SPRINGS

by

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1. Introduction

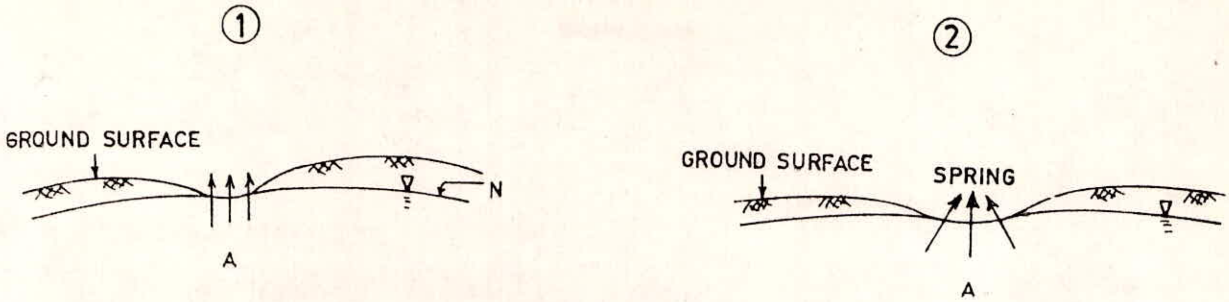
Springs are natural outlets through which the groundwater emerges at the ground surface as concentrated discharge from an aquifer and are most conspicuous forms of natural return of groundwater to the surface. . Springs are part of the groundwater system and may be treated as a flowing well with constant head. Springs could occur in various sizes from small trickle to large stream. Seepage areas are distinguished from springs because of the slower movement of groundwater. from the seepage area unlike the springs. Water in seepage areas may pond and evaporate or flow according to magnitude of the seepage, climate and topography. Likewise excavation, drillings, etc. (wells, boreholes) from which groundwater is drawn, come into the category of artificial discharge centres whereas a spring is the natural groundwater exit.

A few large spring may indicate the existence of thick transmissive aquifers whereas frequent small springs tend to indicate thin aquifers of low transmissivity. So, the springs can aid in the evaluation of groundwater potential of the area. Conditions necessary to produce springs are many and are related to different combination of geologic, hydrologic, hydraulic, pedologic, climatic and even biological controls. Therefore, there are many descriptive terms for springs based on a single or combined controlling factors. But, the most common controlling factors that are used in order to classify springs for different studies are:

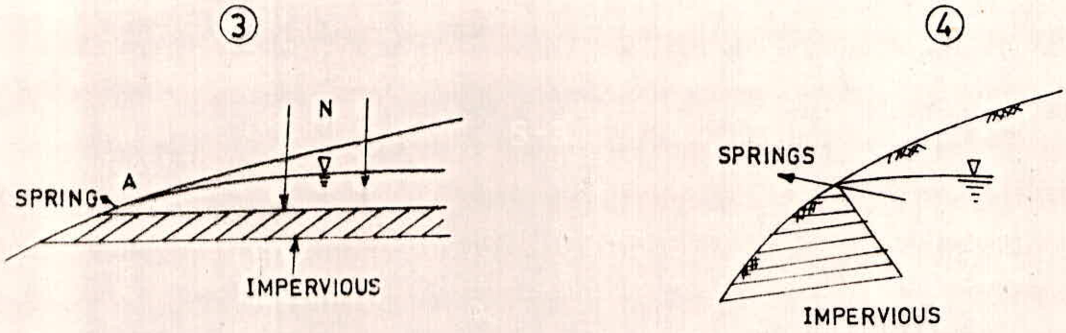
1. Character of opening from which water emerges,
2. Character of water bearing formations,
3. The structure and resulting force that brings the water to surface.
4. Quantity of water discharged,
5. Uniformity and periodicity of the rate of discharge,
6. Chemical quality of water discharged,
7. Temperature of water,
8. Deposits and other feature produced by springs,
9. Source of water shallow or deep seated, and
10. Direction of movement of water.

Discharge rate from a spring depends on the size of the recharge area above it, the rate of precipitation in the area, aquifer geometry, geology and geomorphology of the area, storage coefficient and transmissivity of the aquifer.

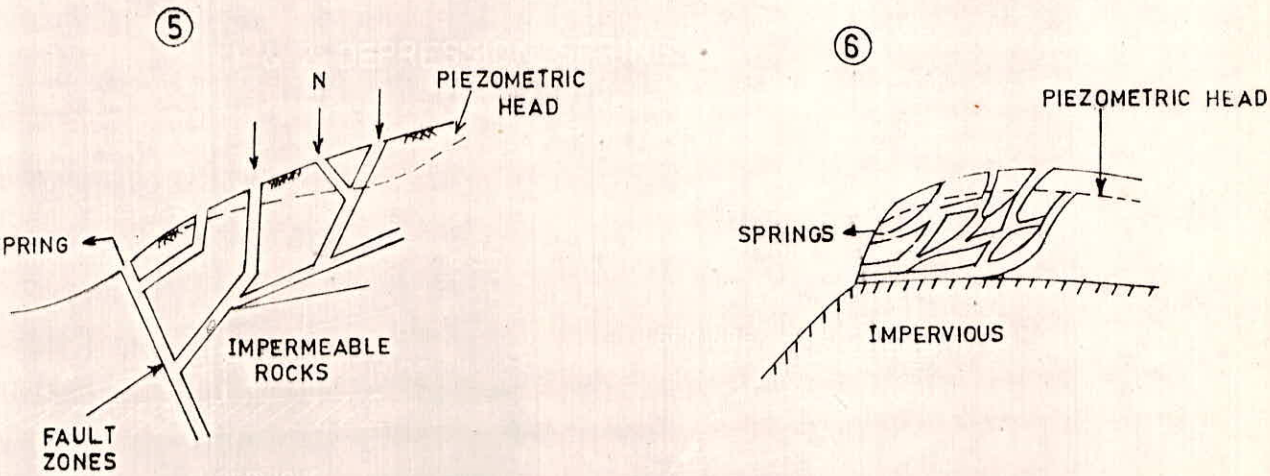
The water from spring are being used from ancient times. Roman empire were supplied with spring water through elaborate aqueducts. In the eastern Mediterranean area spring water was often used to drive small water turbines before being diverted for irrigation and domestic purposes. In the highlands of Persia insignificant seepages were developed into large artificial



1 & 2 DEPRESSION SPRINGS



3 & 4 PERCHED SPRINGS



5 & 6 SPRINGS IN CRACKBED, IMPERVIOUS ROCK

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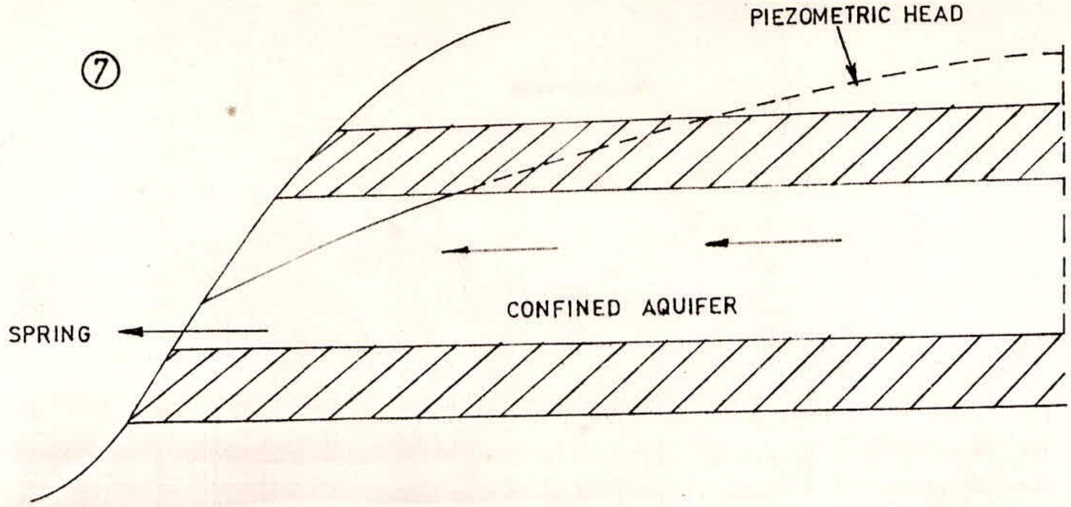

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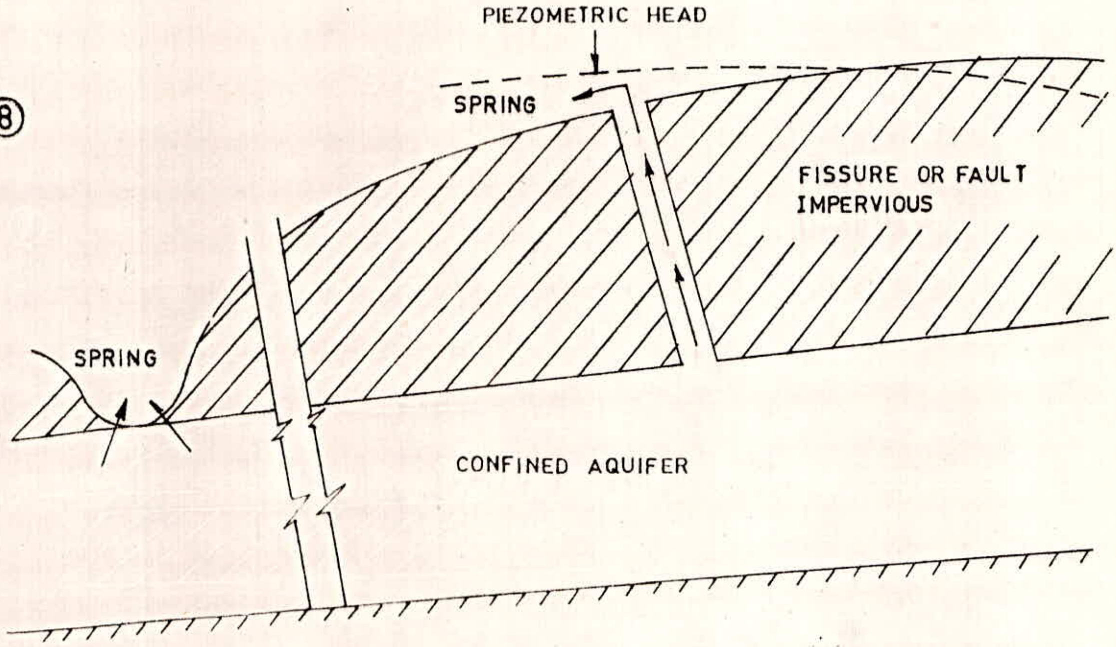

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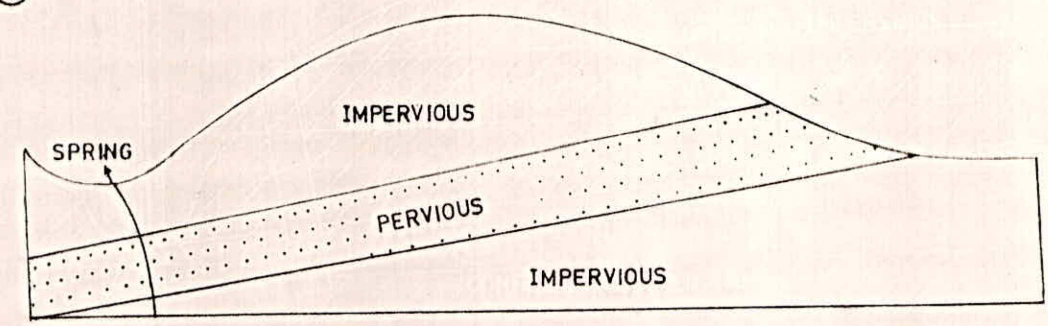

7,8 & 9 SPRING IN ARTESIAN SYSTEM

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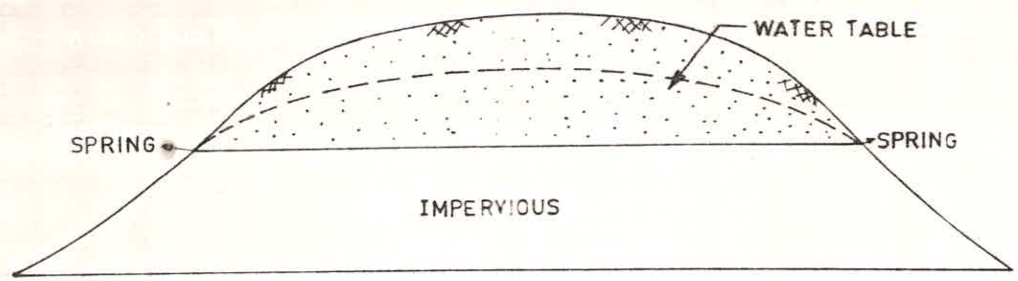

10 CONTACT SPRING

FIG. 1 — TYPES OF SPRINGS

springs by excavating long subterranean galleries, the so called ghanats. Similar methods of diverting springs flow were universally employed until the present century (Mandel and shiftan, 1981). Now a days, it is more convenient or efficient to divert the water directly through wells from the aquifer feeding the spring. Bear (1979) suggested that by an appropriate groundwater management policy, the water levels in the aquifer in the vicinity of a spring can be maintained below spring outlet. The water previously emerging from the spring thus be stored in the aquifer and used according to development programme.

Various hydrological aspects of springs and their flows need to be studied in order to harness them appropriately to meet and supplement different water requirement of the nearby area and for better aquifer management.

EXISTING MODEL

Jacob Bear (1979) suggested a simple model to analyse unsteady flow of a spring. The instantaneous rate of discharges of a spring depends on the difference between the elevation of the water table in the aquifer in the vicinity of the spring, and the elevation of spring's threshold. During dry season, the spring discharge is derived from water stored in the aquifer. So the water levels in the aquifer and spring's discharge will decline. The spring will be inactive when water level reaches spring's threshold. The relationship between rate of decline of discharge thus depends on the storage characteristics of the aquifer(storativity and geometry of aquifer).

Jacob Bear proposed a simple model of a spring draining an unconfined aquifer (Fig.2) with discharge $Q = \alpha h$, where α is a constant.

For the recession period, the spring discharge

$$Q(t)\ dt = \alpha h\ dt = -\ SA\ dh \qquad \ldots(1)$$

Jacob Bear has arrived at the following solution by solving the equation (1) with $t = t_o$, $h = h_o$ and $Q = Q_o = \alpha h_o$

$$t - t_o = (SA/\alpha)\ \ln\ (h_o/h) = (SA/\alpha)\ \ln\ (Q_o/Q)$$

$$Q(t) = Q_o\ \exp\ [-\ \frac{\alpha}{SA}(t - t_o)] \qquad \ldots(2)$$

The solution satisfies the initial condition $Q = Q_o$ at $t = t_o$. The variation of Q(t) with t would plot as a straight line on a semilog paper (on lograithmic scale).

In order to give an interpretation to α, Jacob Bear suggested another simple model as described herein in Fig.3.

An unsteady flow can be considered as succession of steady states. The unconfined flow in Zone-I has been approximated to follow Dupit's condition and flow rate at any time has been expressed as

$$Q = \frac{WK(h_L^2-h_o^2)}{2L} - \frac{WK(h_L+h_o)(h_L-h_o)}{2L}$$

$$= \frac{WT(h_L-h_o)}{L} \qquad \ldots(3)$$

where,

K = Permeability of aquifer

T = Average transmissivity of the aquifer

(h_L-h_o) = Difference of head above the spring's threshold 'p' and

L = Length of the transition zone.

As the spring discharge is linearly proportional to the head available, so by comparison the Eqn.(3) with Eqn.(1), $\alpha = \frac{WT}{L}$ and putting the value of α in Eqn.(2), he obtained $\alpha / SA = \frac{WT}{LAS} = \beta$. Jacob Bear used this coefficient β in Eqn.(2) to express the spring's recession curve by the equation

$$Q = Q_o \exp [-\beta(t-t_o)] \qquad ...(4)$$

DEVELOPMENT OF THE PROPOSED MODEL

A mathematical model is proposed herein which will assess the strength of a spring emerging from an unconfined aquifer.

Configuration:

Configuration of the proposed model has been designed by combining the two simple models of Bear (Figs.2 and 3). Model described in Fig.2 is the zone II of the proposed Model(Fig.4).

Statement of the problem:

h_o is the initial level of groundwater table before the onset of recharge in zone II at which the spring is inactive. A variable recharge occurs in the recharge area of the spring (zone II) from t = 0 to t = t and groundwater table rises to h(t). The time parameter has been discretised into uniform time steps. During a time step the recharge rate is assumed to be constant, but the recharge rate varies from time step to time step.

In the recharge zone (zone-II) which has a surfacial area 'A' the direction of groundwater flow is vertical and as such

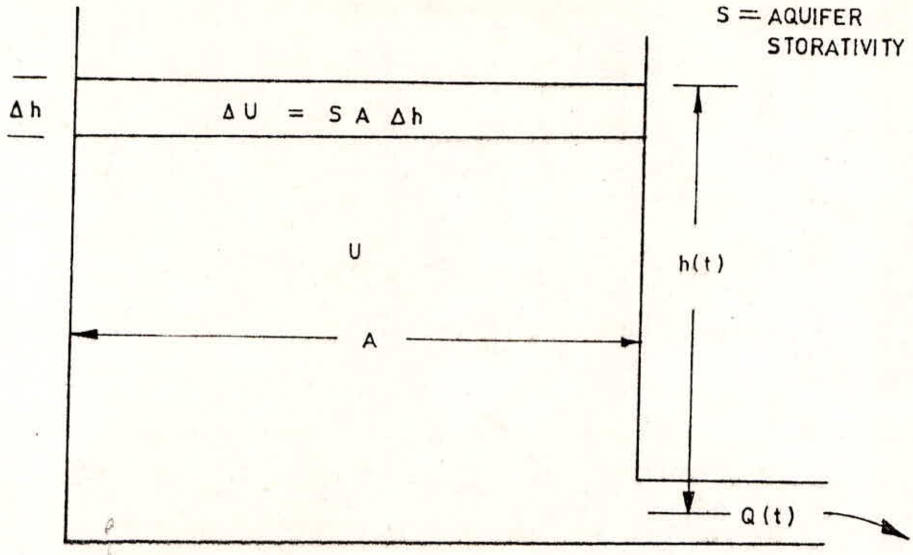

FIG. 2-A SIMPLE MODEL OF SPRING FLOW (BEAR, 1979)

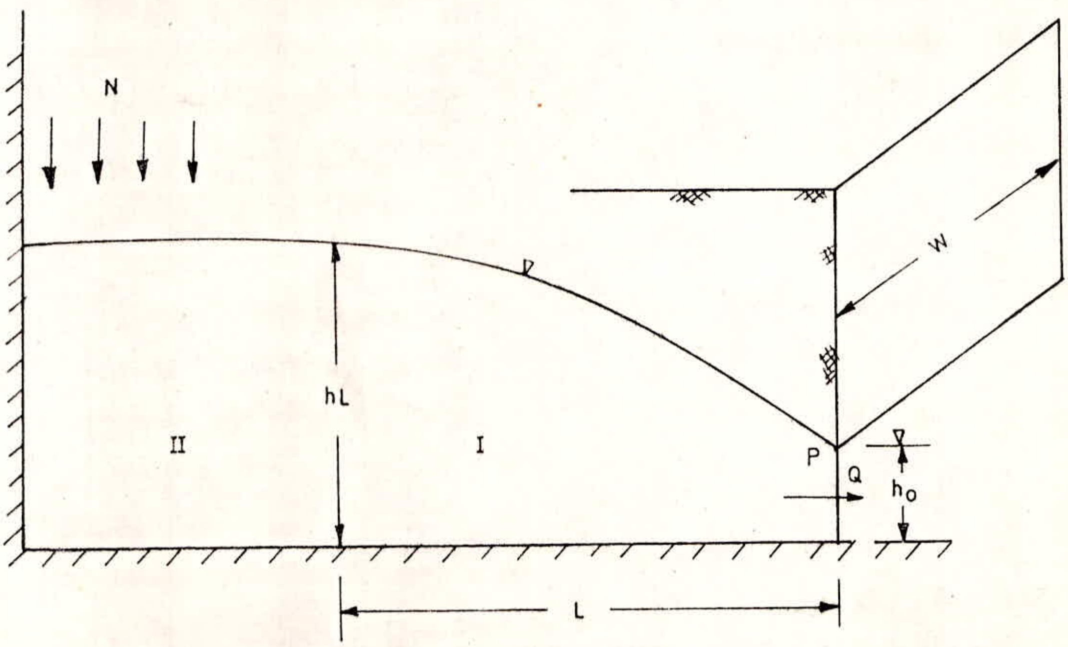

FIG. 3-ANOTHER SIMPLE MODEL OF SPRING FLOW

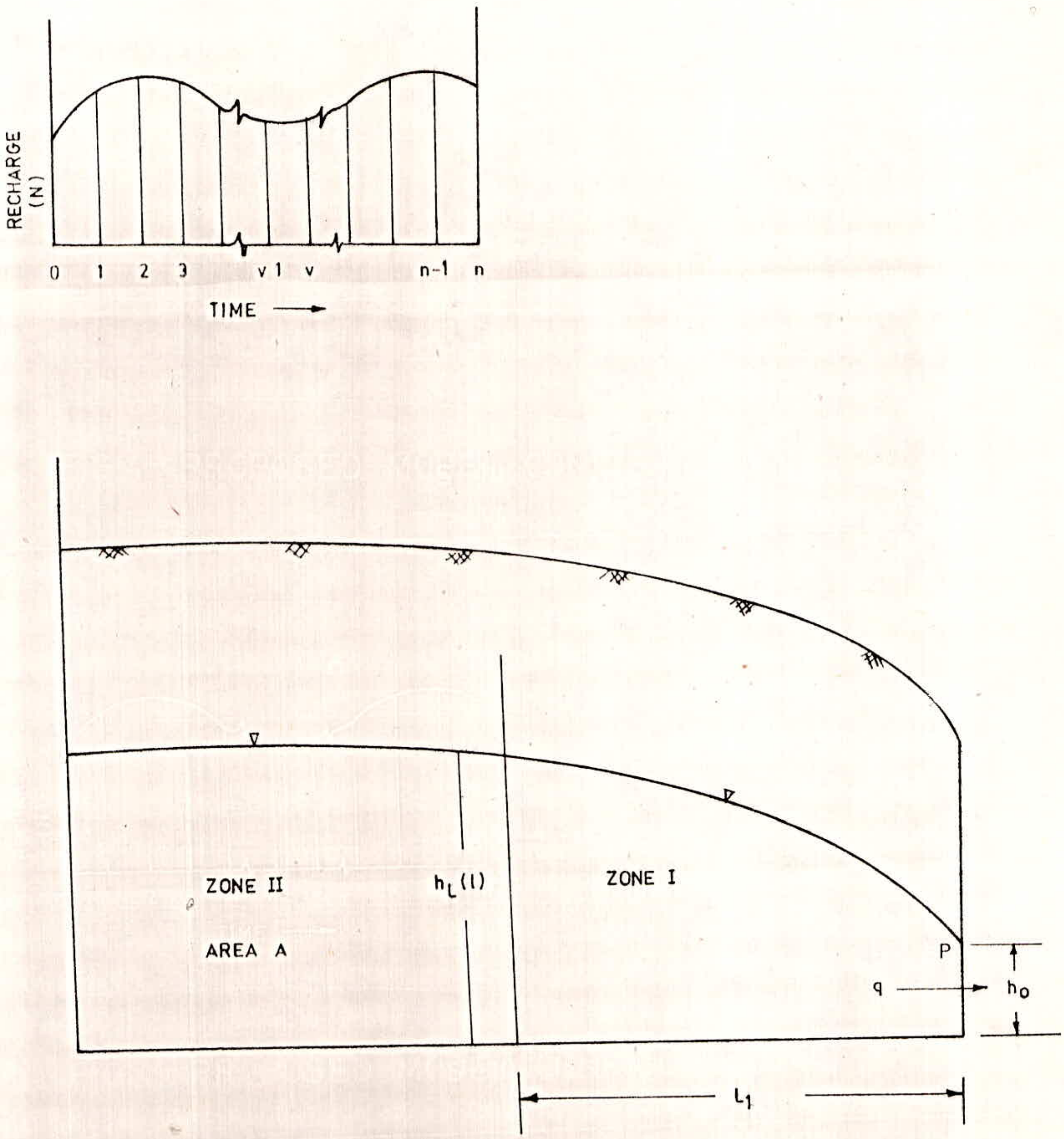

FIG. 4 - PROPOSED MODEL CONFIGURATION

the flow in zone-II is one dimensional. P is the threshold point of the spring outlet, where the boundary head is h_o. The storage in the groundwater due to variable recharge over time t, N(t) which will subsequently be discharged through the spring needed to be assessed. In other words, the dissipation or variation of this recharge at spring outlet as Q(t) is to be determined. T and ϕ are the average transmissivity and storativity of the aquifer.

Assumptions:

i) Assumed flow pattern in the model is two dimensional in the vertical plane.

ii) Flow in zone-I follows Dupit-Forchheimer assumption and the flow is in horizontal direction.

iii) Unsteady state problem has been assumed to be succession of the steady state condition.

iv) Flow leaving zone-I through the spring threshold 'P' is given by the linear equation,

$$Q(t) = \frac{T[h(t)-h_o]}{L_1} \qquad \ldots(5)$$

Methodology:

Let, h(t) be the fall in water level in zone-II during time t due to spring flow. Hence,

$$Q(t)\Delta t = -h(t)\phi A \qquad \ldots(6)$$

Replacing Q(t) by equation 5 and rearranging, Eqn.(6) reduces to

$$\frac{dh(t)}{h(t)-h_o} = - \frac{T.dt}{L_1 A\phi} \qquad ...(7)$$

Integrating,

$$\mathrm{Log}[h(t)-h_o] = - \frac{Tt}{L_1 A\phi} + C \qquad ...(8)$$

Assuming that a recharge of N occurs on zone-II at time t=o, the head at t=0 is given by

$$h(0) = h_o + \frac{N}{\phi}$$

The constant appearing in Eqn.(8) is given by

$$C = \log \frac{N}{\phi}$$

Substituting the value of C in Eqn.(8) and simplifying, the following expression for head in zone-II is obtained after putting $\alpha = T/L_1$.

$$h(t) = h_o + \frac{N}{\phi} e^{-\frac{\alpha t}{A\phi}} \qquad ...(9)$$

The spring flow Q(t), is evaluated by substituting the expression of h(t) in Eqn.(5) and spring flow is given by

$$Q(t) = \frac{T}{L_1}[\frac{N}{\phi} e^{-\frac{\alpha t}{A\phi}}] \qquad ...(10)$$

Development of the model for time variant recharge:

In practice, the recharge to aquifer would occur over a span of time depending upon precipitation values. A typical time variant discontinuous recharge pattern is shown in Fig.(4).

$N(\gamma)$ is the average recharge rate during the time step γ. All the recharge rates are assumed to be independent and constant in the time interval $(0,1),(1,2).....(\gamma-1,\gamma).....,(n-1,n)$. For $N = 1$, Eqn.(10) gives the response of the system to a unit impulse recharge. Let the response of the system to a unit impulse excitation be designated by $K(t)$.

$K(t)$ is given by

$$K(t) = \frac{\alpha}{\phi} e^{-\frac{\alpha t}{A\phi}} \qquad ...(11)$$

For variable recharge, the spring outflow is given by

$$q(n) = \int_0^1 K(n-\tau)N(1)d\tau + \int_1^2 K(n-\tau)N(2)d\tau$$

$$+ .. + \int_{\gamma-1}^{\gamma} K(n-\tau)N(\gamma)d\tau$$

$$+ .. + \int_{n-1}^{n} K(n-\tau)N(n)d\tau$$

$$= \sum_{\gamma=1}^{n} N(\gamma) \int_{\gamma-1}^{\gamma} K(n-\tau)d\tau \qquad ...(12)$$

The integral in Eqn.(12) can be put in a more standard format by using the discrete kernel, $\partial(n)$. A change of variable of integration in Eqn.(12) is the discrete kernel (Morel Seytoux and Daly, 1975) with argument $(n-\gamma+1)$ and Eqn.(12) takes the form

$$q(n) = \sum_{n=1}^{\gamma} \partial(n-\gamma+1)N(\tau) \qquad ...(13)$$

If unit recharge takes place in first unit time period and no recharge occurs thereafter, the spring outflow corresponding to this unit pulse excitation can be obtained by starting from the response of the spring to a unit impulse excitation given by Eqn.(10) and is given by $\partial(n)$

$$\partial(n) = Ae^{-\frac{\alpha n}{A\phi}}[e^{-\frac{\alpha}{A\phi}} - 1) \qquad \ldots(14)$$

The response to a unit pulse excitation at time step 'n' designated as $\partial(n)$ and is given by

$$\partial(n) = \int_0^1 \frac{\alpha}{\phi} e^{-\frac{(n-\tau)}{A\phi}} d\tau \qquad \ldots(15)$$

$\partial(.)$ is the response due to the unit pulse excitation of linear system which was initially at rest before the onset of recharge. So, once the $\partial(.)$ are generated by the model and saved, these could be used for any set of varying recharge over time as $\partial(.)$ are the properties of the aquifer and are independent of the excitation.

UTILITY AND TESTING OF THE MODEL

In the field, we can measure spring flow discharge with time and the rainfall distribution in the area is usually available. But, the transmissivity, storativity of the aquifer and the percentage of rainfall recharge to the ground water are not known.

This model could be used to solve the inverse problem of finding out the fraction of rainfall going to aquifer as recharge and aquifer parameters by making use of the rainfall and spring flow values. Once the aquifer parameters are calibrated and rainfall in the area is known, it is possible to predict the future spring flow.

The developed model has been tested with an assumed time variant (daily) rainfall distributed over 90 days (monsoon period) on the recharge area. The transmissivity of the aquifer has been assigned low value since it is intended to model spring of small strength. Because the infiltrated water from rainfall will first satisfy the soil moisture deficiency in the unsaturated zone before replenishing ground water, the ground water recharge from rainfall is taken as 10% of the rainfall for the first 10 days of rainfall and it is 20% for rest of the rainy season. A lag of two days has been assumed from the day of rainfall to the day of ground water recharge. Aquifer flow domain is taken to be homogeneous. The model is used to simulate the spring flow for 365 days after the first day rainfall (i.e. after the onset of rainfall). The two non-dimensional parameters representing discharge from the spring and the time are plotted in the lograithmic scales. This plot of spring flow for variable recharge is shown in Fig.5 along with the assumed daily rainfall pattern.

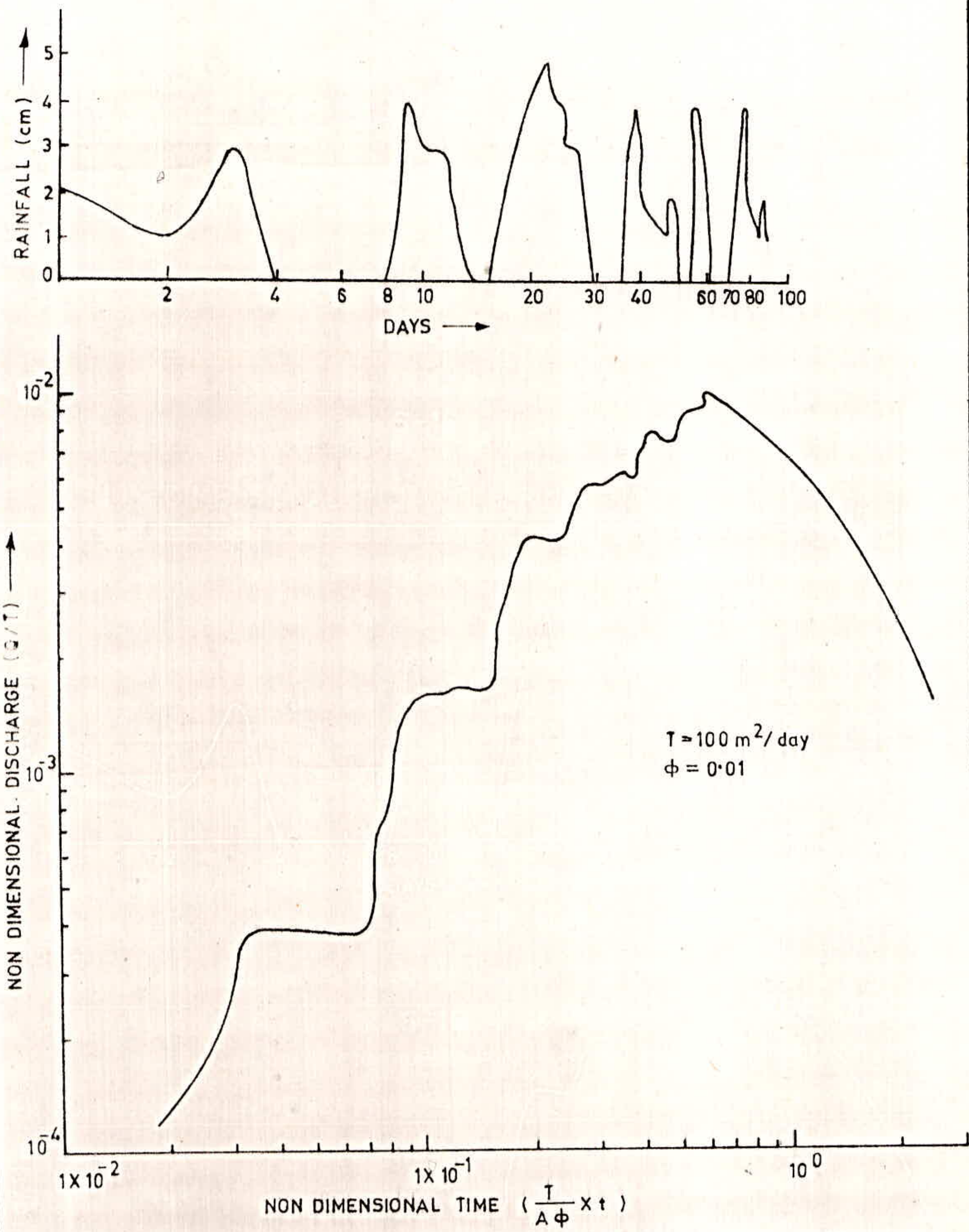

FIG. 5 - NON-DIMENSIONAL PLOT OF SPRING FLOW UNDER VARIABLE RECHARGE

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3. Morel-Seytoux, H.J., and C.J. Daly, (1975), 'A Discrete Kernel Generator for Stream Aquifer Studies', Water Resources Research Vol.II, N.2.