GROUND WATER

WATER ENGG.

$$\int Sec - A$$

Aquifer

An Aquifer is an underground layers of rocks or soil that contains water and yields it in sufficient ~~capacity~~ quantity. unconsolidated deposits of sand and gravel form good aquifers. water is taken from the aquifers to the surface using wells and pumps.

Types of Aquifers :-

There are mainly of two types of aquifers.

① Unconfined Aquifer or water Table Aquifer.
② Confined Aquifer or Artesian Aquifer.

UNCONFINED Aquifer ..

* unconfined Aquifers are those into which water seeps from the ground surface directly above the aquifer.

* Has no confining bed
* open to infiltration from surface.
* unconfined Aquifer are sometimes also called water table aquifer because their upper boundary is the water table.

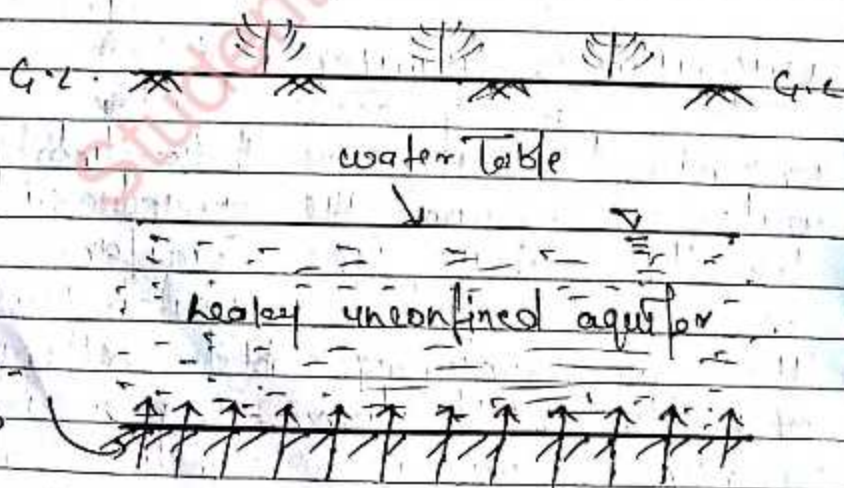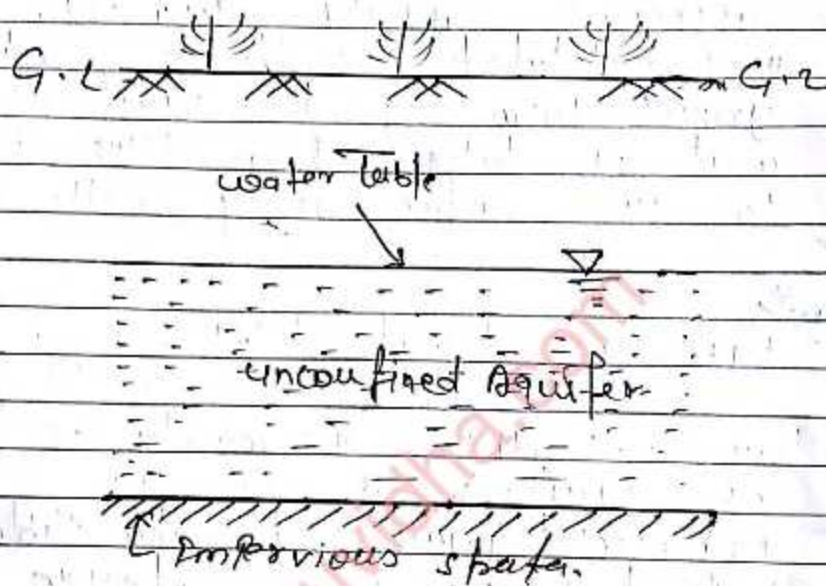☆ An Aquifer having water table in it is known as unconfined Aquifer.

G.L $\overline{\text{XX}}$ ⚘ ⚘ ⚘ ⚘ G.L

water table

unconfined Aquifer ▽

⎣ Impervious strata.

G.L ⚘ ⚘ ⚘ ⚘ G.L

water table

leaky unconfined aquifer

semi-pervious strata ↑↑↑↑↑↑↑↑↑↑

fig — unconfined Aquifer.

Confined Aquifer :

* Confined Aquifers are those in which an impermeable rock layer exists that prevents water from seeping into the aquifer from the ground surface located directly above.

* Instead, water seeps into confined Aquifer from farther away where the impermeable layer does not exist.

* Overlain by a confining bed.

* Confined Aquifer are recharged through cracks in impermeable layer.
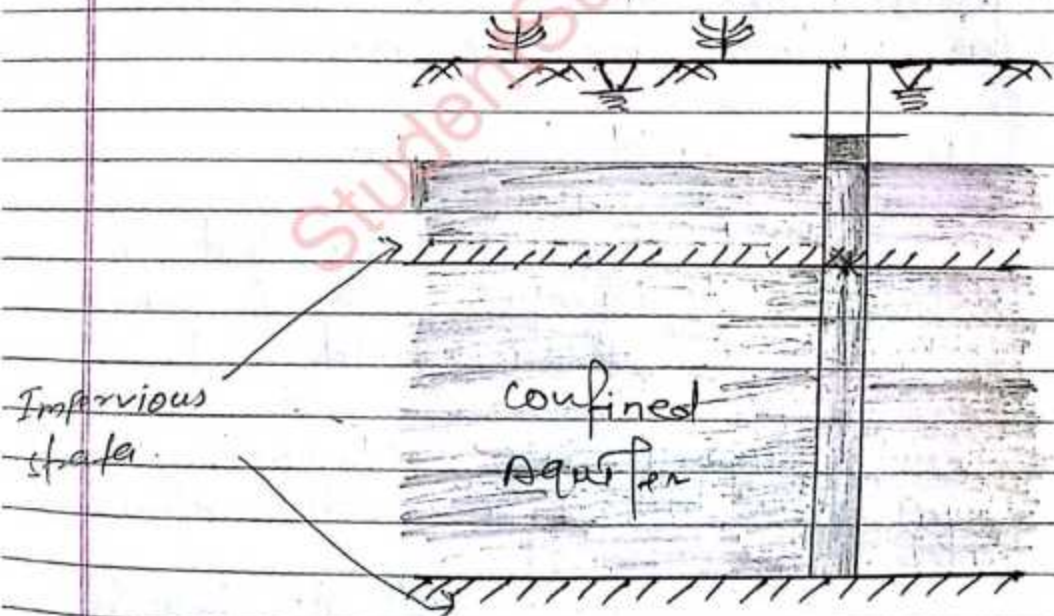
* Also known as Artesian Aquifer.

Impervious shale

confined Aquifer

fig. confined Aquifer.

Properties of the Aquifer :-

1) Porosity (n) :-

The amount of pore space per unit volume of the aquifer material is called Porosity.

$$n = \frac{V_v}{V}$$

In unconsolidated materials, the porosity depends on the shape and size distribution of the particles and their packing arrangement. Porosity of surface soil decreases as particle size increases.

2) Specific Yield (Sy) :-

The actual volume of water that can be extracted by the force of gravity is known as specific yield (Sy).

The fraction of water held back in the aquifer is known as specific retention (Sr)

$$S_y = \frac{V_w}{V}$$ And $$n = S_y + S_r$$

V_w = vol. of water drained or extracted.

3) **Permeability :**

As the Porosity of a soil affects how much water it can hold, it also affects how quickly water can flow through the soil. Thus,

the ability of water to flow through a soil is known as permeability of the soil.

4) **Darcy's law :-**

The law of flow of water through the soil was first studied by Darcy (1856). This law states that -

" The velocity of water is always directly proportional to the hydraulic gradient"

Mathematically -

velocity ∝ hydraulic gradient

$$V \propto i$$
$$V = ki$$

multiplying A on both sides

$$AV = Aki \qquad —①$$

where k is constant of proportionality and is called coefficient of Permeability.

Q stands for discharge and is equal to —

$$Q = \frac{V}{t} = volume/time.$$

$$Q = A \times \frac{L}{t} \qquad [\frac{L}{t} = velocity.]$$

$$Q = Av \qquad —②$$

putting eq^n(2) in eq^n(1), we get

$$\boxed{Q = Aki}$$

which is darcys equation

where —

Q = flow or discharge

K = coefficient of proportionality.

i = Hydraulic gradient.

A = Area of cross-section.

Coefficient of Permeability (Hydraulic conductivity)
flow

$$Q = KAi$$

or $K = Q/Ai$

If $i = 1$ they

$$K = Q/A$$

then K is called coefficient of permeability and K is defined as —
The discharge or rate of flow per unit area of coil mass under unit hydraulic gradient.

Some Important Terms

Storage Coefficient (S) :-

The storage coefficient in case of confined aquifer is defined as the volume of water that an aquifer releases from or takes into storage per unit surface area of the aquifer.

It is also known as storativity.

Drawdown :-

The drop in the water Table elevation at any point from its previous static level is called drawdown.

Aquitard :-

It is a saturated geological formation which is poorly permeable and hence it does not yield water freely to wells.

Sandy clay is an example of a aquitard.

Formation constants :-

The storage coefficient (S) and the transmissibility coefficient (T) are known as the formation constants of Aquifers.

Steady Flow :-

Steady flow implies that no change occurs with time. When the properties in the fluid flow are not changing with respect to time then such a flow is known as steady flow

$$\frac{\partial R}{\partial t}\bigg|_{space} = 0 \qquad - \text{ steady flow}$$

$R \rightarrow$ Fluid property

Unsteady Flow :-
{Opposite}

Transmissibility (T) :-

The transmissibility is the flow capacity of an aquifer per unit width under unit hydraulic gradient and is equal to the product of permeability times the saturated thickness of the aquifer.

$$\boxed{T = K \cdot H} \qquad \text{unit} - m^2/day$$

As the water-table drops, H decreases and the transmissibility T is reduced. Thus, T of an unconfined aquifer depends upon the depth of G.W.T.

Hydraulic Diffusivity :-

The ratio of transmissibility (T) divided by storage coefficient or the hydraulic conductivity divided by the specific storage.

Specific Storage :-

The volume of water released from or taken into storage per unit volume of the porous medium per unit change in head.

V.V.Imp

Ground water Flow Equation for Un.steady flow in Isohopic homogeneous Aquifer :-

Unsteady flow means that -the flow Scale, Piezometric head and -the amount of fluid in aquifer change with time.
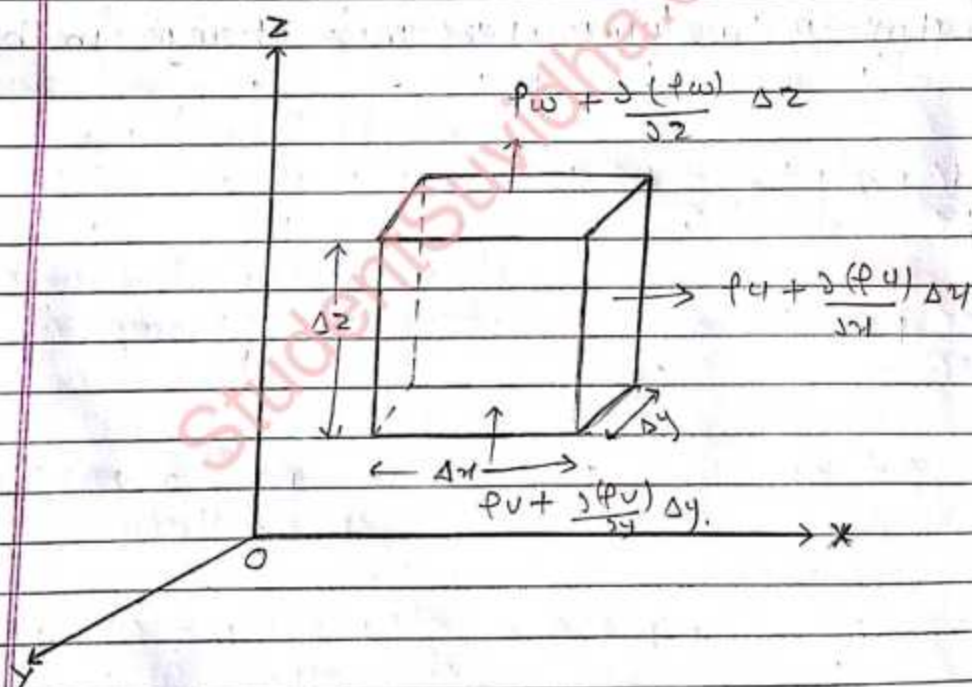

fig- flow of Ground water Through an Elemental Prism.

Consider the flow through an elemental prism of volume $\Delta x, \Delta y, \Delta z$ in the Cartesian coordinate directions x, y, z of the aquifer having velocity velocities u, v and w, as shown in fig —

The equation of continuity for the fluid flow is

$$\frac{\partial (\Delta m)}{\partial t} = -\left[\frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y} + \frac{\partial (\rho w)}{\partial z}\right] \quad — ①$$

Considering the differentials with respect to time and taking the limit as ΔV approaches zero, we get

$$\frac{\partial (\Delta m)}{\partial t} = S_s \rho \frac{dh}{dt} \quad — ②$$

where
$S_s =$ specific storage.

The Aquifer is assumed to be isotropic with permeability constant k, (coefficient)

so that the Darcy's equation for x, y and z directions can be written as —

$$u = -k\frac{\partial h}{\partial x}, \qquad v = -k\frac{\partial h}{\partial y}, \qquad \text{and} \quad w = -k\frac{\partial h}{\partial z}$$
$$— ③$$

$$\boxed{\begin{array}{c} p = h\gamma \\ \gamma = \rho g \end{array}}$$

$$\boxed{\begin{array}{l} h = \dfrac{\rho}{\gamma} + z \\ dh = \dfrac{1}{\gamma} dp + dz \\ \dfrac{dh}{dz} = \dfrac{1}{\gamma} \dfrac{dp}{dz} \end{array}}$$

Also the Piezometric head

$$h = \frac{\rho}{\gamma} + z$$

$$\boxed{\begin{array}{c} \beta = dP / (\rho \, dP) \\ dP = \rho \beta \, dP \end{array}}$$

The right side of eq^n (1) can be written as –

$$\frac{\partial (\rho u)}{\partial x} = \rho \frac{\partial u}{\partial x} + u \frac{\partial \rho}{\partial x} = -k\rho \frac{\partial^2 h}{\partial x^2} - k\rho^2 \beta g \left(\frac{\partial h}{\partial x}\right)$$

$$\frac{\partial (\rho v)}{\partial y} = \rho \frac{\partial u}{\partial y} + v \frac{\partial \rho}{\partial y} = -k\rho \frac{\partial^2 h}{\partial y^2} - k\rho^2 \beta g \left(\frac{\partial h}{\partial y}\right)^2$$

$$\frac{\partial (\rho w)}{\partial z} = \rho \frac{\partial w}{\partial z} + w \frac{\partial \rho}{\partial z} = -k\rho \frac{\partial^2 h}{\partial z^2} - k\rho^2 \beta g \left(\frac{\partial h}{\partial z}\right)^2$$

Assembling these eq^n ① can be written as –

$$k\rho \left[\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2}\right] + k\rho^2 \beta g \left[\left(\frac{\partial h}{\partial x}\right)^2 + \left(\frac{\partial h}{\partial y}\right)^2 \right.$$

$$\left. + \left(\frac{\partial h}{\partial z}\right)^2\right] - \frac{\partial h}{\partial z} = S_s \, \rho \, \frac{\partial h}{\partial t} \quad \text{④}$$

The second term on left. s. hand side is neglected as very small., especially for $\frac{\partial h}{\partial y} << 1$

The eq^n(4) can be re-arranged as –

$$k \mathcal{A} \left[\frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial y^4} + \frac{\partial^2 h}{\partial z^2} \right] = S_s \mathcal{A} \frac{\partial h}{\partial t}$$

$$\frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = \frac{S_s}{k} \frac{\partial h}{\partial t} \qquad —⑤$$

we know that

$$S_s B = S_s \quad kB = T$$

and $\Delta^2 h = \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2}$

eq^n (5) can be written as –

$$\boxed{\Delta^2 h = \frac{S}{T} \frac{\partial h}{\partial t} \qquad —⑥}$$

This is the basic differential equation for unsteady groundwater flow in a homogeneous isotropic aquifer. This form of the eq^n is known as Diffusion equation.
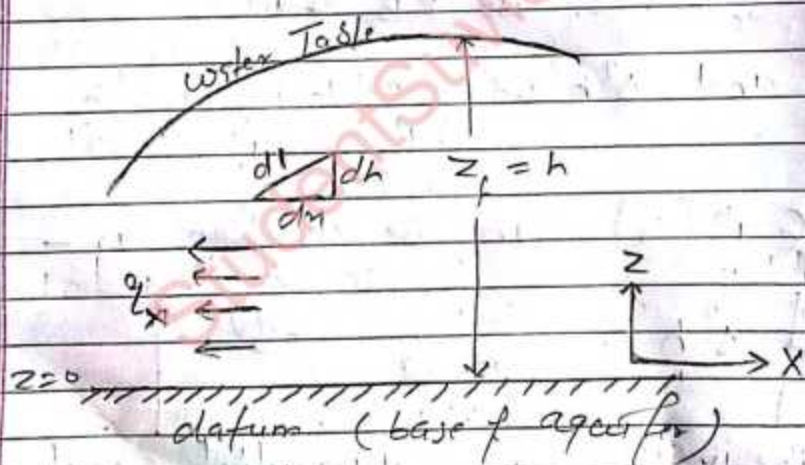If the flow is steady, the $\partial h/\partial t$ term does not exist, leading to –

$$\boxed{\Delta^2 h = 0}$$

This eq^n is known as Laplace eq^n.

Dupuit's Theory

When a well is penetrated into an extensive homogeneous aquifer, the water table initially remains horizontal in the well.

When the well is pumped, water is removed from the aquifer and removal of water from the aquifer lowers the water table.

Dupuit's Equation —

$$q = \frac{k}{2L} \left(h_o^2 - h_i^2 \right)$$

Assumptions :-

For unconfined ground water flow, Dupuit developed a theory that allows for a simple solution based on following assumptions —

1) The velocity of flow is proportional to the tangent of the hydraulic gradient instead of its sine.

2) The flow is horizontal and uniform everywhere in the vertical section.

3) Aquifer is homogeneous, isotropic and infinite aerial extent.

4) The well penetrates and recieves water from the entire thickness of the aquifer.

5) Coefficient of transmissibility is constant at all places and times.

6) Flow is laminar and Darcy's law is valid.

7) water table or free surface is only slightly inclined.

8) Slopes of the free surface and hydraulic gradient are equal.

Unconfined flow with Recharge :-

Darcy's law gives one dimensional flow per unit width as -

$$q = -kh \frac{dh}{dx} \quad \text{---} ① $$

At steady state, the rate of change of q with distance is zero.

$$\frac{d}{dx}\left(-kh\frac{dh}{dx}\right) = 0$$

or

$$\frac{-k}{2} \frac{d^2h^2}{dx^2} = 0$$

which implies that

$$\frac{d^2h^2}{dx^2} = 0$$

Integration of $\frac{d^2h^2}{dx^2} = 0$ yields

$$h^2 = ax + b$$

where a and b are constant.

Setting the boundary conditions
$h = h_0$ at $x = 0$
we can solve for b

$$b = h_0^2 \qquad b = h_0^2$$

Differentiation of $h^2 = ax + b$ allows
us to solve for a.

$$b = h_o^2$$

$$a = 2h \frac{dh}{dx}$$

And from Darcy's law.

So, by substitution

$$h^2 = h_o^2 - \frac{\alpha q x}{k}$$

Setting $h = h_L$ $= h_o^2 - 2q L/k$

Re-arrangement gives -

$$\boxed{q = \frac{k}{2L}(h_o^2 - h_L^2)}$$

Dupuit' eqⁿ.

Then the general eqⁿ for the shape
of the parabola is -

$$\boxed{h^2 = h_o^2 - x/L (h_o^2 - h_L^2)}$$

Dupuit's parabola
eqⁿ.

$$\frac{dx}{\quad} \qquad L$$

The discharge q per unit width of the aquifer is

$$q = -Kh\frac{dh}{dx} = \frac{(h_0^2 - h_1^2)}{2L}K \qquad (9.42)$$

(3) Tile drain problem The provision of drains system is one of the most widely used method of draining waterlogged areas, the object being to reduce the level of the water table. Figure 9.12 shows a set of porous tile drains maintaining a constant recharge rate of R at the top ground surface.
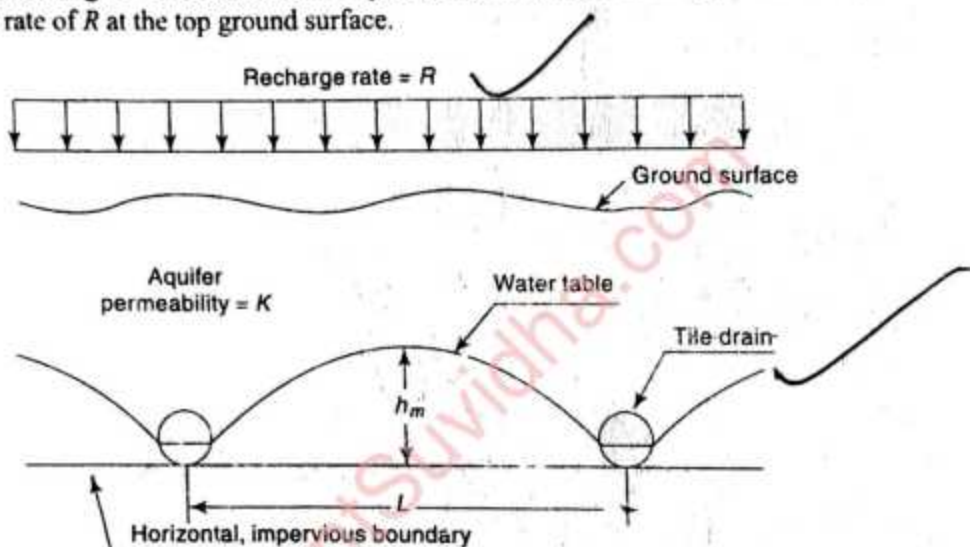

Fig. 9.12 Tile Drains under a Constant Recharge Rate

An approximate expression to the water table profile can be obtained by Eq. (9.37) by neglecting the depth of water in the drains, i.e. $h_0 = h_1 = 0$. The water table profile will then be

$$h^2 = \frac{R}{K}(L-x)x \qquad (9.43)$$

The maximum height of the water table occurs at $a = L/2$ and is of magnitude

$$h_m = \frac{L}{2}\sqrt{R/K} \qquad (9.44)$$

Considering a set of drains, since the flow is steady, the discharge entering a drain per unit length of the drain is

$$q = 2\left(R\frac{L}{2}\right) = RL \qquad (9.45)$$

METHOD OF EXPLOITATION OF GROUND WATER

Any programme of ground water exploitation should have the following equipment for well sinking (boring or drilling) or revitalisation.

(i) Tractor/compressor for blasting or extension drilling.

(ii) Compressors (VT-4, VT-5 etc) for drilling rigs and development of wells

(iii) Bencher units for extension drilling

(iv) Cobra units for drilling blast holes.

(v) Auger rigs and hand boring sets for boring shallow wells, say in the alluvial tract of mirsa or boring cavity wells as in Delhi IARI Pusa area.

(vi) Cable tool or percussion rigs as may be suitable in the areas of Indo-Gangetic alluvium, sediments of Jammu & Kashmir Valley, unconsolidated formation in Bengal.

(vii) Rotary rigs in semi-consolidated formation, and reverse rotary for large diameter and deep holes in soft consolidated formations

(viii) Air rotary is specially suitable for limestones and air foam is used to remove cuttings.

(ix) Rotary cum percussion rigs in the consolidated formation of M.P, Bihar, orissa, Gujrat etc.

(x) Jetting drill is suitable for unconsolidated formations for holes upto 15cm dia. and plenty of water is req. for the water jet.

✳ GROUND WATER INVESTIGATION

The problems facing any ground water investigation programme are the zones of occurrence and recharge. The various phases of a ground water investigation programme are given below :-

a) Hydrometeorological study

b) Hydrogeological study
(i) Geological mapping
(ii) Test drilling, sampling & logging
(iii) Pumping tests (aquifer tests)

(C) Geophysical survey
(i) Surface (ii) Down-the-hole

(d) Aerial photographic survey
(i) Black & white (ii) Colour
(iii) Infra-red (iv) Radar imagery

(e) Tracer techniques

(f) Geochemical & geothermal surveys

(g) Systems analysis, mathematical modelling and computer applications for ground water basin management.

(h) Water balance studies.

(I) Intensive Irrigation & water management.

The obj. of any hydrogeological invest. —
① Define recharge & discharge areas
② Define major water bearing units
③ Define location, extent & inter-relationship of aquifers
④ Estimate total subsurface storage capacity.