More specifically the recharge ($\sum R$) is composed of the following:

1. Natural infiltration derived from rainfall and snow melt;
2. Infiltration from surface bodies of water;
3. Underflow;
4. Leakage through confining layers, or water displaced from them by compression; and
5. Water derived from diffusion, charging and water spreading operations.

Conversely, the discharge includes:

1. Evaporation and transpiration;
2. Seepage into surface bodies of water;
3. Underflow;
4. Leakage through confining layers or absorbed by them by reduction of compression; and
5. Water withdrawal through wells and infiltration galleries.

The associated change in storage volumes, ΔS, depends on the properties of soil or rock particularly, the porosity or void ratio, size, shape and compaction of the formation which are all reflected in the specific yield of the formation. ΔS increases with the specific yield.

(b) Rate Of Groundwater Flow

The flow of groundwater through aquifers under the hydraulic conditions of non-turbulent or straight line flow is governed by Darcy's Law which states that head loss due to friction varies directly as velocity of flow and is expressed as:

$$V = KI \qquad (5.3)$$

where

V = velocity of flow in metres per day

I = slope of hydraulic grade line, i.e. slope of the groundwater table or piezometric surface

K = Coeff. of permeability or proportionality constant for water of a given temperature flowing through a given material in metres/day

and

$$Q = ApV \qquad (5.4)$$

where,

Q = Groundwater flow in m^3 per day

A = cross-section of aquifer in m^2

p = porosity of water-bearing medium, it being assumed that the product 'Ap' represents the areas of the channels through which flow is taking place.

This should not be used for flows having Reynolds number greater than 10. This limit is generally reached as water approaches face of wells in coarse-grained sandy soils. In practice no lower limit has been observed even at small hydraulic gradients.

Since 'I' is dimensionless ratio, 'K' has the dimension of velocity and in fact is the velocity of flow under a hydraulic gradient of unity.

(c) Conditions Of Groundwater Flow

The groundwater is obtained from aquifers through a "gravity well" or "pressure well" or an "infiltration gallery".

In the "gravity well" the surface of the water outside of and surrounding the well is at atmospheric pressure.

In a "pressure well" the aquifer holds water under pressure greater than atmospheric.

An "infiltration gallery" is a horizontal tunnel or open ditch constructed through the aquifer in a direction nearly normal to the direction of groundwater flow. The tunnel type of gallery is sometimes called a horizontal well.

If a gravity or pressure well is pumped at a constant rate, the drawdown in the well around the area of influence will continue to increase until the rate of replenishment is equal to the rate of pumping i.e. until the equilibrium has been established. The flow into the well until this equilibrium is established is under "Non-equilibrium" conditions. The flow into the well after the equilibrium has been established will be under "Equilibrium" conditions and the flow will be called steady. The steady flow may be "unconfined" or "confined". The flow in a gravity well is "unconfined" and in a pressure well is "confined".

(d) Formulae For Flow Under Equilibrium Conditions

Assumptions

- Direction of the flow of groundwater is horizontal;
- The flow is at a constant rate and in a radial direction towards the centre of the well; and
- The well penetrates to the bottom of the aquifer and is in equilibrium condition unless it is specified to the contrary.

(i) Flow Into A Gravity Well Under Equilibrium Conditions (Refer Fig 5.1)

The flow into a gravity well under equilibrium conditions is given by the formula:

$$Q = \frac{1.36K\left(H^2 - h^2\right)}{Log\frac{(R)}{(r)}} \qquad (5.5)$$

Where,

Q = Rate of flow into well in m^3/d

K = Permeability constant in m/d

H = Depth of the water in the well before pumping in m

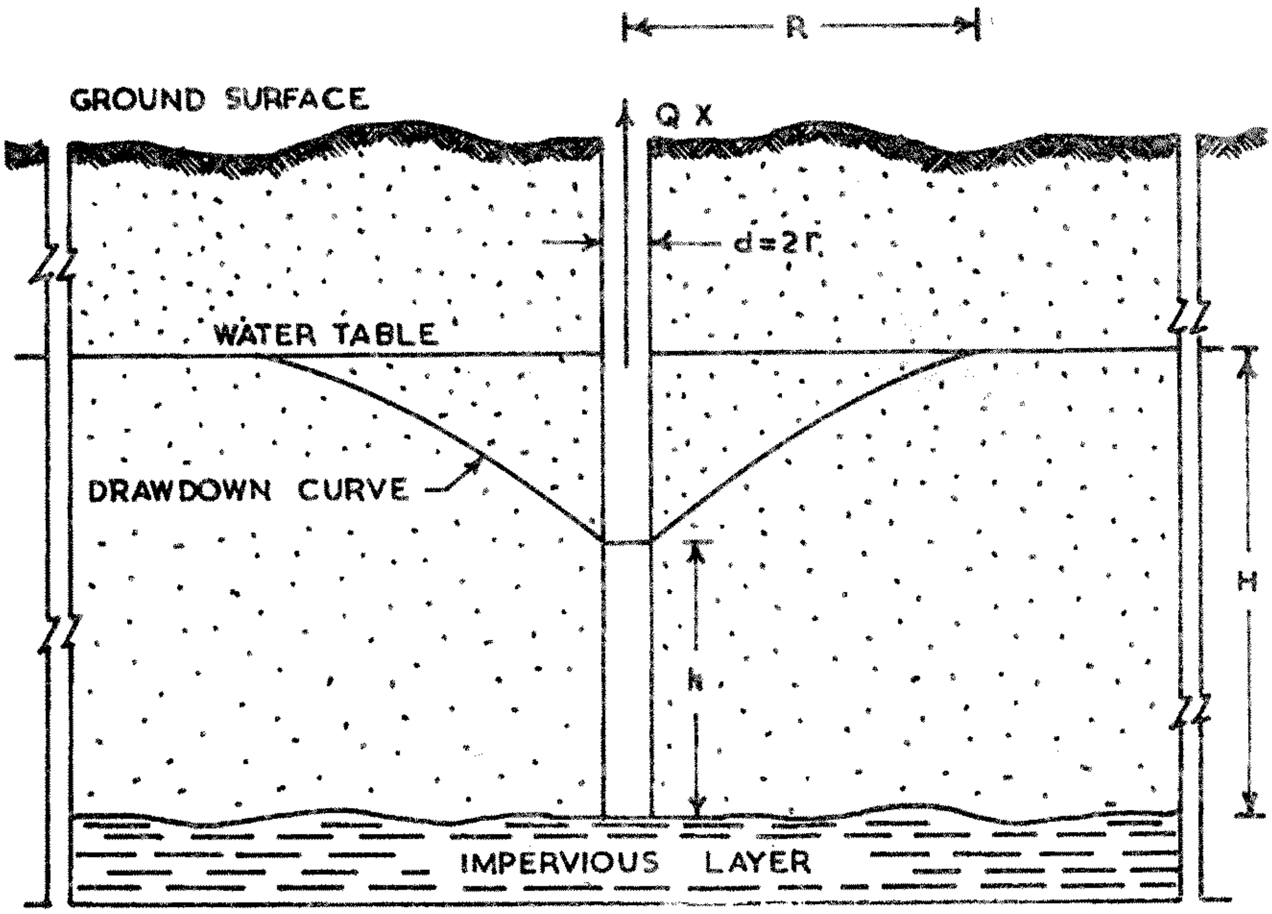

FIG5.1: GRAVITY WELL UNDER EQUILIBRIUM CONDITIONS

h = Depth of water in the well after pumping = (H – drawdown) in m

R = Radius of influence in m

r = Radius of well in m

(ii) Flow into a pressure well under Equilibrium Conditions. (Refer fig 5.2)

Flow into a pressure well under equilibrium conditions is given by the formula:

$$Q = \frac{2.72 K m (H - h)}{Log \frac{(R)}{r}} \tag{5.6}$$

Where,

Q = rate of flow into well in m^3/d

K = permeability constant in m/d

m = thickness of the confined aquifer in m

H = depth of water in the well before pumping in m

h = depth of water in the well after pumping in m

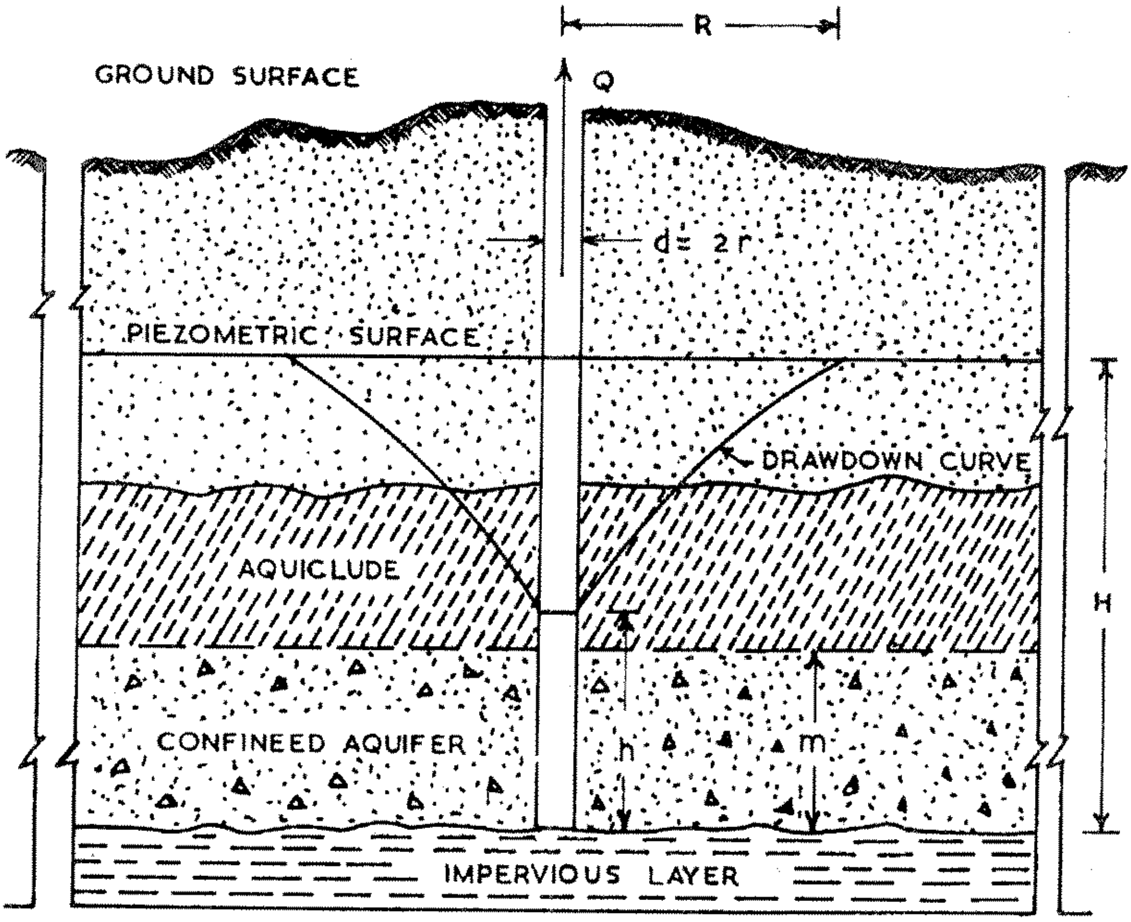

FIG 5.2 : PRESSURE WELL UNDER EQUILIBRIUM CONDITIONS

R = radius of influence in m

r = radius of well in m.

(iii) Flow Into An Infiltration Gallery Under Equilibrium Conditions (Refer Fig 5.3)

The expression for the rate of flow into an infiltration gallery is given by the formula:

$$Q = KL\frac{H^2 - h^2}{2R} \qquad (5.7)$$

where,

Q = rate of flow in m^3/d

K = permeability constant in m/d

L = length of the gallery in m

H = initial depth of water level in m

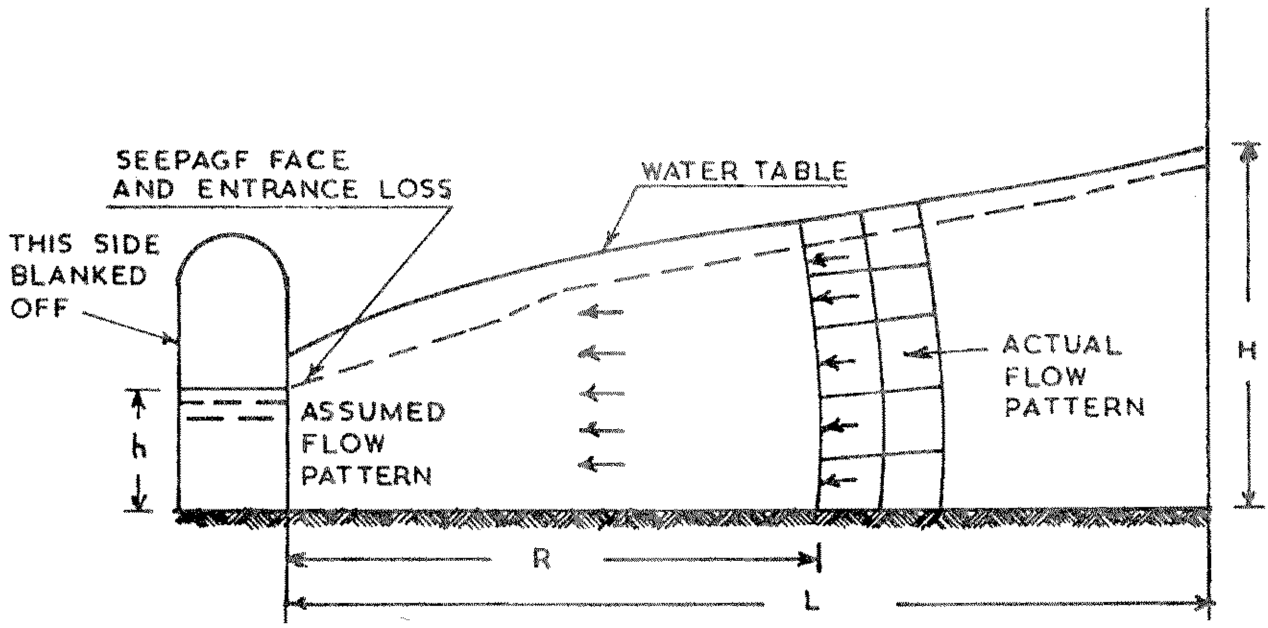

FIG5.3: INFILTRATION GALLERY UNDER EQUILIBRIUM CONDITIONS

h = final depth of water level in m

R = radius of influence in m

(iv) Partial Penetration Of An Aquifer By A Well

If the gravity well does not penetrate to the bottom of the aquifer, the expression (5.5) is not applicable. The flow into a partially penetrating gravity well is given by the expression:

$$Q = \frac{1.36K\left(H^2 - h^2\right)}{Log\frac{R}{r}}\left[p\left(1 + 7\sqrt{\frac{r}{H_1}\cos\frac{\pi p}{2}}\right)\right] \qquad (5.8)$$

where,

R = radius of influence in m

r = radius of well in m

H = thickness of aquifer in m

H_1 = thickness of aquifer penetrated in m

p = H_1/H

$\pi p/2$ = angular perimeter in radians

(e) Flow Into Wells Under Non-Equilibrium Conditions Or Unsteady Flow Conditions

The rate of flow under non-equilibrium conditions is given by the expression:

$$p = \frac{114.60Q}{T} F(u) \qquad (5.9)$$

$$u = \frac{250S}{T}\frac{x^2}{t} \qquad (5.10)$$

where,

F(u) = well function of u whose values could be found out from the Table at Appx 5.4 or the type curve at Appendix-5.5 for different values of u

Q = uniform rate of pumping in lpm

S = storage coefficient

t = time during which the well has been pumped (expressed in days)

T = coefficient of transmissibility in lpd per metre width

x = distance from the well in m

p = draw-down in m.

Q, S and T are considered to be constant.

Then, $\frac{Q \times 114.6}{T} = C_1$ $\frac{T}{250S} = C_2$ are also constants

The equations (5.9) and (5.10) above be written as:

$$\log C_1 = \log p - \log F(u) \qquad (5.11)$$

and

$$\log C_2 = \log \frac{x^2}{t} - \log(u) \qquad (5.12)$$

The values of C_1 and C_2 can be found out from the field observations. Drawdowns in the observation wells (x metres away from the central well) are observed at different intervals, when the central well is pumped out at uniform rate.

The measured values of 'p' are plotted as ordinates against measured values of x^2/t as abscissae on a log-log paper and a curve drawn as at Appendix-5.5

Because of the similarity of expressions (5.11) and (5.12) and the methods of plotting this curve and the type curve (plotted with values of F(u) as ordinates against values of u as abscissae on a log-log paper) there is a corresponding point on the type curve which is displaced vertically by a fixed distance representing log C_1 and horizontally by a fixed amount representing log C_2. Therefore, a fixed amount of vertical and horizontal shift will bring the two curves into coincidence.

If transparent paper is used for the plot of the observed data and it is placed over the type curve, to be shifted horizontally and vertically until a best fit of the plotted points to the type curve is obtained, then any matching point will identify the values of F (u) and u that correspond to the values of p and x^2/t by which equations (5.9) and (5.10) can be solved for T and S.

Though these equations apply rigidly only when (i) the aquifer is homogenous; (ii) the aquifer is infinite in areal extent; (iii) the well penetrates the entire thickness of the aquifer (iv) the coefficients of transmissibility and storage are constant at all times and places; and (v) water is released from storage as soon as the cone of depression develops, they could be used in the field conditions generally encountered.

This method is very useful for long term prediction of groundwater yield and regional planning of groundwater extraction (Appendix-5.6)

5.2.6 Development Of Subsurface Sources

The subsurface sources include springs, wells and galleries. The wells may be shallow or deep. Shallow wells may be of the dug well type, sunk or built, of the bored type or of the driven type. They are of utility in abstracting limited quantity of water from shallow pervious layers, overlying the first impermeable layer.

Deep wells are wells taken into pervious layers below the first impermeable stratum. They can be of the sunk well type or the bored or drilled type. They are of utility in abstracting comparatively larger supplies from different pervious layers below the first impervious layer. Because of the longer travel of groundwater to reach pervious layers below the top impermeable layers, deep wells yield a safer supply than shallow wells.

5.2.6.1 Classification Of Wells

The wells are classified according to construction as follows:

(a) dug wells;

(b) sunk wells;

(c) driven wells; and

(d) bored wells.

(a) Dug Wells

Dug well of the built type has restricted application in semi-permeable hard formations. The depth and diameter are decided with reference to the area of seepage to be exposed for intercepting the required yield from the sub-soil layers. Unsafe quality of water may result if care is not taken in the well construction. It is necessary to provide a water-tight steining upto a few metres below the vertical zone of pollution which usually extends 3 to 5 m or more below natural ground surface.

The steining should extend well above the ground surface and a water-tight cover provided with water-tight manholes.

The bottom of the well should be at a level sufficiently below the lowest probable summer water table allowing also for an optimum drawdown when water is drawn from the well. Adequate provision should also be made to take care of interference by other pumping wells. To facilitate infiltration into the well, either the steining is constructed in dry masonary or, weepholes are left in the steining at suitable intervals. It is usual to insert cut lengths of pipes in the steining with the outer end covered with a wire gauze and shrouded with gravel to arrest ingress of fine material..

(b) Sunk Wells

Sunk wells depend for their success on the water bearing formations which should be of adequate extent and porosity. The sunk well is only the inter-position of a masonary barrel into such a deposit so as to intercept, as large a quantity of water, as is possible.

(i) Size vs Yield

The yield of any form of a well is dependent on the rate of flow of the groundwater and the area made tributary by the depression of the water level in the well rather than on the size or form of construction. As is well known, the effect of size alone is very small and an increase in the yield of large wells will not commensurate with the increase in size.

The large well has an advantage over the small well in its storage capacity and facility for placement of pump sets economically. Trouble may often be experienced in the small wells through clogging and the entrance of fine sand. This is largely avoided in the large well as the entrance velocity of the water is correspondingly small. Opportunity is also given for the settling of fine material.

Wells for water supply are constructed of diameters normally ranging from 3 m and above. As the cost of a well increases with increase in diameter, more rapidly than does the yield, any large diameter should be adopted after a careful consideration.

(ii) Construction Methods

The minimum depth of a well is determined by the depth necessary to reach and penetrate, for an optimum distance, the water bearing stratum allowing a margin for dry seasons for storage and for such draw-down as may be necessary to secure the required yield. The method of construction employed depends on the size and depth of the well, characteristics of material to be excavated and quantity of water to be encountered. The procedure generally adopted is to have open excavation upto the sub-soil water table and thereafter to commence sinking the steining built in convenient heights, over a wooden or R.C.C. curb with a cutting edge at the bottom, the curb projecting about 4 cms beyond the outside face of the steining to facilitate easy sinking. Mild steel holding down rods are run from the bottom of the curb through the steining spaced about 2 metres circumferentially, with horizontal ties in steel or of concrete rings, spaced about 2 metres vertically. The material from inside the well is dredged and removed either mechanically or by manual labour using divers with diving equipment.

(iii) Measures to Increase Yield

Dewatering the well to an optimum extent is resorted to, during the sinking operations. The constructions supervision should ensure uniform vertical sinking of the steining. Entry for the infiltration water into the well is usually at the bottom below the curb. In order to reduce the velocity of entry and to abstract a larger yield for the same draw-down, weepholes in the steining at suitable intervals, horizontally and vertically, would be useful. These could be of cut length of pipes 75 or 100 mm dia, built into the steining, with wire gauze at the outer end, which will be kept flush with the outside face of the steining. Such weepholes would draw water from the pervious layers extending over the depth of the steining, apart from the influx at the bottom. In the initial stages of pumping and during the training of the yield, the fines from water bearing strata round each weephole would be drawn out facilitating a larger influx through each weephole under normal pumping.

(iv) Porous Plugs

In the case of infiltration wells sunk in sandy soils, a porous plug in the form of a reverse filter is placed at the bottom of the well after the initial training of the yield from such well, to facilitate the abstraction of a greater yield, as the plug would permit increased velocities of entry without sand blows. The graded plug is usually an inverted filter comprising of coarse sand and broken metal of appropriate sizes to suit the texture of the sub-soil layers in the aquifer immediately below the well-curb. The depth and the composition of the porous plug will be designed to maintain the natural sandy layer immediately below the curb level undisturbed during pumping.

Radial strainer pipes are driven horizontally from the interior of sunk wells into the water bearing pervious strata as a measure of increasing the yield for the same draw-down. The arrangement in effect enlarges the zone of influence of the well. Further details are given under Radial Collector Wells in 5.2.6.3.

(v) Protection Measures

All wells should be covered so as to prevent direct pollution of water. Where infiltration wells are sunk in the bed of streams liable to carry floods, the top of the well should be kept 0.5 to 1 m above the maximum flood level if it is not very high. If the well top is kept below flood level, provision should be made for ventilating the well with a porous concrete ring placed below the cover slab or with holes in the cover slab filled with a graded filter material.

(c) *Driven Wells*

(i) Construction

The shallow tube well, also called a driven well, is sunk in various ways depending upon its size, depth of well and nature of material encountered. The closed end of a driven well comprises a tube of 40 to 100 mm in diameter, closed and pointed at one end and perforated for some distance therefrom. The tube thus prepared is driven into the ground by a wooden block until it penetrates the water bearing stratum. The upper end is then connected to a pump and the well is complete. Where the material penetrated is sand, the perforated portion is covered with wire gauze of suitable size depending upon the fineness of the sand. To prevent injury to the gauze and closing of the perforations, the head of the shoe is usually made larger than the tube or the gauze may be covered by a perforated jacket.

Such a driven well is adopted for use in soft ground or sand upto a depth of about 25 m and in places where the water is thinly distributed. On account of the ease with which it can be driven, pulled up and redriven, it is especially useful in prospecting at shallow depths and for temporary supplies. It is useful as a community water standpost in rural area.

(ii) Protection Measures

Special care is necessary during construction to avoid surface pollution reaching the sub-soil water level directly, through any passage between the pipe and the soil. The usual precaution is to have the perforations confined to the lower depths of the aquifer with the plain tubing extending over the top few metres of the soil. In addition, a water-tight concrete platform with a drain should be provided above ground level, in order to deflect any surface pollution away from the pipe.

(d) Bored Wells

(i) General

Bored wells are tubular wells drilled into permeable layers to facilitate abstraction of groundwater through suitable strainers inserted into the well extending over the required range or ranges of the-water bearing strata. There are a variety of methods for drilling such wells through different soils and for providing suitable strainers with a gravel shrouding where necessary.

Bored wells useful for obtaining water from shallow as well as deep aquifers are constructed employing open end tubes, which are sunk by removing the material from the interior, by different methods. The deeper strata are usually more uniform and extensive than strata near the surface, so that in regions already explored, deep wells can be sunk with far more certainty of success than is usually the case with shallow wells. Methods of sinking deep wells are in many respects different from those already described and matters of spacing, pipe friction, arrangement of connections, etc., are much more important than in the shallow wells.

For bored wells, the hydraulic rotary method and the percussion method of drilling such wells through hard soils are popular. For soft soils, the hydraulic jet method, the reverse rotary recirculation method and the sludger method are commonly used.

(ii) Direct Rotary Method

With the hydraulic direct rotary method, drilling is accomplished by rotating suitable tools that cut, chip and abrade the rock formations into small particles. The equipment used consists of a derrick, suitable cables and reels for handling the tools and lowering the casing into the hole, a rotary table for rotating the drill pipe and bit, pumps for handling mud laden fluid and a suitable source of power. As the drill bit attached to the lower end of the drill pipe is rotated, circulating mud is pumped down the drill pipe, out through opening in the bit and up the surface through the space between the drill pipe and the walls of the hole. The mudladen fluid removes the drill cuttings from the hole and also prevents caving by plastering and supporting the formations that have been penetrated. For soft and moderately hard materials a drilling tool shaped like the tail of a fish, the 'fishtail bit' is used. In hard rock a 'rock bit' or 'roller bit' is substituted. This bit has a series of toothed cutting wheels that revolve as the drill pipe is rotated.

Water wells drilled by the hydraulic rotary method generally are cased after reaching the required depth, the complete string of casing being set in one continuous operation. If the water-bearing formation lies so deep that it probably cannot be reached by a hole of uniform diameter, the hole is started one or more sizes larger than the size desired through the water-bearing formation. Separate strings of casing are used as required through the separate sections of the hole. If the formation is so well consolidated that the hole will remain open without casing, a well may be finished with one string of casing and a well screen.

This method is most suitable for drilling deep holes in unconsolidated formations. It is unsuitable for drilling in boulders and hard rocks due to slow progress and high cost of bits. It is also unsuitable for drilling in slanted and fissured formations and serious lost circulation zones. Mud drilling is harmful in low pressure formations due to mud invasion. The hydraulic rotary drilling generally requires large quantity of water which may have to be brought from long distances, if not locally available. Because of adding large quantities of water and sand or clay to the drill cuttings, the hydraulic rotary method is less suitable for obtaining accurate logs of the strata encountered.

A recent advance is the use of organic drilling fluids instead of inorganic and permanently gelatinous clays such as bentonite. The organics are almost completely self-destructive within a period of few days which means no drilling muds are left in the pores of the aquifer and, therefore, almost always higher yields are obtained with accompanying lesser development expenditures. In addition to higher specific capacities, cleaner holes (more cuttings settle on the surface equipment) and faster drilling rates also result.

(iii) Percussion Method

In the percussion method of drilling, the hole is bored by the percussion and cutting action of a drilling bit that is alternately raised and dropped. The drill bit, a clublike, chisel-edge tool, breaks the formation into small fragment; and the reciprocating motion of the drilling tools mixes the loosened material into a sludge that is removed from the hole at intervals by a bailer or a sand pump. The drilling tools are operated by suitable machinery; which is usually of the portable type mounted on a truck or a trailer so that it can be moved readily from job to job. This method is best suited for drilling on boulders, slanted and fissured formations and lost circulation zones. Rate of drilling in alluvial formations, particularly those having clay or sticky shale strata, is much lower as compared to direct or reverse rotary methods. Percussion drilling in hard rock is a slow process and is being gradually replaced by pneumatic rotary drilling because of economy and speed of completion regardless of the higher initial cost.

'Pneumatic Drilling'

Pneumatic drilling with top-hammer and eccentric bit and pneumatic drilling with down the-hole hammer are the two principal methods available for drilling in consolidated (hard rock) formations:

(a) Top Hammer and Eccentric Bit

This rapidly expanding drilling method is most valuable when drilling in hard rocks covered with difficult over-burden. The overburden, even if it is of the collapsible type, presents no problem as the method is based on the simultaneous drilling and inserting of casing tubes down to and even into the bed rock. The principle of the drilling method is as follows:

A compressed air powered rock drill with a separate rotation coupled to it, works at the top of a drill string. At the bottom of the string is a tungsten carbide set drill bit, the pilot bit, to which the impact and rotation is transmitted. Immediately above this bit is a reamer with a tungsten carbide set cutting edge. With normal rotation to the left, the reamer will swing out eccentrically and cut a hole which is of larger diameter than the pilot bit, allowing the. casing tubes which enclose the drill string to enter into the hole at the same pace as the drilling proceeds. Since no external obstructions can be tolerated on the string of casing tubes, they will have to be flush-jointed with male and female threads or, preferably, by welding. The cuttings are flushed up between the drill string and the casing tubes. To make this effective and also prevent the formation of large amounts of dust, foam-producing chemicals are introduced into the flushing air.

(b) Down-the-Hole Hammer

This drilling method, called DTH for short; permits rapid and effective drilling in rock and through over-burden which is not susceptible to collapse. In this method the impact mechanism blows directly on the drill bit and accompanies it down into the hole. Compressed air for the impact mechanism is supplied through drill tubes which are jointed as required as the drilling advances. The same air is, after it has passed the hammer, made use of for flushing. The necessary rotation is supplied from a rotation unit connected to the upper drill tube.

As the drill tubes are not required to transmit the violent impact energy of the hammer, they can be manufactured with large diameter and still be relatively thin walled. This gives the method better flushing characteristics than conventional top hammer drilling. Theoretically, the rate of penetration is independent of the hole depth with the DTH method no water is required during drilling. The equipment is also cheaper and lighter as a much smaller compression is required than for top hammer drilling.

(iv) Hydraulic Jet Method

This is the best and most efficient method for small diameter bores in soft soils. Water is pumped into the boring pipe fitted with a cutter at the bottom and escapes out through the annular space between the pipe and the bored hole. The pipe is rotated manually with the aid of pipe wrenches with a steady downward pressure. The soil under the cutter gets softened and loose by the action of the jet of water and is washed with it as the cutter proceeds, down with the weight of the pipe. Additional lengths of pipe are added till the required depth is reached. The wash water emanating from the annular space indicates the type of soil that is being encountered by the cutter. When the desired depth is reached, the pipes are withdrawn and the well tube with the strainer is lowered by the same process using a plug cutter with the plug removed instead of the ordinary steel cutter. When the pipe is in position, the plug is dropped down to seal the bottom. Then the tube well is cleaned by forcing water through a 20 mm pipe lowered right to the bottom of the tube well. Then it is withdrawn and the pump fitted on top.

For bigger diameter tube wells, casing pipes are used and mechanically driven pump set is used for jetting. The tube well pipe with the strainer is lowered into the casing pipe and the outer casing withdrawn. Generally compressed air is used for developing the well. To economise the use of water during the operation, the wash water carrying from the bore is led to a sump wherefrom the water is again drawn for being forced into the bore.

(v) Reverse Rotary Method

In this method the water is pumped out of the bore through the pipe and fed back into the annular space between the bore and the central pipe. No casing is required in this method which is used only in clayey soils with little or no sand. This method is suitable for large diameter bores upto a depth of 150 m. The cutting pipe is clamped to a turn-table which rotates slowly operating the cutter. The water pumped out of the tube contains the washings and is led to a series of sumps for effective sedimentation of the solid particles before the water is put back to flow into the bore. Bentonite or some clayey material which can adhere to the sides of the bore firmly, is used from time to time.

After the required depth is reached, the pipe with the cutter is taken out of the bore and the well pipe with the strainer is then lowered into the hole. The annular space between the bore and the well screen is then shrouded with pea gravel.

(vi) Sludger Method

In this method the boring pipe with the cutter attached is raised and lowered by lever action and the bore filled with water from a sump nearby. When the boring has proceeded a few metres down, the pumping out of the water from the inside of the bore pipe is carried out in an improvised manner by the operator closing the top end of the pipe during the upward stroke and releasing it during the downward stroke. This method when done with quick up and down strokes enables the washings from the bore pipe to come out of the pipe. The bore is always kept full with the water from the sump. Bentonite or some clayey material is added sometimes. This method is suitable for depths upto about 50 metres. When the proper depth is reached, the bore pipe is taken out and the well tube with the strainer is lowered as in other methods. This method is suitable for small diameter wells in soft soils and medium hard soils. This is particularly applicable for use in areas not easily accessible where labour is available for the unskilled complement.

(vii) Casing of Wells

Wells in soft soils must be cased throughout. When bored in rock, it is necessary to case the well atleast through the soft upper strata to prevent caving. Casing is also desirable for the purpose of excluding surface water and it should extend well into the solid stratum below. Where artesian conditions exist and the water will eventually stand higher in the well than the adjacent groundwater, the casing must extend into and make a tight joint with the impervious stratum; otherwise water will escape into the ground above.

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If two or more water bearing strata are encountered, the water pressures in different strata are likely to be different, that from the lower usually being the greater. Where different pressures thus exist, it is only possible to determine their amount by separately testing each stratum as reached, the others being cased off. This operation is an essential part of the boring and should be carefully performed. Important differences in quality and yields are discovered in this way.

When quality stratification exists, which may be ascertained from geophysical logs or drill-stem tests, blank casings should be provided against zones containing undesirable quality of water and the annular space between the casing and hole wall should be sealed with cement grout or packers. This will ensure that the fresh water aquifers are not contaminated by leakage.

Large casing is generally made of welded or riveted steel pipe. For smaller sizes of pipes which are to be driven, the standard wrought iron pipe is ordinarily used, but for heavy driving extra strong pipe is necessary. The life of good heavy pipes is ordinarily long, but they are liable to rapid corrosion due to the presence of excess amount of carbonic acid. The use of rust resisting alloys would be economical in such special cases. Non-reinforced plastic, usually PVC, casing upto 100 mm dia and reinforced plastic casing and fibre glass for longer dia upto 400 mm are coming into vogue.

(viii) Well Strainer and Gravel Pack

In providing the strainer arrangement whereby water is admitted and sand or gravel excluded, it is desirable to make the openings of the strainer as large as practicable in order to reduce friction, while at the same time preventing entrance of any considerable amount of sand.

The openings in well strainers are constructed in such a fashion as to keep unwanted sand out of the well while admitting water with the least possible friction. In fine uniform strata, the openings must be small enough to prevent the entrance of the constituent grains. Where the aquifer consists of particles that vary widely in size, however, the capacity of the well is improved by using strainer openings through which the finer particles are pulled into the well, while the coarser ones are left behind with increased void space. A graded filter is thereby created around, with the aid of back-flushing operations or by high rates of pumping.

The selection of the well screen is important; on it depends the capacity and the life of the well. The size of the openings may be selected, after a study of the mechanical analysis of the aquifer, to permit the passage of all fine particles representing a certain percentage, by weight, of the water-bearing material. It is common practice to use openings that will pass about 70 per cent or more of the sand grains in the natural aquifer whose uniformity coefficient should range between 2 to 2.5. For soils with a uniformity coefficient less than 1.5, gravel shroud should be used. The shape of the openings should be such as to prevent clogging and bridging, which can be diminished by V-shaped openings with the larger end towards the inside of the well. Long, narrow, horizontal or vertical slotted pipes are preferred for large diameters. The openings should be placed as close together as the strength of the screen will permit.

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The total area of the openings in a screen should be such as to maintain an entrance velocity less than necessary to carry the finest particle of sand that is to be excluded by the screen. In general, it should be less than about 4 to 6 cm/s. with gravel shrouding. It is generally desirable that the length of the screen is made slightly less than the thickness of the aquifer penetrated and placed centrally in respect of the aquifer. The length, diameter and total area are inter-dependent dimensions that must be adjusted to give the desired entrance velocity. Some margin of safety in screen size is desirable to allow for incrustation and clogging and to prolong the life of the screen.

Where the water-bearing sand stratum contains little or no gravel, it is very advantageous to insert a layer of fine gravel between the strainer and the sand strata, thus permitting the use of larger orifices in the strainer and greatly decreasing ground friction. The gravel wall so provided may vary in the thickness to suit the size and depth of the boring. It may vary from 10 cm to 25 cm, but it is usually 10 cm. The size of the gravel to be provided would be decided by the particle size distribution in the layer penetrated and the slot size in the well screens proposed to be adopted. Since screen sizes can now be custom-tailored to fit any grading of desired gravel, there is a shift from the former multiple (concentrically placed) gravel packs to single ones.

Well effectiveness and performance may be adversely affected if the gravel pack ratio, that is, the mean size of gravel divided by mean size of formation material, exceeds 5. Beyond this limit, wells may require longer time for development or, if the ratio is excessive, they may turn out to be sand pumpers ultimately resulting in failure. The gravel size should be related to the size of the formation materials in the finest section of the aquifer materials against which screen is provided.

In gravel packed wells the screen size should be related to the gravel in about the same manner as it is related to the aquifer materials in a non-gravel pack (for natural pack) well, i.e. it should correspond to the size that separates 90 per cent of coarser fractions of gravel.

(a) Bimetal Strainers

For small driven tube wells generally of 3 cm to 5 cm dia, the strainers are generally of bimetal-sometimes called jacketed strainers. It consists of a galvanised iron pipe with about 300 rectangular slots of 1 cm x 1 1/2 cm in a standard length of pipe of 1.8 m, having an area of opening of about 17% covered with a brass wiremesh of 24 or 32 mesh which again is enveloped by a perforated brass metal sheet of 26 gauge, having about 2 to 3 holes of 3 mm dia per cm^2 or an area of opening of about 18.5%. The effective area of opening resulting is roughly 5 to 7%. These are available upto 150 mm dia. Gravel shrouding is not essential for this type of strainer.

(b) Monometal strainers

The monometal type is of a single metal with diameters in the range 30 mm to 300 mm usually fabricated from brass sheets 2 or 3 mm thick. These have V-shaped slots of varying sizes to permit a proper selection of strainer to suit the sand size in the aquifer. Slots 2.5 mm wide and 30 nun long are usual.

A thin gravel shroud (50 to 75 mm) is also provided in some cases.

Sometimes the brass monometal strainer is strengthened with an inner G.I. slotted pipe for greater rigidity and longer service.

(c) Slotted Pipe Strainers

Galvanised iron or brass pipes having bigger slots about 3 mm in width and 750 mm in length are provided in-conjunction with pea gravel shroud, 100 mm to 250 mm thick. The slots are V-shaped with the smaller opening on the outside. The gravel shroud makes it possible to use strainers with large sized slots and abstract a larger yield than is otherwise possible. The slots are preferably to be kept horizontal with unslotted strips left between successive rows or columns of slots.

The advantage with this type of strainer over the others is that there is less damage by galvanic action or chockage due to incrustation.

(d) New Type of Strainers

Strainers of different makes are marketed claiming specific advantage for each. One such is a slotted mild steel pipe core, coated with special anti-corrosive plastic paint and provided with an enveloping graded sand shroud bonded with heat resistant, water repellant plastic.

Strainers made of special alloys such as stainless steel (types 304 and 316), monel metal, red brass etc., are also used where indicated and if available..

High density polythene or P.V.C. and metal combined strainers are gaining popularity in view of their non-choking, non-corroding and non-incrusting properties which give long and uninterrupted service.

5.2.6.2 Infiltration Galleries

(a) Wells Vs. Galleries

Infiltration galleries offer an improvement over a system of wells, in that a gallery laid at an optimum depth in a shallow aquifer serves to abstract the sub-soil flow along its entire length, with a comparatively lower head of depression. Moreover, in the case of a multiple system of infiltration wells, the frictional losses contributed by the several connecting pipes diminish the draw-down in the farther wells to that extent and the utility of a well becomes less and less in the total grid. All the same, wells have to be located with a minimum distance in between each pair, so as to avoid mutual interference under normal pumping. It also becomes uneconomical to lay long lengths of connecting pipes in river beds at depths where constructional difficulties add to the cost of their laying and jointing against high sub-soil water level conditions. These pipes are themselves vulnerable to damages from undue scour during high floods if adequate safeguards are not provided. The pipes are liable to break at their junction with the well steining, should there be a subsidence of the well structure under floods.

(b) General Layout

Essentially, a gallery is a porous barrel inserted within the permeable layer, either axially along or across the groundwater flow. A collecting well at the shore end of the gallery serves as the sump from where the infiltrated supply is pumped out. The collecting well is the point at which the maximum head of depression is imposed under pumping operation, the depression head being diffused throughout the length of the gallery to induce flow from the farthest reach.

The exact alignment of a gallery must be decided with reference to the actual texture of the sub-soil layers, after necessary prior investigations to map out the entire sub-soil. A gallery could be laid axially along a river or across a river. In both the cases, the head of depression induced is the factor influencing the abstraction of the sub-surface flow into the gallery liner; and the zone of influence exerted along the entire length of the gallery line will have the same variations irrespective of the direction of the gallery. A cross gallery would have the advantage of the same potential head in the sub-soil water level along its entire length, whereas the axial gallery will have a varying potential in the sub-soil water level, from a maximum at the farthest end upstream, to a minimum at its other end down stream. But a cross gallery has a distinct advantage when it is used as an instrument for abstracting the maximum available sub-surface flow, in the river-bed if this was possible, in which case the cross gallery becomes virtually a sub-surface barrage.

(c) Structure of a Gallery

The normal cross section of a gallery comprises loosely jointed or porous pipe or rows of pipes, enveloped by filter media of graded sizes, making up a total depth of about 21/2 m and a width of 2 1/2 m or above, depending on the number of pipes used for collection of the infiltrated water. The enveloping media round the collecting pipe functions more as a graded plug whereby water from the sub-surface sandy layers of the river bed is abstracted without drawing in fine particles at the same time. Total reliance need not, therefore, be placed on the filter media of the gallery as such, for effecting the full scale purification of the inflow.

The gallery has necessarily to be located sufficiently below the lowest groundwater level in the aquifer, under optimum conditions of pumping during adverse seasons. The gallery should, of course, be located lower than the scouring zone of the river bed under high floods, so that the top-most sand layer of the gallery media remains undisturbed at all times. The natural permeable layers of the aquifer over the gallery media serve as the initial filtering layers for the sub-soil flow and also safeguards the gallery from scouring effects.

The disposition of the filter media around the porous collecting pipe and the particle size distribution for each layer of the media are of importance. If the invert of the gallery is taken up to an impervious layer, there is no need to provide any filter media underneath the collecting pipe except perhaps a nominal layer of coarse aggregate to separate the pipe from the soil immediately below and to ensure a uniform bedding for the pipe. The galleries consist of either a single or double row of stoneware or concrete pipes loose jointed with cement lock filters. Perforated PVC pipes can also be used. The pipes are laid usually horizontally or to a gradient if aligned in the direction of flow. The coarse aggregate envelope in the pipe material is in three layers, followed by coarse and medium sand layers, as detailed below:

Filtering medium near pipe line - 38 mm broken stone.

2nd layer - 38 to 19 mm broken stone.

3rd layer - 12 to 6 mm broken stone.

4th layer	-	Coarse sand passing through a sieve of 3.35 mm size and retained on a sieve 1.70 mm size.
5th layer	-	Fine sand retained on 70 micron sieve and passing through 1.70 mm sieve.

In the older practice, the pipe was surrounded on three sides by two or three layers of the coarse media, while the finer layers of the coarse media and sand formed further horizontal layers on the top alone. This is not quite rational, as the entry into the gallery is also through the sides and a repetition of all the layers of the enveloping media on both sides of the collecting pipes is also necessary.

The particle size distribution between each successive layer should preferably be based on a multiple of four. Precast perforated concrete barrels are also used as collecting pipes with the enveloping media on the three sides.

Filter media round the gallery pipe-line may be said to function like graded plugs to infiltration well bottoms. In the latter case, the plug has to be designed to suit the actual particle sizes of the sub-soil layers on which the well is founded, in order to arrest the entry of fine particles into the well under continuous pumping operation and to induce a greater head of depression than is otherwise possible without the plug. It eventually serves to train the yield into the well and increase it to an optimum quantity under actual pumping operations. Likewise, the enveloping media round the gallery pipe line is best designed to suit the actual layers of the sub-soil which will immediately surround the gallery media. Preliminary boring operations and sieve analysis of samples could help to decide on the different variations in such sub-soils, so that if a gallery system was on an extensive scale, the gallery media could be designed suitably for the different reaches, in order to obtain maximum yield under optimum heads of depression.

(d) Constructional Features

The constructional features during the execution of such galleries are of importance. Trenches are dug with adequate shoring or piling facilities right down to the required level decided upon for the invert of the gallery, which would normally be placed several metres below the sub-soil water level, a greater depth indicating a greater potential for the yield from the gallery. The gallery can be laid under water, if dewatering the trench completely for the purpose is not feasible or economical. Manholes should be provided at intervals of about 75 m for inspection. These are sunk into the bed before the gallery is laid and the floor of these wells are taken a little below the invert level of the gallery pipe. The pipes are covered with R.C.C. slab with water-tight manhole frame and cover.

A practical limit on the yield potential of the gallery is set by the diminishing effect of the depression head, if the gallery is unduly extended from a single point of pumping. For maximum effects to be realised, the pumping operations are best located centrally with reference to the gallery grid, with manhole wells located at the junction of all gallery arms as also at the blind end of each gallery arm. The arrangement could be duplicated with a second pumping point, if the grid system necessary to abstract the required quantity of supply, should be too extensive and unwieldy for a single pumping point. The limiting factor for the total length of gallery under any single arrangement is the ratio between the total quantity abstracted and the total sub-surface flow in the river past the gallery section. So long as the flow abstracted is less than the total flow past the area, additional gallery systems could be inserted in the same area, with one or more pumping points, in order to draw out the maximum quantity. When the maximum quantity possible has been abstracted through a gallery system at a single location, the potentiality of the source at that point will have been fully exploited. In such a case, any augmentation of the supply from the same river as the source will have to be attempted at a new point either upstream or downstream, with a distance left in between, such as would bring into the stream course adequate supplies from the catchment, which could be tapped, without affecting the yield from the gallery already in service.

When infiltration gallery systems are inserted in aquifers with confined groundwater, the rate of abstraction from the gallery must bear a practical relation to the replenishable capacity of the sub-surface area which comes within the influence of the gallery under pumping.

The provision of a gallery within a tank or a lake-bed suffers certain inherent disadvantages in that the static water on top, in a state of continuous sedimentation, builds up a silt blanket on the top of the gallery, which may retard the free passage of water through the lake-bed under-layers and into the gallery media. Periodical removal of the surface silty layer so collected would overcome such a handicap.

(e) Check-dams

Under certain conditions, the provision of a sub-soil barrage or check dam across a river just downstream of a gallery system, helps in inundating the river-bed area over the gallery and providing permanent saturation of the sub-soil layers contributing to the yield through the gallery. The barrage is usually keyed into the river-bed on an impermeable layer and into the banks for it to function successfully. Incidentally, it would also save the gallery system against damages by scour during floods.

5.2.6.3 Radial Collector Wells

A collector well consists of a cylindrical well of reinforced concrete say 4 to 5 m in diameter, going into the aquifer to as great a depth of the sub-strata as possible, i.e. upto an impermeable stratum. Normally the saturated aquifer should not be less than 7 m above the top of the radial pipes. From the bottom of the well, slotted steel pipes, normally of 200 mm to 300 mm diameter on the inside and going upto 30-35 metres in length are driven horizontally. The length is determined by the composition and yield from the aquifer. The drain tubes are made up of short length of pipes each 2.4 metres in length which are welded to each other electrically one after the other.

These steel pipes are driven horizontally into the aquifer by means of suitable twin jacks placed in the well and crossing the steining of the well, through the special openings or port holes. At the same time, desanding operation is carried out through the head of the drain pipes. This operation is very important and results in the removal of all the fine particles in the alluvium thus increasing the draw-off.

A sketch of a collector well is given in Appendix-5.7.

(a) Desanding Operation while Driving Radials

An important operation in the driving of the drains is the operation of desanding of drain tubes of 200 mm to 300 mm dia which will remain inside the sand bed being driven to a certain distance. An inner tube is then introduced into the drain which is used for sending a blast of compressed air for loosening and separating the fine particles of the alluvium at the head of the drain. When the compressed air is turned off, the pressure of the water, due to the head of the water table, enables the fine particles into the interior of the well to be carried until clear water without any fine particles is obtained. This indicates that the pressure of the water is insufficient to move the fine particles. Then the drains are driven further.

This process ensures formation of big sheath around the steel drain, composed of the coarser particles in the alluvium; this sheath itself forms a drain of large section of a reverse filter. During the course of desanding, the quantities of sand removed are measured carefully which enables one to estimate the diameter of the sheath thus formed around the drain.

(b) Advantages

(i) The surface of draw-off of collector well is many times greater than that in the case of an ordinary or traditional well. It also ensures a very low velocity of flow with a high total yield.

(ii) The danger of clogging is eliminated by the process of desanding which removes all fine particles around the drains and creates a high sheath through which a large yield with low velocity is obtained.

(iii) The collector well uses 90% of the head available from the water table whereas ordinary well under water table conditions can use only 66%.

(iv) The collector well is able to obtain high yields varying from 500-2500 m^3/hr depending upon the strata and depth of submergence.

(v) The draw-off from a collector well is regulated by valves controlling each radial pipe. The valves have shafts extending to the top of the well, which make control and regulation of the supply easy. This also enables the well to be easily cleaned by closing the valves, if cleaning is ever necessary. The facility of cleaning by repeating the desanding process, if at all there is any clogging and resulting falling off in the yield, ensures a much longer life for the installation, while cleaning of infiltration gallery is difficult and expensive.

(vi) In coarse and saturated river beds, installation of radial collector well system is cheaper both in capital and operation costs than any conventional method.

(c) Limitations

(i) A saturated aquifer of minimum depth of 7-8 m is necessary,

(ii) The aquifer should be coarser than 2mm,

(iii) The aquifer should be homogeneous and loose.