- Drill bit
- Drill stem
- Drilling jars
- Rope socket

The drill bit is used to loosen the formation material and its reciprocating action breaks it down to smaller particles or muck. Water injected from the top converts the muck into slurry. For this purpose water is added as long as drilling continues in dry formations. The slurry flows up due to the pressure of water. The drill stem fixed just above the bit provides additional tools in order to maintain a straight line. The drilling jars consist of a pair of linked steel bars and can be moved in a vertical direction relative to each other. The rope socket connects the string of tools to the cable.

- ***Rotary Drilling method***

There are two main types of rotary drilling methods:

- Direct rotary methods, and
- Reverse rotary method

In either case, a rotating bit is used as a drilling bit. The major difference is in the direction of the flowing fluid (Figure 13).

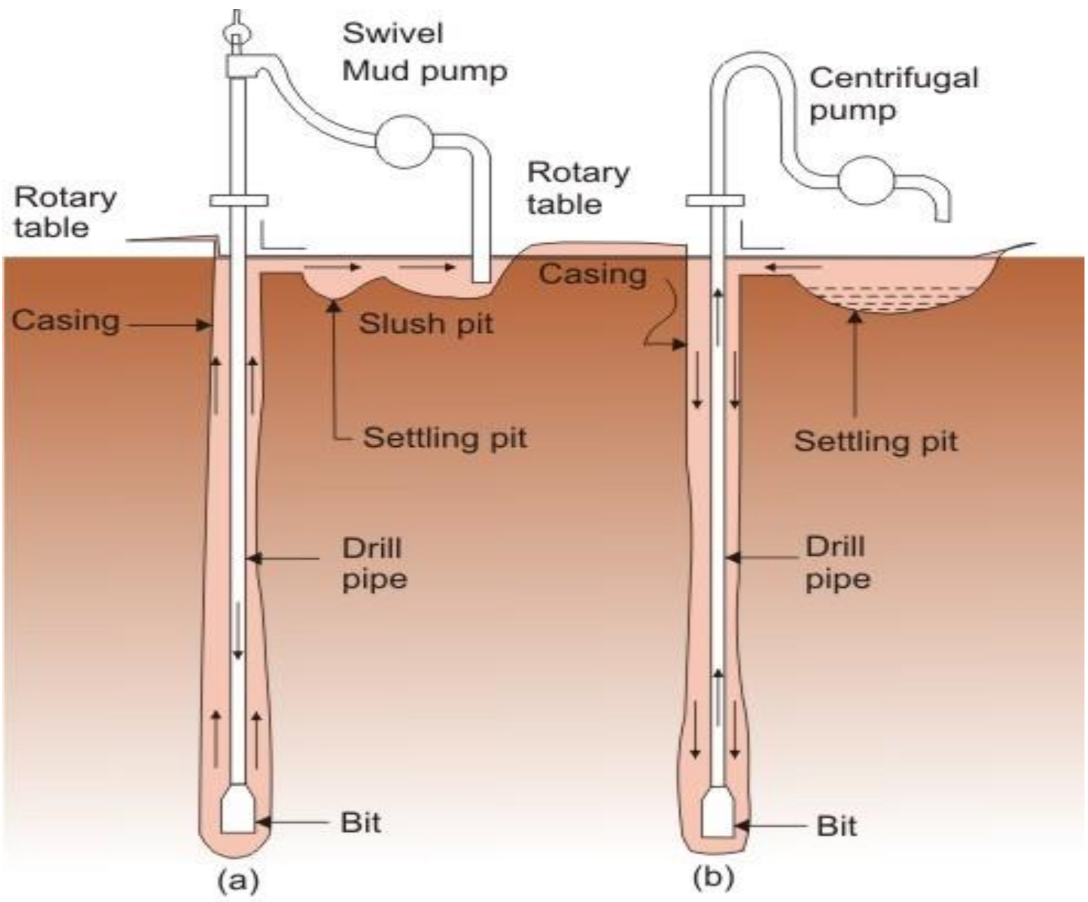

FIGURE . 13 ROTARY DRILLING (a) Hydraulic rotary
(b) Reverse rotary

The rotary drilling method, also sometimes called the hydraulic rotary method of drilling, uses continuously circulating pumped fluid. The power to the drill bit is delivered to the bit by a rotating hallow steel pipe or drill pipe. The drilling fluid or bentonite slurry is pumped down through the drill pipe and out through a nozzle in the drill bit. The mud then rises to the surface through the hole and also removes the drilled formation material or muck. At the surface the fluid is led to a setting pit and then to a storage pit from where it is pumped back into the hole. Water and clay are added to the storage in to maintain quantity and consistency.

Well screens

For installation of well screens, different methods are used depending upon the design of the well, the type of well, locally available facility and the type of problems encountered in drilling operation. The Pull-back method is generally used with the cable-tool percussion method of well drilling. After the casing pipe has reached to the depth where the bottom of the screen is to be located, the sand that might have flowed into the pipe is removed. The well assembly consisting of screen and blind pipe lengths is lowered into the well. A heavy plate bail handle is provided at the bottom of the screen. The lowering of the assembly may be accomplished by suspending it by the bail handle using a flat hook attached to the sand line to engage the bail. After lowering the complete well screen assembly inside the casing pipe, the casing rip is pulled back.

For rotary drilled wells generally the Open-Hole method of screen installation used, though the Pull–Back method can also be used in this case too. In the open-hole method, after drilling the hole below the well caring, the drill stem is withdrawn and a telescope–size screen is lowered into the hole by any suitable method. The depth of the hole should be checked such that when the screen rests on the bottom of the hole, the lead packer should remain inside the lower end of the casing.

Gravel packing

Well can either manually ground packed or artificially ground packed. Natural ground packed condition is created by removing the fine sand from the formation either by pumping or by surging. An artificially gravel packed well has a envelop of specially grand sand or gravel placed around the well screen. Ground pack is designed on the basis of sieve analysis of the aquifer materials obtained during drilling. Aquifer consisting of coarse materials of less uniform sizes may not require any gravel pack.

Well Development

This process is used to remove sand, silt and other fine materials from a zone immediately surrounding the well screen. This is done by flow reversal through the screen openings so as to rearrange the formation particles in a naturally developed well and form a graded filter with materials of increasing porosity and permeability towards the well in an artificially gravel packed well, so that ultimately the well will yield clear sand free water.

Advantages and Disadvantages of WELL IRRIGATION

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Advantages:

1. Whenever necessity is felt, in any tract locally, well may be sunk to start open well irrigation. Much consideration need not be given to any of the other factors which are given proper weightage while introducing canal irrigation.

2. There is no need of constructing many and expensive hydraulic structures. The cost of well irrigation project is therefore much less.

3. When the water is withdrawn from the subsoil formation by means of wells the waters table obviously lowers and water-logging of the land is prevented.

4. The water is used more economically as cultivator has to put in labour for lifting water.

5. The water can be used at any time depending upon the choice of cultivator and water needs of crops.

6. As the water is assured for whole of the year, provided groundwater conditions are favourable, two to three corps can be grown on the same field in one year.

7. Maintenance cost of a well is less. Also as the well is situated usually in the middle of the field water losses in transit are less.

8. By constructing number of wells in any tract intensive irrigation of some valuable crops can be done.

9. In well irrigation duty realized is higher.

10. Well water irrigates the un-commanded patches of the culturable land in the canal irrigated tract. Thus it assists the canal irrigation.

11. Well water is cooler in summer season and warmer in winter season. This water when applied to the crops, tries to neutralize the bad effects of the hot or cold season.

Disadvantages:

1. To make the water available for irrigation purposes it is necessary to lift it from underground. For lifting the water power is required. Thus the well irrigation is much dependent on the availability of power or trouble free working of the machinery which is very rare thing.

2. Sometimes cost of well water is so high that the returns obtained from it are not justifiable.

3. Availability of water from the wells depends on groundwater storage. The discharge from well is low and area commanded is less.

4. The water in well is static and therefore it is free of suspended silt. Water carrying silt together with some useful suspended salts is very beneficial to the crops. Well water thus lacks in this respect.

Waterlogging :-is the saturation of soil with water. Soil may be regarded as waterlogged when it is nearly saturated with water much of the time such that its air phase is restricted and anaerobic conditions prevail. In extreme cases of prolonged waterlogging, anaerobiosis occurs, the roots of mesophytes suffer, and the subsurface reducing atmosphere leads to such processes as denitrification, methanogenesis, and the reduction of iron and manganese oxides.

Causes of water logging

1. Inadequate surface drainage

   When the surface drainage is not adequate, the heavy precipitation in the area is not drained off quickly and the rain water remains stagnant over the area for considerable time. This gives rise to heavy percolation and water-table rises in the area.

2. Over-irrigation of field

   When the irrigation water applied to the field is in excess of the requirement of the crop, deep percolation takes place which is retained in the intermediate zone augmenting the ground water storage.

3. Obstruction of nature drainage

   If the nature drainage is obstructed by irrigation channel, rail or road embankments, it will not be able to pass the rain water of catchment. There will thus be flooding of land and consequent water logging.

4. Obliteration of natural drainage

   Sometime the cultivators plough up and obliterate an existing natural drainage. This results in to stoppage of storm water flow, consequent flooding and waterlogging.

Effects of water logging:-

1. Inhibiting activity of soil bacteria

The liberation of plants food is dependents upon the activity of soil bacteria, which requires adequate amount of oxygen in the air for proper functioning. When the soil pores within the root zones of crops normally grown are so saturated as to effectively cut off the normal circulation of air, the land is said to be waterlogged.

2. Decrease in available capillary water

   Plant life draws its substance from the soil-solution round the soil particles which is drawn into the plants by capillary action and osmosis. If the water table is high, the roots of the plants are confirmed to the top layers of the soil above the water table while if the water table is lower, the root of plants have more room for growth.

3. Fall is soil temperature

   A waterlogged soil warms up slowly and due to lower temperature, action of soil bacteria is sluggish and plant food available is less.

4. Defective air circulation

   When the water-table is high, the drainage becomes impossible and the carbon dioxide liberated by plants root cannot be dissolved and taken away. Consequently fresh air containing oxygen is not drawn and activity of soil bacteria and plant growth suffers.

GROUND WATER AND WATER WELLS - DEFINITIONS AND EXPLANATIONS

Abandoned well
A term used when a well’s use is permanently discontinued or if it is in a condition that makes it uneconomic to repair. Wells not in use, but which are properly capped may be referred to as out-of-use wells. To prevent the risk of contamination, abandoned wells should be sealed from the bottom up.

Aquaculture
Farming of plants and animals that live in water, such as fish, shellfish, and water cress. Usually some aspects of the natural aquatic environment is modified, controlled and managed and may include ponds/ diversion weirs or drilled wells to make aquaculture commercially viable. Many hatcheries and fish farms use wells as their supply source because the water has a constant temperature and chemistry.

Aquatic
Associated with and dependent upon water. For example, aquatic vegetation.

Aqueduct
A pipe, conduit, or channel designed to transport water from a distant remote source, usually by gravity. Part of the water system of ancient Rome was supplied with water conveyed by elaborately

engineered aqueducts. Much of the water transferred from north to south in California and other western states is conveyed by aqueducts.

Aquiclude
A saturated rock formation or layer of geologic sediments with low permeability. Aquicludes do not yield significant amounts of water to wells but may be important as water storage zones that release water to more permeable formations.

Aquifer recharge
The process/processes by which water from precipitation (or some other part of the hydrologic system) reaches and hence increments stores of ground water.

Aquifer
(1.)The three dimensional sub-surface geometry of a geologic rock formation (or, group of rock formations or part of a formation) that contains ground water in the spaces between sediment grains, in voids, or in fractures.
(2.) A geological formation or structure that has the capability to store and/or transmit water to wells and springs. Use of the term aquifer is usually restricted to those water-bearing formations capable of yielding water in sufficient quantity to constitute a usable supply source.
See confined aquifer, unconfined aquifer.

Aquifer test
Hydraulic test of an aquifer based on calculations using data from measurements of ground water level response (drawdown and recovery) to controlled pumping. (Occasionally tests may add water to a well). Aquifer tests typically allow hydrologists to predict the amount of water in an aquifer and the rates at which it may be safely withdrawn.

Aquitard
A geologic formation having very low permeability through which water cannot move.

Area of Influence
The land area overlying the extent of a pumping well's cone of depression.

Artesian water
Ground water that is under pressure when tapped by a well and is able to rise above the level at which it is first encountered. It may or may not flow out at ground level. The pressure in such an aquifer commonly is called artesian pressure, and the formation containing artesian water is an artesian aquifer or confined aquifer.
See also flowing well

Artesian aquifers
Artesian aquifers (confined aquifers) occur where overlying impermeable rock layers "trap" ground water under pressure. Depending on geology and topography, a single aquifer may be artesian (confined) in one place and unconfined in another.

Artesian wells
Wells (bore holes) that penetrate artesian aquifers. Water will rise up the well casing to the pressure

level of the aquifer. Artesian flow describes the natural flow to the surface of water from confined aquifers. In some parts of the US any well drilled into bedrock is (incorrectly) called an artesian well.

Artificial recharge
A process where water is put back into ground water storage by use of engineering devices such as spreading basins or recharge wells.
See also ASR

ASR (Aquifer Storage Recovery)
A management strategy involving engineered devices such as detention ponds or recharge wells that deliberately adds water to ground water storage with a view to later withdrawal for some economic purpose. ASR is likely to become an increasingly important water management strategy in the western USA.

Baseflow
The proportion of water flowing in streams and rivers that comes from ground water. River flow during dry weather conditions may be virtually all baseflow. At least 40% of all the annual flow total of rivers in the U.S. is derived from baseflow.

Coefficient of storage
The volume of water that an aquifer adds or loses from storage per unit area/per unit change of head.

Cone of depression
A shape in the form of an inverted cone that develops in the water table (or potentiometric surface) as a result of pumping from a well. In practice the shape of the "cone" resulting from pumping from a well is often not symmetrical.

Confined Aquifer
An aquifer, overlain by an impermeable layer, in which the water is under pressure greater than that of the atmosphere.

Confined aquifer
Soil or rock below the land surface that is saturated with water. There are layers of impermeable material both above and below it and it is under pressure so that when the aquifer is penetrated by a well, the water will rise above the top of the aquifer.

Specific capacity
The rate of discharge of a well per unit depth of drawdown. Expressed as gallons per minute per foot, (liters per minute per meter). It is used as a measure of well efficiency. The ideal for a well is high discharge and low drawdown.

Specific yield
The ratio (%) volume of water yielded by a rock to the volume of rock. In practice some water always "sticks" to the rock and so not all the water stored in a unit volume of rock is available to flow to a well.

Springs
Areas where there is a concentrated discharge of ground water that appears as a flow of water at the surface. The distinction between springs and seepages is arbitrary. Vast amounts of groundwater discharges continuously to rivers and lakes, the majority of which occurs unseen in streambeds or as bank seepage. A "spring-fed" river may not have a visible "spring." There are many different geologic and hydrologic circumstances that can result in springs. Wetlands, springs, and seepages may occur where the water table intersects the land surface.

Streamflow
The water discharge that occurs in a natural channel. A more general term than runoff, streamflow may be applied to river discharge whether or not it is affected by diversion or regulation.

Subsurface Water
All water occurring beneath the earth's surface. It includes soil moisture and ground water.

Surface water
Water that is on the Earth's surface, such as in a stream, river, lake, or reservoir.

Surfactant
A substance used to reduce surface tension in a liquid. Foam sufactants are used in some drilling processes. Sufractants are also used to increase the efficiency of some ground water remediation techniques.

s to obtain information about geologic and/or hydrologic conditions. Test holes are usually drilled at a small diameter. Based on the information obtained, productions wells of a larger diameter may be installed.

Test well
A well used to assess and/or test the geologic and hydraulic properties of an aquifer. A series of test wells may be drilled in order to determine the most effective location for a (much more expensive) production well. Test wells are usually of a smaller diameter than production wells.

Transmissivity
The capacity of a rock to transmit water under pressure. The rate at which water moves through a unit width of an aquifer under a unit hydraulic gradient. The coefficient of transmissibility is the rate of flow of water, at the prevailing water temperature, in gallons per day, through a vertical strip of the aquifer one foot wide, extending the full saturated height of the aquifer under a hydraulic gradient of 100 percent. A hydraulic gradient of 100 percent means a one foot drop in head in one foot of flow distance.

Unconfined aquifer
An aquifer with no confining layer between the water table and the ground surface above. Under non-pumoing conditions, wells drilled in unconfined aquifers will have water levels the same as the surrounding water table elevation.

Well screen
A steel or plastic device that admits water to a well from the surrounding geologic formations but which prevents or reduces the likelihood of sediment entering the well. Design and selection of well screens is based of geologic and hydraulic criteria.

Well Rehabilitation
The process of using mechanical or chemical techniques to restore declining well yield caused by biological and or chemical encrustation of well casing and/or the gravel pack or rock formations immediately adjacent to the well bore.

Well sealing
Unused wells may need to be sealed in order to protect aquifers from surface contaminants, or to prevent comingling of waters from different aquifers in the same well, or from aquifers interconnected by different wells.
See also abandoned wells

Well
A hole in the ground made to gain access to an aquifer to obtain water for economic use. Wells may be dug (mostly old wells less than 50 feet deep) or drilled. Drilled water wells in solid rock are typically up to 300 feet deep. Wells in alluvial and glacial sediments are typically about 100 feet deep.

Well point
A screened cylinder (usually steel and less than 4 inches in diameter) that is driven into the ground and which can serve to access ground water.

Well Development
The application of techniques after and during the drilling process that bring the well to its maximum yield capacity and achieve maximum well efficiency.

Withdrawal
Water removed from a ground or surface water source for use.