INTERACTION OF LARGE DEPRESSION STORAGE WITH AQUIFER IN GHAGGAR BASIN

A.K.BHAR*

G.C.MISHRA*

Abstract

An interaction problem of depression storage with an aquifer has been studied by mathematical modelling. A linear mathematical model has been developed using discrete kernel generator. Impoundment in Surathgarh depressions of Lower Ghaggar basin has been studied with this model. The recharge quantity and the water level in the aquifer have been estimated for the condition when the depressions are filled with water and subsequently the water level in the depressions declines because of recharge

Introduction

Large depression storage plays an important and intricate role in the hydrologic cycle. It influences the ground water regime and moderates the agro-climatic set-up of an area. The depression storage may also act as a principal source of recharge to ground water.

The benefits that might accrue from a depression storage are: creation of irrigation facilities, flood cushion, pisiculture,bird sanctuary, and recreational facilities. The depression storage may be the only source of water during the non-monsoon period. But, seepage losses from the depression storage may make the area waterlogged and saline unless precautionary measures are taken. The conflicting issues of land and water resources development essentially envisage the need of a proper operational policy of the depression storage. The water logging problems can be reduced by taking measures for reduction in seepage and through conjunctive use practice. The interaction of depression storage and aquifer is either neglected or calculated as a residual of the other components of a water balance study. This may lead to serious misunderstanding about the role of depression storage in a hydrologic system. From the literature survey, the mathematical modelling has been found to be a potential tool to study the multifacet and complex interaction between ground and surface water. In the present study a mathematical model of depression storage and aquifer interaction has been developed.

Scientist,National Institute of Hydrology,Roorkee

Development of the Mathematical Model

The basic differential equation which describes the saturated unsteady flow in an unconfined aquifer is the Boussinesq's equation. If the water table position does not fluctuate much in the unconfined aquifer compared to its thickness, the Boussinesq's equation after linearlization can be written as

$$\phi \frac{\partial s}{\partial t} - \frac{\partial}{\partial x}\left(T \frac{\partial s}{\partial x}\right) - \frac{\partial}{\partial y}\left(T \frac{\partial s}{\partial y}\right) = Q_w \delta_w \qquad \ldots(1)$$

in which,

ϕ =aquifer storage coefficient,

s =drawdown,

t =time,

x,y=horizontal cartesian coordinates,

T =aquifer transmissibility,

Q_w =instantaneous abstraction or recharge through well w (+ve for abstraction, and -ve for recharge), and

δ_w =Dirac delta function singular at well point and at time τ

This equation being linear, the theory of linear system can be applied in order to solve the complex depression storage and aquifer interaction.

In the development of the mathematical model for depression storage and aquifer interaction, the discrete kernel approach which is applicable for a linear system can conveniently be used. The discrete kernel coefficients are the response of a linear system originally at rest in response to a unit pulse excitation. Complex stream aquifer and well interaction problem has been analyzed by Morel Seytoux et al.(1975) using discrete kernel generator. A square grid system can be superimposed on the area of study containing the large depressions and abstraction wells. The depressions can be discretised into numbers of circular bowl shaped depressions with their centres situated at the nodal points of the grid. The plan area of a circular depression at a grid is equal to the plan area of the portion of the water body lying within the area of influence of the grid. The circular bowl shaped depressions can be visualized as a battery of wells recharging to ground water when the water table is below the depression water level. The recharge rate during n^{th} time period from L^{th} depression can be written as:

$$Q_L(n) = \Gamma_L(n) \left[\sigma_L(n) - \{ S_L(n) + \bar{H} \} \right] \qquad \ldots(2)$$

in which,

$\Gamma_L(n)$=lake transmissivity of L^{th} depression during n^{th} time period,

$\sigma_L(n)$=water level in the L^{th} depression during n^{th} time period measured from a high datum,

$S_L(n)$=drawdown of the ground water table at the centre of the L^{th} depression had the L^{th} depression not been present, due to recharge taking place from all depressions including from L^{th} depression, and due to abstraction by the pumping well, measured from the initially rest water table level, and

$\bar{H}$ = the ground water table position before the depressions were filled measured from the high datum.

If all the depressions are interconnected, the drawdown in all the depressions at a particular time period will be the same. In such a case,

$$\sigma_1(n) = \sigma_2(n) = \ldots \sigma_L(n) = \ldots = \sigma_N(n) = \sigma(n)$$

where, N is the total numbers of depressions.

The drawdown in ground water table, $S_L(n)$, is due to recharge from all the depressions including the L^{th} depression which have occurred from time step 1 to n, and abstraction by the pumping well ,if any.

Hence,

$$S_L(n) = \sum_{i=1}^{N} \sum_{\gamma=1}^{n} Q_i(\gamma) . \delta_{iL}(n-\gamma+1) + \sum_{p=1}^{P} \sum_{\gamma=1}^{n} Q'_p(\gamma) \delta'_{pL}(n-\gamma+1) \qquad (3)$$

where,

P =total number of abstraction wells,

$Q'_p(\gamma)$=pumping rate from the p^{th} well during γ^{th} time period,

$Q_i(\gamma)$=recharge from the i^{th} depression during γ^{th} time period,

$\delta_{iL}(.)$=discrete kernel for drawdown at L^{th} depression due to recharge from i^{th} depression,

$\delta'_{pL}(.)$=discrete kernel for drawdown at L^{th} depression due to pumping at p^{th} well

Let $\sigma(n-1)$ be the drawdown of the water level in the depression at end of $(n-1)^{th}$ time period, $r_L(n)$ be the radius of the L^{th} depression at the water level position during time step 'n'; $\Delta\sigma(n)$ be the change of drawdown in the depression water level during n^{th} unit of time step, $V_L(n-1)$ be the depression storage volume of L^{th} depression during $(n-1)^{th}$ unit time period, and $V_L(n)$ be the depression storage volume of L^{th} depression during n^{th} unit period.

It can be proved that the change in storage volume in the L^{th} depression during the n^{th} unit time period is

$$[V_L(n-1) - V_L(n)] = \pi r_1^2(n-1)\ \Delta\sigma(n) \qquad \ldots(4)$$

The total change in depression storage during n^{th} time period is the algebraic sum of the individual recharge from the depressions during n^{th} unit time period.

Hence,

$$Q_1(n) + Q_2(n) + \ldots\ \ldots + Q_L(n) + \ldots\ \ldots + Q_N(n)$$

$$= \Delta\sigma(n)\pi\ [r_1^2(n-1)+r_2^2(n-1)+\ \ldots + r_L^2(n-1)\ \ldots + r_N^2(n-1)] \qquad \ldots(5)$$

or,

$$\Delta\sigma(n) = \sum_{i=1}^{N} Q_i(n) / \{\pi \sum_{i=1}^{N} r_i^2(n-1)\} \qquad \ldots(6)$$

Hence, $\sigma(n)$ can be expressed as

$$\sigma(n) = \sigma(n-1) - \sum_{i=1}^{N} Q_i(n) / \{\pi \sum_{i=1}^{N} r_i^2(n-1)\} \qquad \ldots(7)$$

Assuming $\Gamma_L(n) = \Gamma_L(n-1)$ and substituting for $\sigma_L(n)$ and $S_L(n)$ in equation (2) and rearranging,

$$Q_L(n)\left[\frac{1}{\Gamma_L(n-1)} + \frac{1}{\pi\sum_{i=1}^{N} r_i^2(n-1)} + \delta_{LL}(1)\right] + \sum_{\substack{i=1 \\ i\neq L}}^{N} Q_i(n)\delta_{iL}(1) + \sum_{i=1, i\neq L}^{N} Q_i(n) / \{\pi \sum_{i=1}^{N} r_i^2(n-1)\}$$

$$= \sigma(n-1) - \sum_{\gamma=1}^{n-1}\sum_{i=1}^{N} Q_i(\gamma)\ \delta_{iL}(n-\gamma+1) - \bar{H} - \sum_{p=1}^{P}\sum_{\gamma=1}^{n} Q'_r(\gamma)\delta'_{PL}(n-\gamma+1) \qquad \ldots(8)$$

'N' numbers of such equation can be written for all the 'N' depressions. The 'N' unknowns can be solved by matrix inversion for each time step starting from time step 1 in succession.

When the aquifer is not homogeneous, discrete kernel coefficients i.e., $\delta_{iL}(.)$ and $\delta'_{pL}(.)$ are to be obtained by using numerical technique.

Description of Pumping Kernel $\delta'_{pL}(m)$

The discrete kernel coefficient $\delta'_{pL}(m)$ is the drawdown at the end of m^{th} unit time period at a distance r from the pumping well in response to withdrawal of an unit quantity of water from the aquifer storage during the first time period. A unit time period may be 0.1 day, 1 day or a week.

Mathematically $\delta'_{pL}(m)$ is given by [Morel-Seytoux et al.(1975)]

$$\delta'_{pL}(m) = \frac{1}{4\pi T} \; -E_1(\frac{r^2}{4\beta m}) - E_1(\frac{r^2}{4\beta(m-1)})] \qquad ...(9)$$

where $\beta = T/\phi$.

Description of Discrete Kernel for Drawdown due to Recharge from Depression $\delta_{iL}(m)$

When the point of observation and point of excitation are different the expression for $\delta_{iL}(m)$ is same as that of $\delta'_{pL}(m)$. When the point of excitation and point of observation are the same, $\delta_{iL}(m)$ is given by [Rao (1981)]

$$\delta(L,L,m) = \frac{1}{\pi r^2 \phi} + \frac{1}{\pi r^2 \phi} \, [(m-1)e^{-r^2/\{4\beta(m-1)\}} - me^{-r^2/(4\beta m)}]$$
$$+ \frac{1}{4\pi T} \, [E_1(r^2/(4\beta m) - E_1\{r^2/(4\beta(m-1))\}] \qquad ...(10)$$

Determination of Depression Transmissivity

Let the circular bowl shaped depression have depth d and radius r. R be the radius of sphere of which the depression is a part (Fig.1). e_1 be the saturated thickness at the aquifer below the depression. The radius r of the depression is given by $r = \sqrt{A/\pi}$ where A is the plan area of the depression water surface andradial distance R_o is generally equal to 8r. Making use of these, the expression for depression transmissivity (Γ_L) given by Rao (1981),

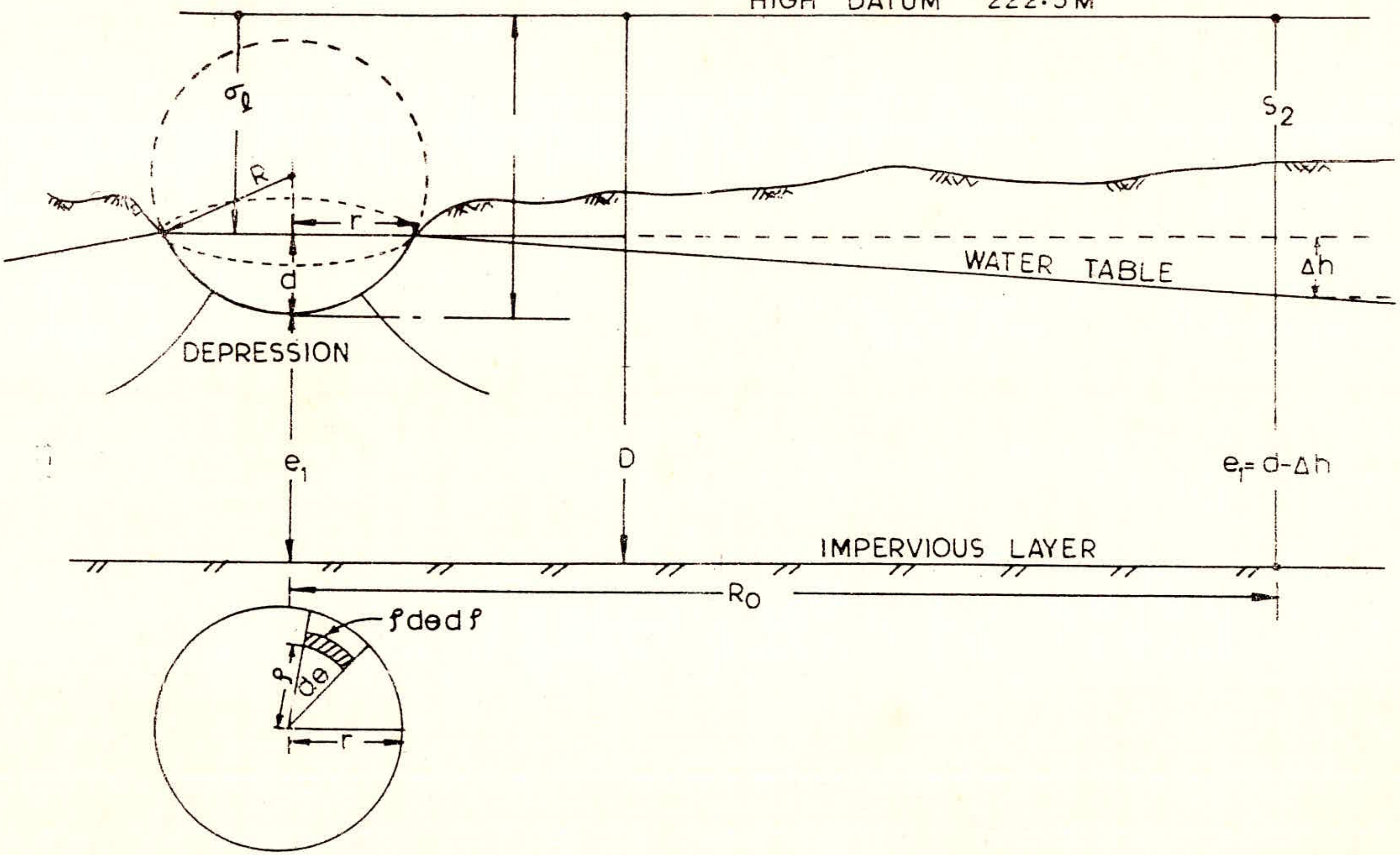

FIG.1 FLOW DOMAIN NEAR A DEPRESSION

$$\Gamma_L = \frac{T\pi}{e_1(e_1+15\sqrt{A/\pi})}\ [\{\sqrt{(A/\pi)} + d\}^2 + \sqrt{(A/\pi)}(14d + 16\ e_1)] \quad ...(11)$$

Results and Discussion

Sriganganagar district of Rajasthan once an unproductive desert, was brought under irrigation by introduction of Gang Canal in 1928. The area received an additional irrigation facility through Bhakra and Rajasthan canal system making Sriganganagar district a very well irrigated area. Today Sriganganagar district is a granary of Rajasthan. The fertile flat low lying area of the lower Ghaggar river basin comprising of a major part of Sriganganagar district used to get flooded every year with the Ghaggar flood water causing extensive damage to the Kharif crops.

To save the area from flooding arrangements were made for diverting Ghaggar flood water through a 48 Km long and 340 m^3/sec discharge capacity diversion channel to the sand dune depressions near Surathgarh (Fig.2). The sand dune depressions were converted to water storage bodies by plugging the low lying area by means of saddle dams. Nineteen isolated sand dune depressions were interconnected by channels These interconnected depressions created a large depression storage of the capacity 900 mcm for the maximum pond level of 184.15 m above msl. The depression started receiving flood water since 1968.In the early period of filling of depressions the seepage rate was observed to be very high which was reduced in the succeeding years. In due course of time permanent impounding of flood water became a regular source of recharge due to which the water table in the vicinity of the depression rose rapidly causing water logging problem.

The mathematical model has been developed to study the depression storage-aquifer interaction when there is no control on the water level of the depression after the initial impoundment. Such situation occurs when the depressions are filled up during monsoon or flood season and are allowed to deplete of their own due to recharge to ground water.

The drawdown in the depression water level at various time after the first filling are estimated by this model and are shown in Figure 3. As seen from this Figure, some of the depressions are

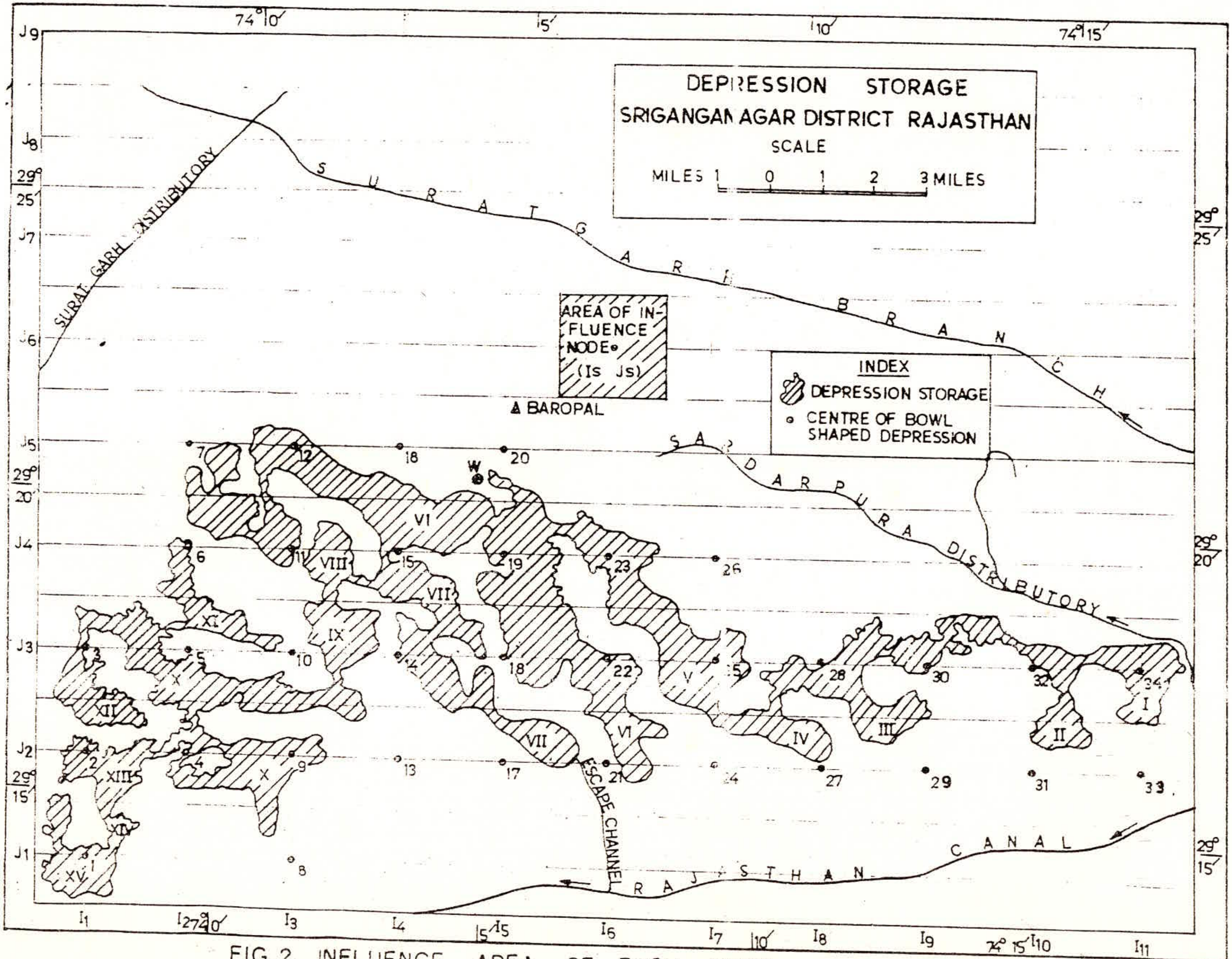

FIG. 2. INFLUENCE AREA OF EACH NODE.

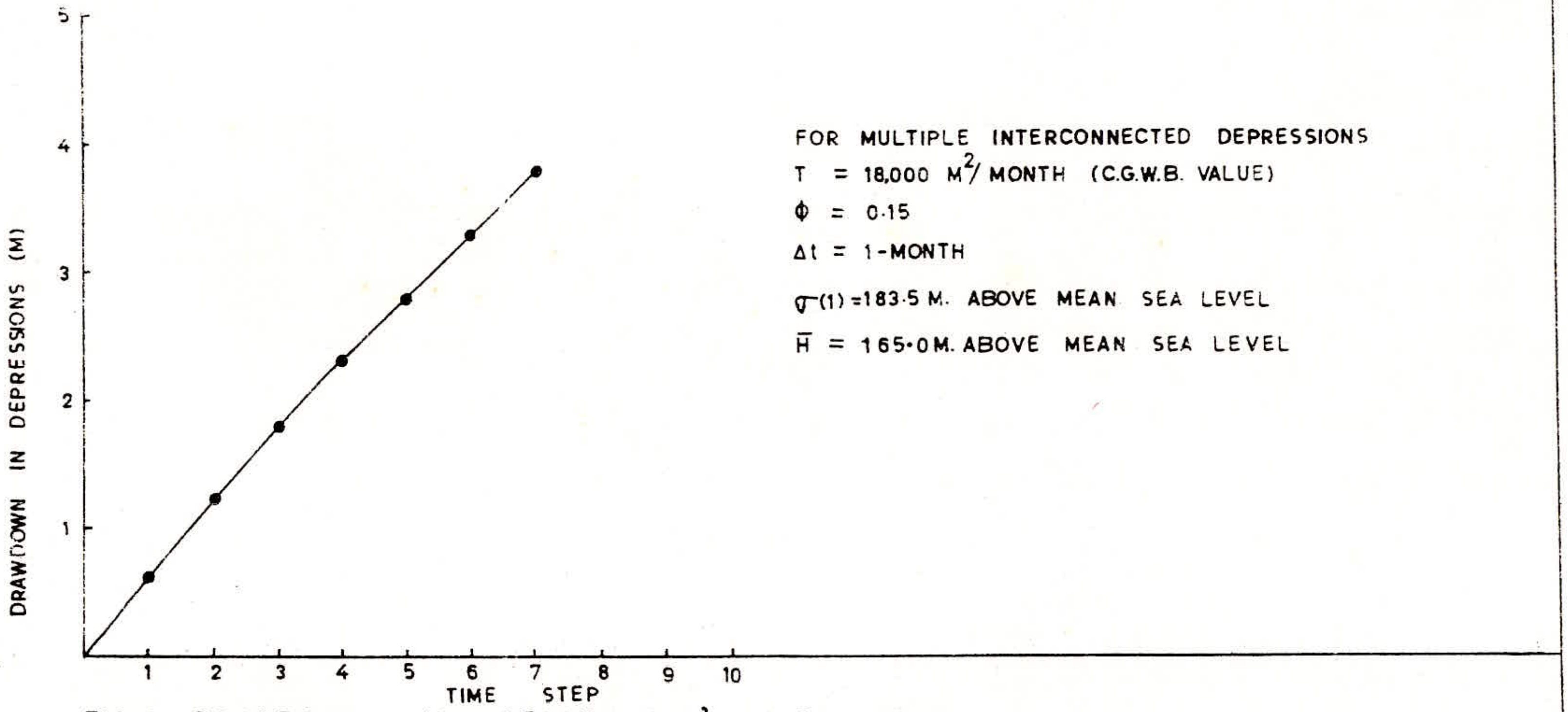

FIG. 3. DRAWDOWN IN DEPRESSIONS' WATER LEVEL.

emptied after 7 months. The corresponding monthly recharges from the depressions are shown in Figure 4. At the end of 7th month since filling up, recharge is not zero as still water is available in some of the depressions. The recharge rate is maximum in the beginning but it reduces by 64% during the 7th month. The total amount for recharge from Surathgarh depressions after they are filled up is 3×10^8 cubic metre after 7 months.

References :

Morel-Seytoux, H.J., and C.J. Daly. 1975. A discrete kernel generator for stream aquifer studies. Water Resources Research, 11, no.2, 253-260.

Rao, N.B., 1981. Interaction of large depression storage and an aquifer. M.E. (Hydrology) dissertation, University of Roorkee, Roorkee.

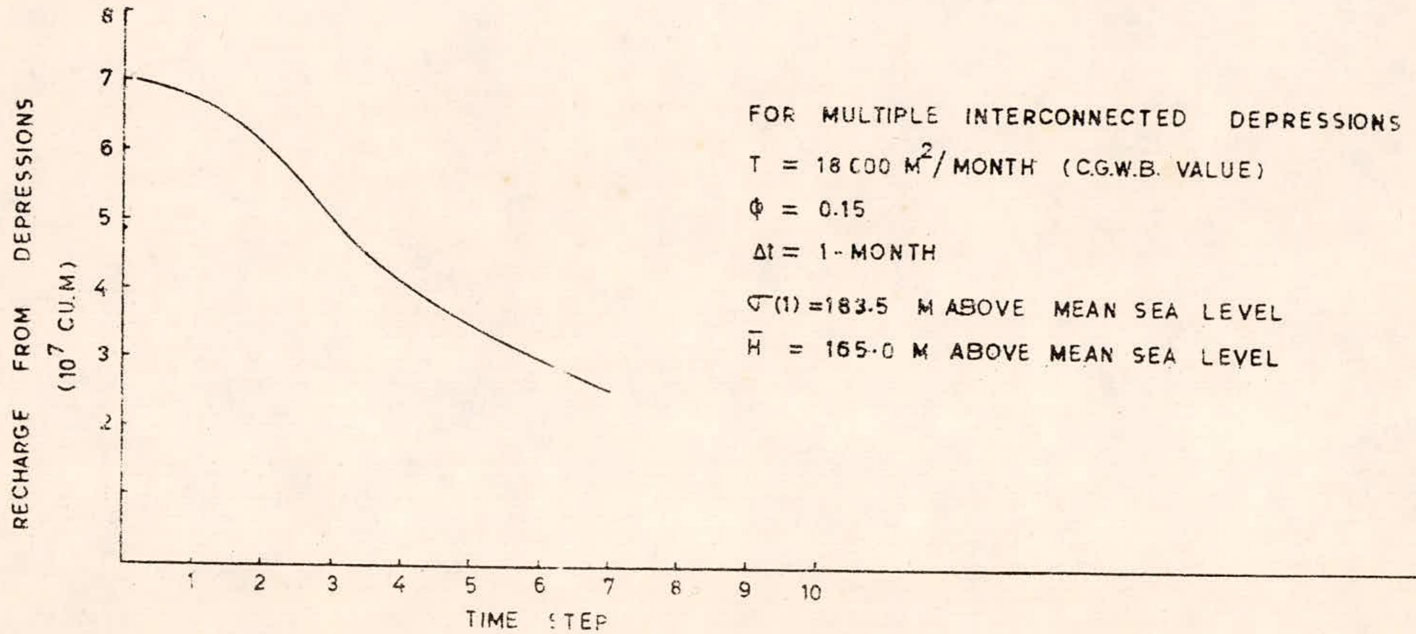

FIG. 4 . VARIATION OF RECHARGE FROM DEPRESSIONS.