TN-5

WATER BALANCE AND INTERACTION OF LARGE DEPRESSION STORAGE WITH AQUIFER IN GHAGGAR BASIN

SATISH CHANDRA
DIRECTOR

STUDY GROUP

G C MISHRA

A K BHAR

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAVAN
ROORKEE-247667(UP)
INDIA

1983-84

CONTENTS

LIST OF SYMBOLS

A	=	Plan area of depression water surface
H	=	Head difference
$\bar{H}$	=	Depth of initial average water table from high datum
i, L	=	Depression number
m, n, γ	=	Time period
N	=	Numbers of depression
P	=	Numbers of abstraction well
Q	=	Seepage flux per unit length
Q'	=	Pumping rate from well
Q_L	=	Recharge rate from depression
Q_w	=	Instantaneous abstraction or recharge through well
p	=	Well number
R_o	=	Radial distance
r	=	Radius of depression at the water level position
S	=	Aquifer storativity
s	=	Drawdown in water table
S_L	=	Depth to water table from initial average water table
T	=	Aquifer transmissivity
t	=	Time since recharge began
V	=	Depression storage volume
x, y	=	Cartesian coordinate
Γ_L	=	Depression transmissivity
σ_L	=	Depth to water surface in depression from high datum
ϕ	=	Aquifer storage coefficient
β	=	T/ϕ
δ_{iL}	=	Discrete kernel for drawdown due to recharge from depression

δ_w = Dirac delta function

δ'_{pI} = Discrete kernel for drawdown due to pumping

LIST OF FIGURES

ABSTRACT

Interaction of depression storage and aquifer till recently was either neglected or taken as a residual of a water balance study. Understanding of the interaction of surface water body with the aquifer is necessary in order to have a meaningful regional water balance study. Mathematical modelling has been found to be a potential tool to study this interaction.

In the eastern fringe of lower Ghaggar basin, there exist nineteen interconnected sand dune depressions in Suratgarh area of Sriganganagar district of Rajasthan which are used as flood cushion from 1968. The depressions have plan area to the tune of 100 sq. km. with storage capacity of 900 million cu. meters at full storage level. Due to the impoundment of water in the depressions, waterlogging in the isolated patches in the surrounding area has been first noticed since 1975.

In the present study, the recharge taking place from the depression storage to the aquifer has been assessed. A linear mathematical model has been developed using discrete Kernel generator and method of superposition to study the interaction between Suratgarh depression storage and aquifer. The discrete kernels for recharge have been generated by making use of solution of Boussinesq's equation for unit step rise in the depression water level. The recharge quantity from the depression has been estimated for the drawdown in the depressions because of recharge. It is found that emptying of some of the Suratgarh depressions takes 7½ months after being filled-up

1.0 INTRODUCTION

Large depression storage plays an important and intricate role in the hydrologic cycle. It influences the groundwater regime and moderates the agro-climate set-up of an area. The depression storage may also act as a principal source of recharge to ground water which may be the only source of water during the non-monsoon period.

The benefits that might accrue from a depression storage are: creation of irrigation facilities, flood cushion, pisiculture, and recreational facility. But, seepage losses from the depression storage may make the area waterlogged and saline unless due precautionary measures are taken. So, 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 conjunctive use practice i.e., by installation and pumping the wells during the lean period and using the pumped water for irrigation purpose. Until recently, 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, aquifer, and well interaction has been developed.

2.0 REVIEW

The hydrologic system is a synthesis of various components. Interaction of ground water with surface water is one of the important components of hydrologic system and its comprehensive understanding is sine qua non for developing water and land resources of a region. Further research works have been emphasized and recommended in this regard by the hydrologic community. Few of the points of particular relevance which warrant special research efforts are coined in the deliberation of international symposium on ground water balances in Bulgaria (1982) are worth-mentioning. They are:

a) emphasizing the study of physical aspects of the processes of surface and ground water interactions,

b) encouraging the development of combined mathematical models of surface and ground waters for use in solving the scientific and practical questions, including the aspects of ground water regime effects on large and small areas,

c) underscoring the need to study the human influence on ground water regime, and

d) encouraging the development of remote sensing methods for monitoring of time-dependent changes in ground water regime over large areas.

The role of large depression storage in the ground water regime is quite significant in surface and ground water interaction study. Incidentally, with a few exception, the relationship with ground water depression storage or lake has been a minor part of hydrologic study. The ground water component of lake has been ignored or considered unimportant with relation to other components of hydrologic system in the recent past. Recharge to ground water component is usually considered as the residual in a water balance study. This can lead to serious misunderstanding about interaction of lakes. Studies undertaken in recent past are described briefly here for supplementing the above mentioned statement.

The relation of ground water to prairie potholes in North Dakota was studied by Eisenlohr and others (1972 vide Winter, 1976). In the earlier stage of study, the ground water component was calculated as a residual. But in the later stage, wells were placed to determine the relationship of ground water levels to potholes water levels (Sloan, 1972 vide Winter, 1976).

The ground water relation to small lakes in Minnesota was studied in a similar fashion by Mason and others (1968 vide Winter, 1976) and Allred and others (1971 vide Winter, 1976). It was concluded that most of the lakes had a net loss to ground water.

McBride (1969 vide Winter, 1976) studied ground water component of the lake water balance. Closely spaced wells were made at different depths to define the vertical component of ground water flow. He used a digital modelling technique to define the vertical distribution of hydraulic head in ground water system near a lake.

Meyboom (1966, 1967 vide Winter, 1976) studied ground water flow system in the vicinities of lakes and potholes in a prairie provinces of Canada. He is the first scientist to examine the problem of determining ground water flow systems, and the strength and position of ground water divides beneath lakes.

Everdingen (1972 vide Winter, 1976) as part of an intensive study of the Lake Diefenbaker, Saskatchewan, studied potentiometric level of different aquifers through a closely spaced group of observation wells constructed at different depths near the lake. The study indicated reversals of flow within some of the aquifer zones as a result of the creation of Lake Diefenbaker.

The review of the above literature reveals that much work is needed to identify and evaluate the factors that control the ground water flow from or to lakes. While undertaking steady state digital model simulation of ground water flow near one lake and multiple lakes, Winter (1976) highlighted that the height of the water table on the downslope side of the lake relative to lake level, spatial distribution of hydraulic conductivity of ground water system, and regional and lake slopes are the major factors that influence the interaction of lakes and ground water. Besides, the factors like height of the water table on the upslope side of a lake relative to bed level, ground water, reservoir thickness, and presence of lake sediments are of lesser significance to lake ground water interaction. It seems that only the model study has the unique potential to show the detailed patterns of ground water flow beside and beneath the lakes in a wide variety of hydrogeologic settings which provide the opportunity to make an expedient attempt to study the interaction between depression storage and ground water.

Central Ground Water Board (CGWB) under the aegis of UNDP Project has conducted a ground water survey of Ghaggar basin from 1975-78 (1980). The Ghaggar basin is bounded by the Siwalik hills in the north east and the international boundary on the south west. In the south west part of the lower Ghaggar basin before Ghaggar basin meets the international boundary, there exist nineteeninterconnected sand dune depressions in the Surathgarh area of Sriganganagar district of Rajasthan. It has been reported that these depressions are being used to store upstream flood water and monsoon water since 1967 by creating a reservoir by plugging and bunding the low-lying area between the sand dunes. Nineteen natural reservoirs thus formed have a storage capacity of about 900 MCM for the highest pool elevation of 184.15 m. A diversion channel of 48.17 km. length with 340 m^3/sec capacity was constructed for diverting the upstream flood flows of Ghaggar to depressions. The elevations of the bottom of the depressions range between 170 and 180 m above mean sea level, whereas the ground elevations at the north of these depressions range between 165 and 173 m above mean sea level. The average thickness of aeolian sand in surroundings of the depressions is 50 m and a relatively impervious layer occurs at an elevation of 131 m above mean sea level. CGWB report envisaged that the area around the depressions where waterlogging has been noticed is to the tune of 350 hectares. However, it has been warned that the condition may go bad to worse if the prevailing situation is allowed to persist. Baropal village shared about 200 hectares of the reported waterlogged area. Other villages situated in the north of the depressions where waterlogging has been reported are Kishanpura and Manaktheri (Fig.1).

CGWB formulated a finite difference ground water simulation model to study the effects of impoundment of water in the depressions and to predict the rate of water table rise and the areal distribution of waterlogging in the Surathgarh area. The model encompasses an area of 4000 sq.km. with 35 nodes in east-west direction and 19 nodes in the north-south direction. Two transmissivity zones were delineated in the model except for the area lying between Kishanpura and Surathgarh for which a value of 600 sq.m/day had been considered. The storativity value was assumed to be constant throughout and was 0.15. The average ground water

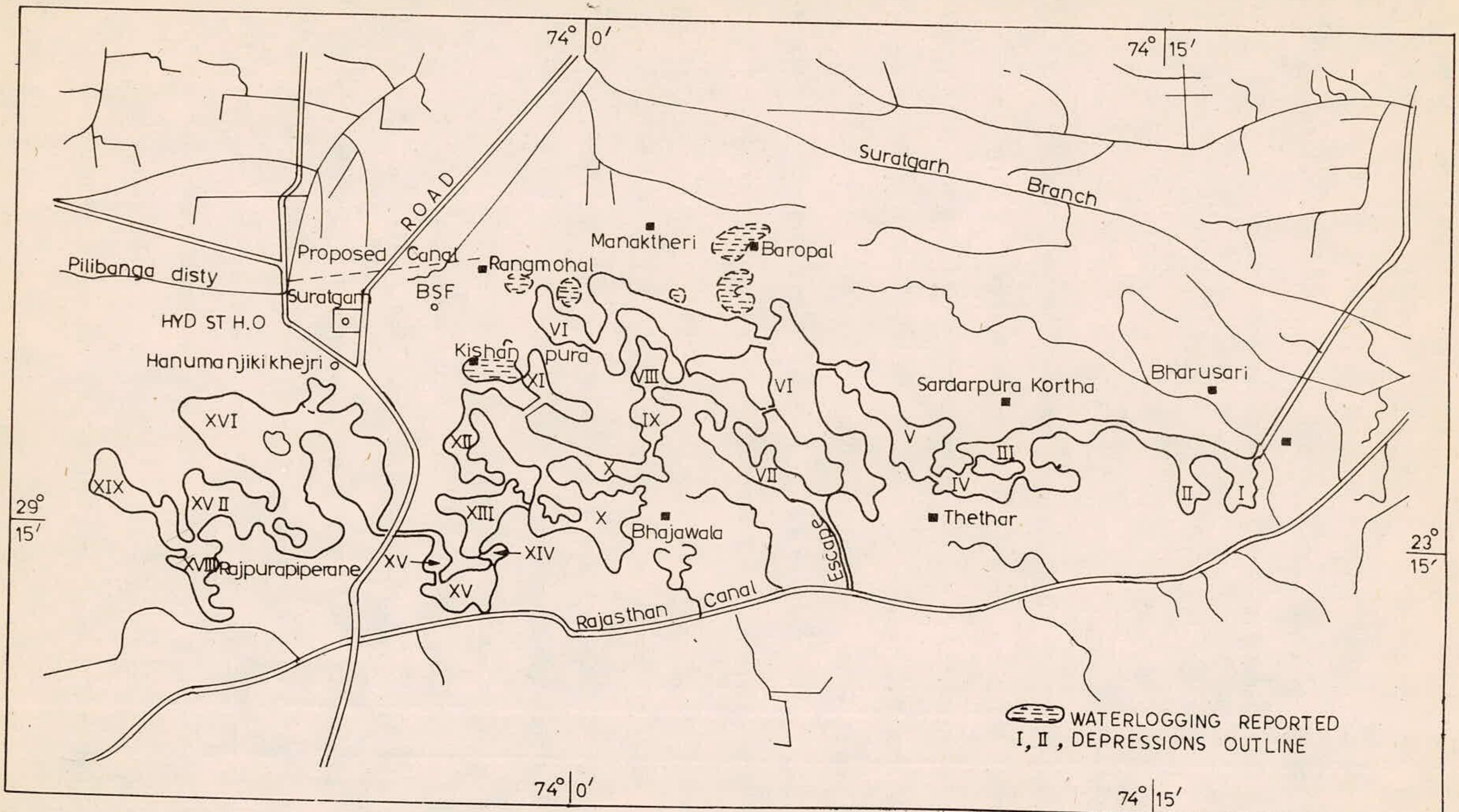

FIGURE 1 - MAP SHOWING DEPRESSIONS AND SURROUNDING AREA IN SURATHGARH.

level elevation of 1968 (140 m. above mean sea level) were used.

The seepage rate to ground water was estimated from the following equation:

$$Q = \sqrt{H \times TS/\pi t}$$

where
Q = Seepage flux per unit length,

H = Initial head difference between depression pool elevation and ground water level,

T = Aquifer Transmissivity,

S = Aquifer storativity, and

t = Time since recharge began.

Based on the above relation, the seepage rate decreases with time. The comparison of ground water levels generated by this model for 1978 showed good correlation with the observed data. It indicated the potential waterlogging hazard areas, namely, Thethar, Baropal and Kishanpura. In order to ameliorate the hazard of waterlogging in future, the suggestion was made to reduce the flood inflow to the depression and the excess flood water be diverted to sandy tracts of western Rajasthan where the depth of groundwater are deepar than 25 m. The simulated value of water table position for 1999 by this model envisages serious waterlogging problems in the areas of Thethar, Bhojewala, Kishanpura, Rajpura-Piperan, Baropal, Manaktheri, Rangmahal, and southern part of Surathgarh town.

The hydrological models developed have been designed to predict the behaviour of the system in response to a particular set of numerical values of excitations, but could not provide for a functional relationship between the excitation and its response. A new approach that deals with the complex hydrology of the stream-aquifer interaction with sufficient accuracy and incorporates the same explicitly in the management optimization problem is that of discrete Kernel generator {Maddock (1972), Morel Seytoux (1975), Morel Seytoux and Daly (1975)}. The discrete Kernel is the response of a system which is initially at rest when a unit excitation for a unit time given and then stopped. Morel Seytoux et al (1975) have developed a functional relation between the response and excitation by using discrete Kernel approach for a stream-aquifer system. They have obtained a mathematical expression for drawdown in a homogeneous aquifer and proved its validity for non-homogeneous case also. This approach is more advantageous over the other approaches due to following reasons:

a) The discrete Kernel coefficient are the properties of the aquifer alone i.e., they are independent of the excitation. So, once these basic response functions (discrete Kernels) are calculated by a finite difference model and saved, simulation of aquifer behaviour to any excitation pattern is obtained without even making use of the numerical model.

b) The finite difference model is used only to generate the response functions, so smaller grid sizes and time increments can be used to calculate the functions.

Using discrete Kernel approach,a model has been developed for depression storage & aquifer interaction and was used to test the response for Surathgarh depression (Rao, 1981).Water body has been discretised into number of circular bowl shaped depressions with their centre situated at nodal points of the grid. The plan area of a circular depression is equal to plan area of the position of the water body lying within the area of influence of a node (Fig.2). The depressions are regarded as battery of wells recharging and discharging depending on whether the ground water level is below or above the water level in the depression. Recharge from the L^{th}

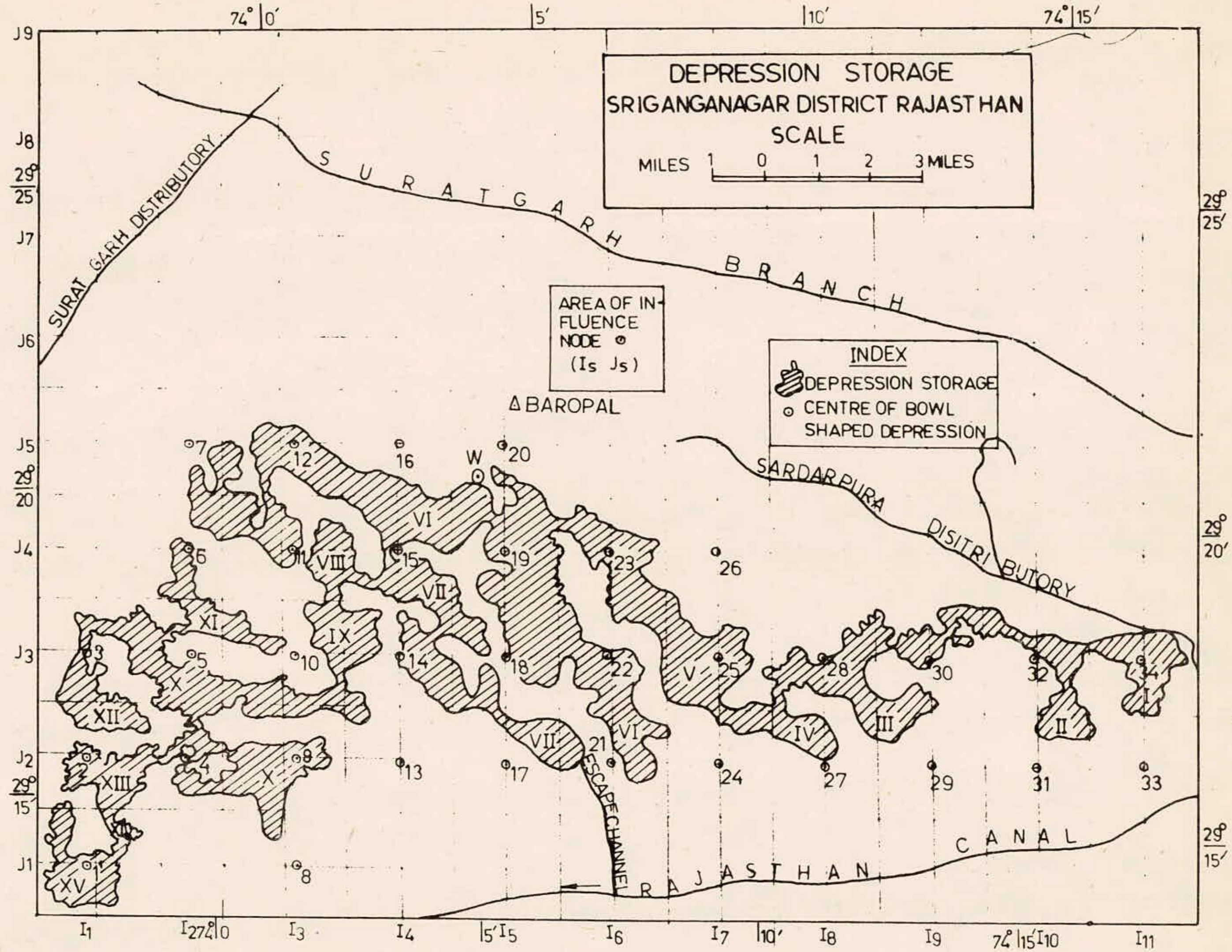

FIGURE 2- INFLUENCE AREA OF EACH NODE

depression during n^{th} time step has been described by the expression

$$Q_L(n) = \Gamma_L(n) \{\sigma_L(n) - S_L(n) - \bar{H}\}$$

where $\Gamma_L(n)$ = depression transmissivity for L^{th} depression at n^{th} time step,

$\sigma_L(n)$ = depth to water surface in the L^{th} depression at n^{th} time step measured from high datum positive downwards,

$S_L(n)$ = depth to water table at n^{th} time step at the centre of the L^{th} depression had the depression not been present, measured from initial average water table position, and

$\bar{H}$ = depth to initial average water table measured from high datum.

Assumptions that have been made herein are:

a) Initially the ground water is at rest condition and it is located at a depth of $\bar{H}$ from the assumed high datum and all the depressions are empty; (b) the depressions are filled up with water and a constant level is maintained during the particular time step, but the level varies from time step to time step.

As envisaged earlier, Surathgarh area of Sriganganagar district of Rajasthan is situated in the arid zone and the model is essentially developed for the area. As such, the model does not take into account any other recharge components except seepage from the impounded depression storage, though it is flexible enough to provide for other components of recharge, if necessary. Using the model, the aquifer parameters were estimated. The optimum parameters thus estimated are T = 37600 m^2/ month and ϕ = 0.13. The drawdown (response) of the aquifer for unit pulse excitation is calculated. The total monthly recharge from the depression storage has been estimated for existing depression water level fluctuation for the period 1975-77. It has been concluded that model is quite endeared to simulate the hydrological system of the area with reasonable and acceptable accuracy. Correlation between fluctuations of water level in the depression storage and the corresponding water table response for their mutual interdependence have been found to be in the order of 95 per cent (Rao, 1981). The ground water contours in the vicinity of the depressions have been simulated by making use of Rao's model. The aquifer parameters which have been estimated by Rao have been used. Response of the aquifer has been studied for the following conditions:

a) the minimum depression water level for infinite period;

b) the maximum depression water level for infinite period; and

c) fluctuating water level in the depression between maximum and minimum during wet and dry seasons respectively.

The ground water contours for these three conditions are given in Figure 3, 4 and 5.

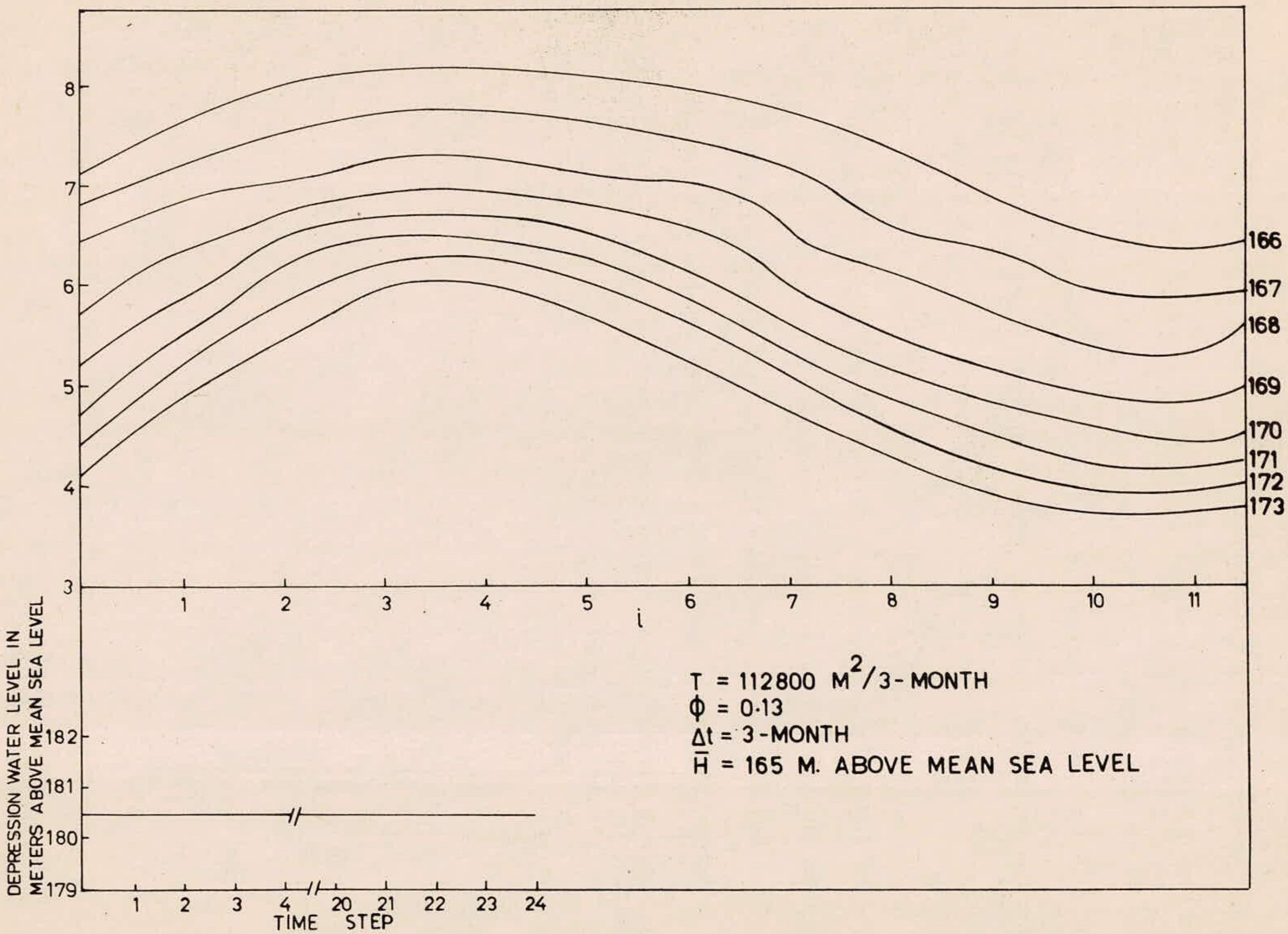

FIGURE 3 - GROUND WATER CONTOUR IN METERS AT THE END OF 24th TIME STEP.

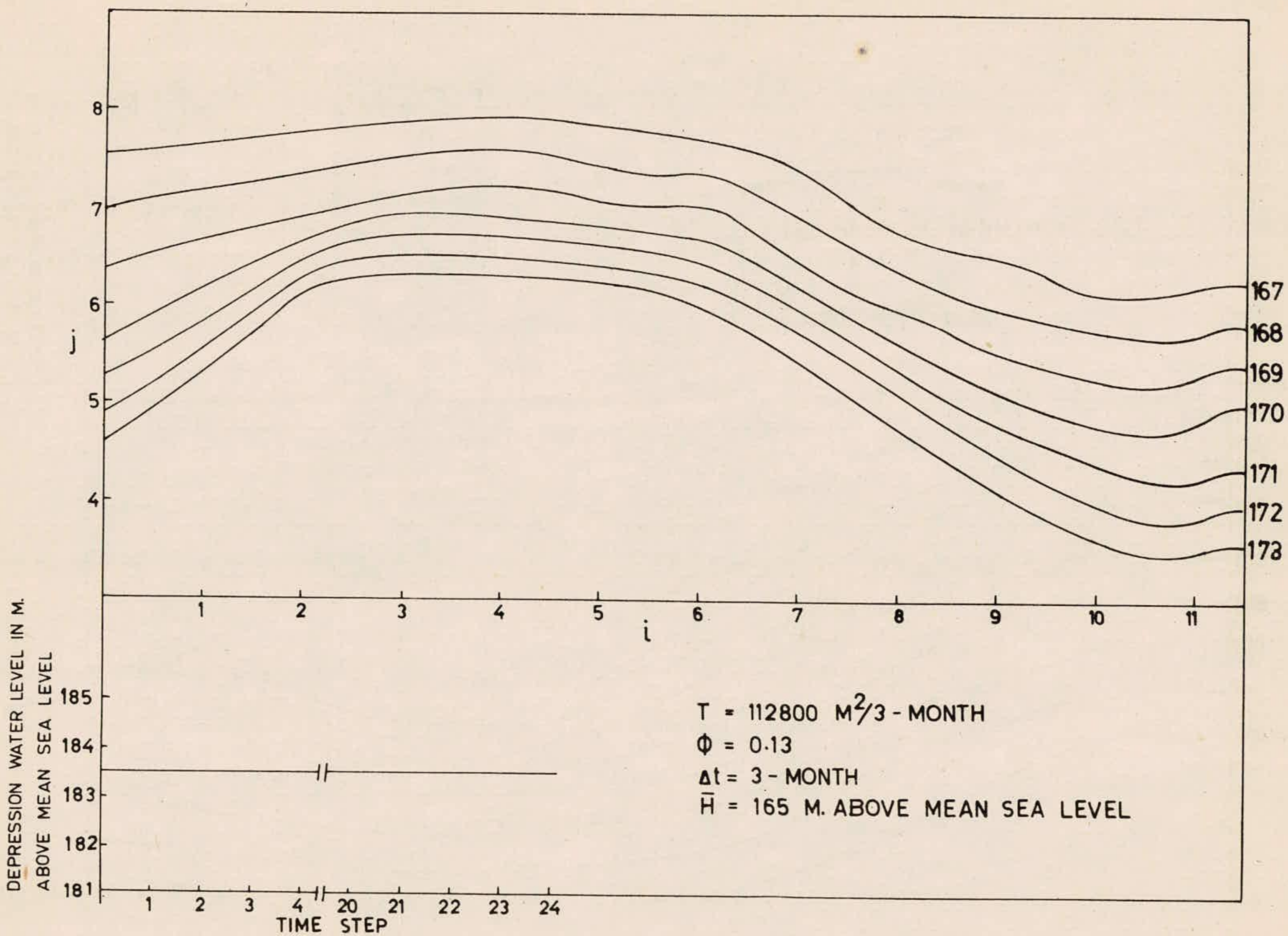

FIGURE 4 - GROUND WATER CONTOUR IN METERS AT THE END OF 24th TIME STEP.

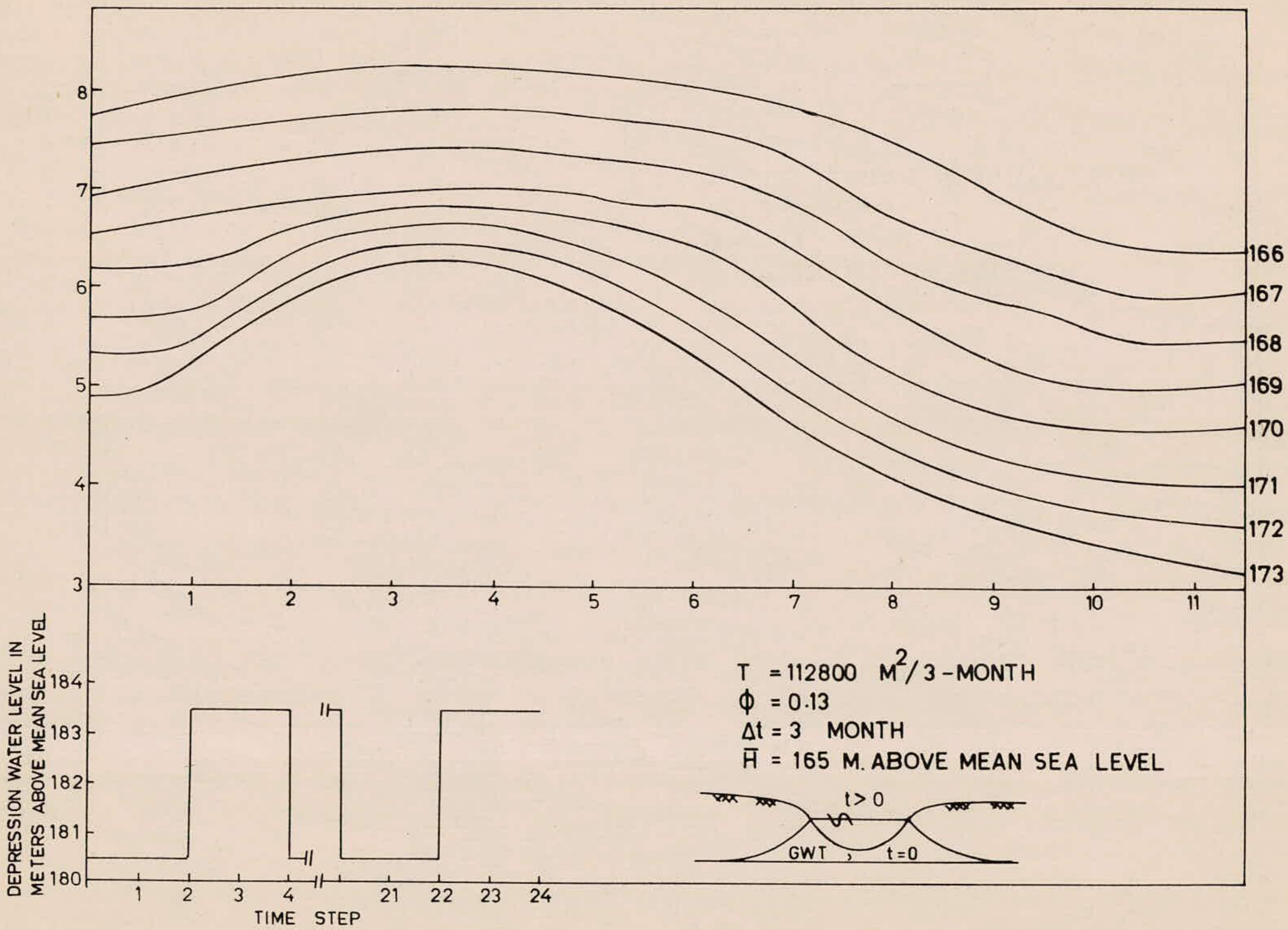

FIGURE 5 - GROUND WATER CONTOUR IN METERS AT THE END OF 24^{th} TIME STEP.

3.0 PROBLEM DEFINITION

A group of depression storage which are interconnected are filled up at a time t=0. It is assumed that the ground water system is initially at rest condition. The recharge from depressions to ground water commences after the depressions are filled up. Once the depressions are filled up and recharge to ground water initiates, there is no further addition of water to the depressions. It is aimed to find the depressions water level and recharge that is taking place to the aquifer from the depressions at different times.

4.0 METHODOLOGY

4.1 Development of the Mathematical Model

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

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

in which,

ϕ = aquifer storage coefficient,

s = drawdown,

t = time,

x,y= horizontal cartesian coordinates,

T = aquifer transmissivity

Q_w= instantaneous abstraction or recharge through well w (+ ive for abstraction, and - ive 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 - aquifer - well interaction.

In the development of the mathematical model for depression storage - aquifer -well interaction, the discrete kernel approach which is applicable for a linear system can conveniently be used. The discrete kernel coefficients are the response of linear system originally at rest in response to a unit pulse excitation. Complex stream -

aquifer - 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 meant for pumping ground water at the time of need. 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 can be visualized as a battery of wells recharging to ground water when the water table is below the depression water level Fig. 6. The recharge rate during n^{th} time period from L^{th} depression can be written as

$$Q_L(n) = \Gamma_L(n) \{\sigma_L(n) - (S_L(n) + \bar{H})\} \qquad \dots (2)$$

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 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 depression 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 measured from a high datum before the depressions were filled.

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

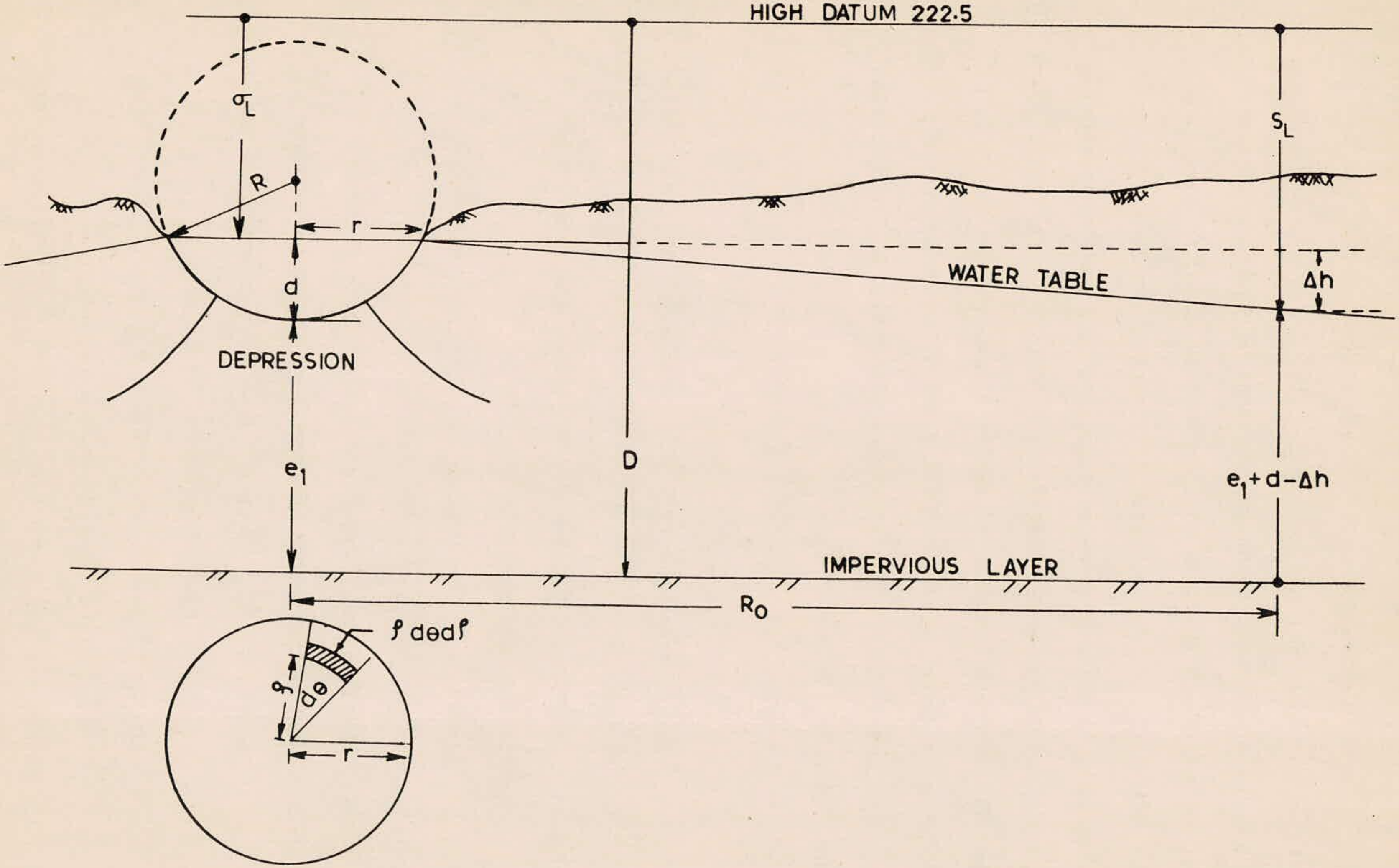

FIGURE 6 - FLOW DOMAIN NEAR A DEPRESSION

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 number of depressions.

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

Hence,

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

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 due to recharge from depression, and

$\delta'_{pL}(.)$ = discrete kernel for drawdown due to pumping.

Let

$\sigma(n-1)$ = drawdown of the water level in the depression at the end of $(n-1)^{th}$ time period.

$r_L(n)$ = radius of the L^{th} depression at the water level position during time step 'n',

$\Delta\sigma(n)$ = change of drawdown in the depression water level during n^{th} unit of time step,

$V_L(n-1)$ = depression storage volume of L^{th} depression during $(n-1)^{th}$ unit time period, and

$V_L(n)$ = 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

$$\{ V_L(n-1) - V_L(n)\} = \pi r_L^2 (n-1). \Delta\sigma(n) \quad \ldots (4)$$

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

Thus,

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

$$= \Delta\sigma(n)\pi\{r_1^2(n-1) + r_2^2(n-1) + \ldots + r_L^2(n-1)+\ldots \ldots + r_N^2(n-1)\} \quad \ldots (5)$$

or,

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

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

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

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

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

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

'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.

4.2 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 a 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)

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

where $\beta = T/\phi$

4.3 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)

$$\delta(L,L,m) = \frac{1}{\pi r^2\phi} + \frac{1}{\pi r^2\phi}\left\{(m-1)e^{-r^2/4\beta(m-1)} - me^{-r^2/4\beta m}\right\}$$

$$+ \frac{1}{4\pi T}\left\{E_1(r^2/4\beta m) - E_1(r^2/4\beta(m-1))\right\} \qquad \ldots(10)$$

4.4 Determination of Depression Transmissivity

Let the circular bowl shaped depression have depth d and radius r. R be the radius of the sphere of which the depression is a part (Fig.6). 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 and radial distance R_o is generally equal to 8r. Making use of these, it can be shown that the depression transmissivity Γ_L will be given by (Rao, 1981)

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

5.0 APPLICATION

As stated earlier, in the south-western part of the Ghaggar basin (lower Ghaggar basin), there exist an isolated but interconnected series of nineteen aeolian sand dune depressions in Surathgarh area of Sriganganagar district of Rajasthan as described in Fig.1. The depressions have plan area to the tune of 100 sq. km with storage capacity of 900 million cu.meters at full storage level. These depressions are being used as flood cushion since 1968.

The depressions have been discretised into a number of circular bowl shaped depressions with their centres situated at the nodal points of the grid. There are 34 numbers of such nodal points after discretisation of the depressions(Fig.2). The model developed herein has been applied to Surathgarh depression.

6.0 RESULT

The drawdown in the depression water level at various time after the first filling are estimated by this model and are shown in Fig. 7. It is observed that some of the depressions out of 19 interconnected depressions are emptied after 7 months. The corresponding monthly recharges from the depressions are shown in Figure 8. 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 all filled up is 3×10^8 cubic meter after 7 months with Central Ground Water Board aquifer parameter values ($T = 18{,}000\ M^2/$ month and $\phi = 0.15$).

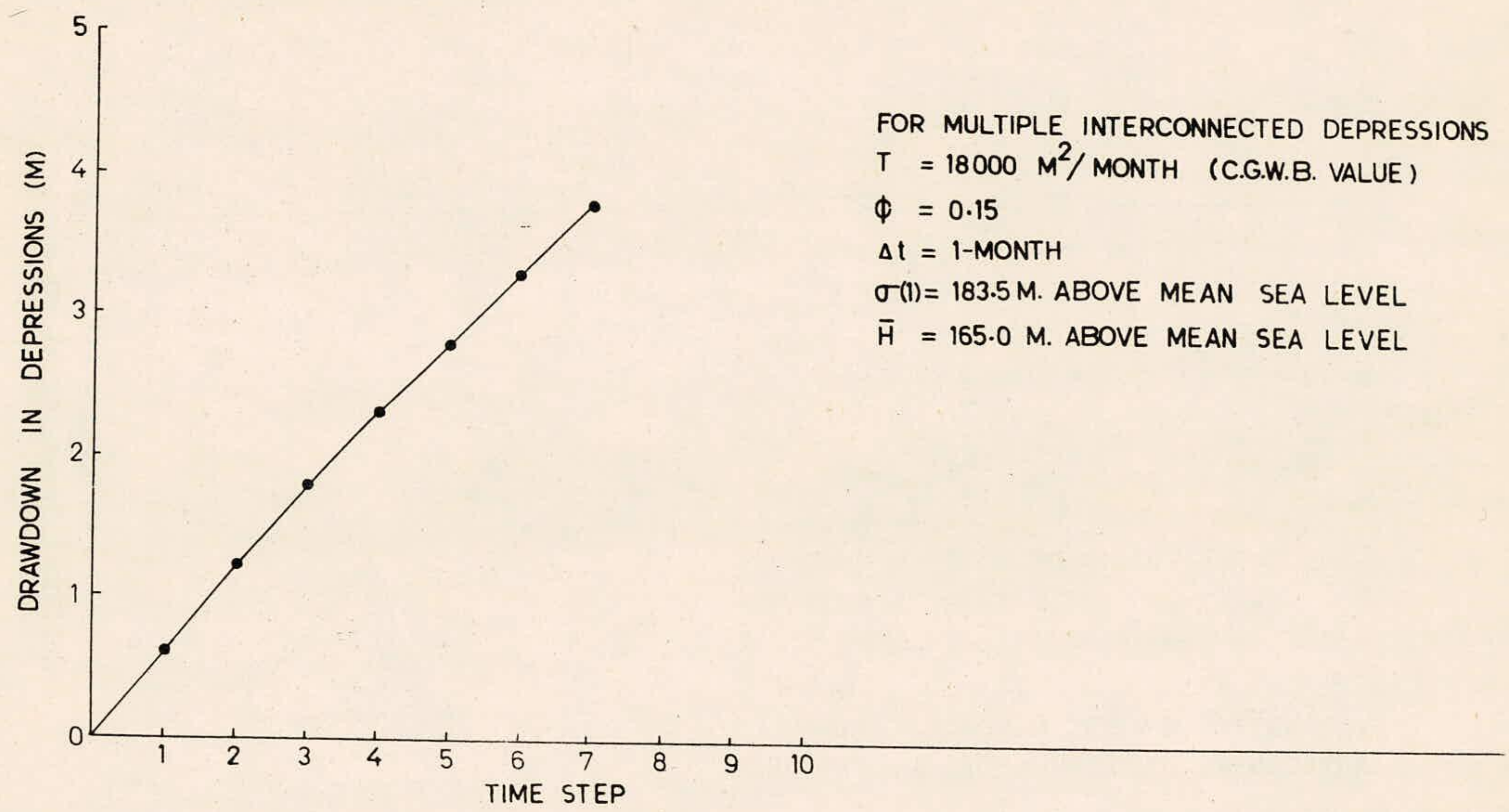

FIGURE 7 - DRAWDOWN IN DEPRESSION' WATER LEVEL

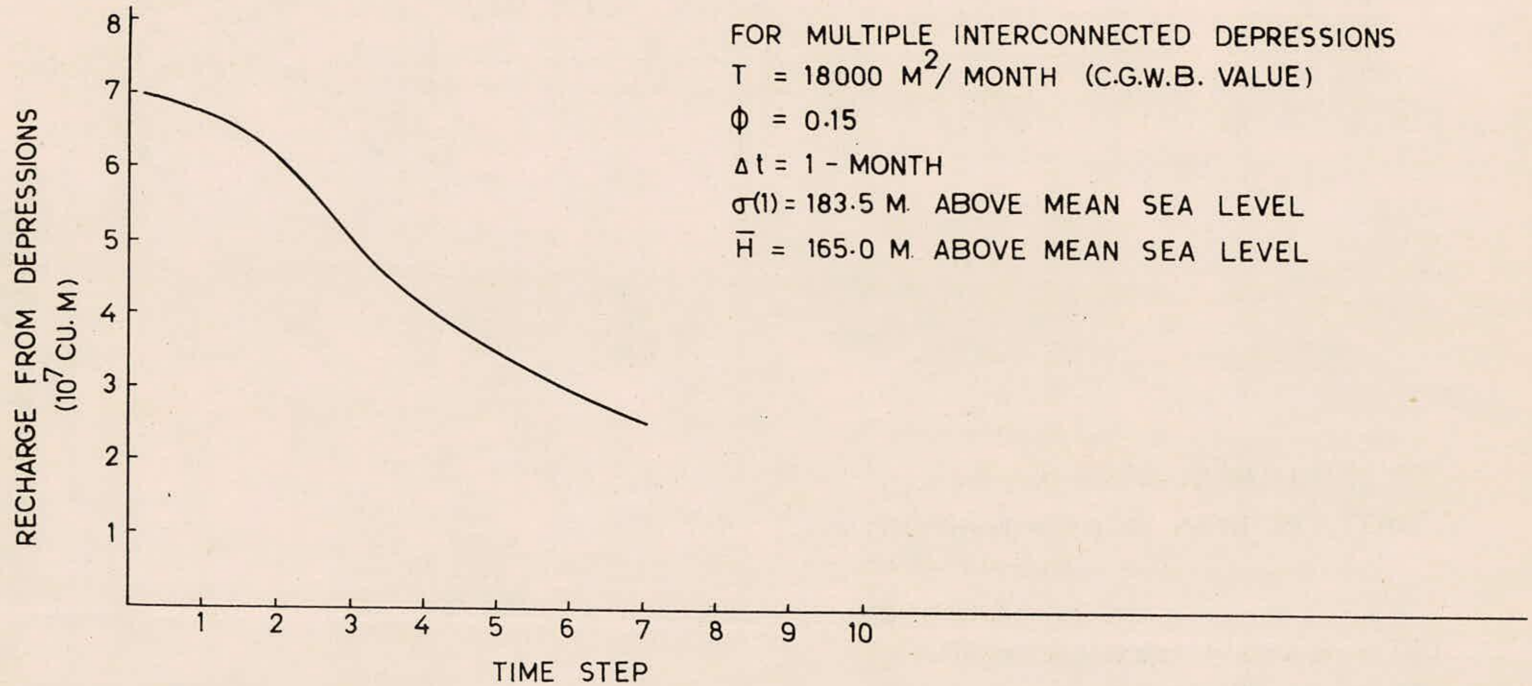

FIGURE 8 - VARIATION OF RECHARGE FROM DEPRESSIONS

7.0 CONCLUSION

A mathematical model using discrete kernel generator has been developed to study the interaction of depression storage and a shallow water table aquifer, . when a group of inter-connected depressions are filled-up with water and the storage is allowed to deplete as recharge to ground water without any interference.

The model has been applied for Surathgarh depressions which are already being used as flood cushion from 1968. Depressions are assumed to be filled-up to the maximum level (183.5 m above mean sea level) which gives an average of 3 meters water depth in the depression. Using aquifer parameters suggested by CGWB, it is observed that it takes about 7 months for some of the depressions to become empty and the total recharge to ground water during this period is to the tune of 3×10^8 cu. m. Recharge rate from the depressions at the seventh month is approximately 1/3 of the initial recharge rate.

The model can be used as a subroutine in water resources management having the aim of saving the land from waterlogging and at the same time realizing the benefits from water-storage like pisiculture and irrigation during non-monsoon period, reduction of flood damage, and provision of recreation facility.

REFERENCES

1. Allred, E.R., Manson, P.W., Schwartz, G.M., Golany,P., and Reinke, J.W. (1971),'Continuation of studies on the hydrology of ponds and small lakes', Agr. Expt.Sta.,University of Minnesota Tech.Bull.274,62 pp.

2. Eisenlohr,W.S., and others(1972), 'Hydrologic investigations of prairie pot holes in North Dakota', 1959-68, USGS Prof. Paper 585-A, 102 pp.

3. Everdingen, R.O. Van,(1972),'Observed changes in ground water regime caused by the creation of Lake Diefenbaker, Saskatchewan', Canadian Dept.of Environment,Inland Waters Branch,Tech.Bull.59,65pp.

4. Maddock, T.I.(1972),'Algebraic Technological Functions from a simulation model', Water Resources Research, V.8,n.1,pp.129-134.

5. Manson,P.W.,Schwartz,G.M., and Allred,E.R.(1968),'Some aspects of the hydrology of ponds and small lakes', Univ.of Minnesota Agric. Exp.Sta.Tech.Bull.257, 88 pp.

6. McBride,M.S.(1969),'Hydrology of Lake Sallie, northwestern Minnesota with special attention to ground water - surface water interactions', Univ.of Minnesota, M.S.Thesis , 61 pp.

7. Meyboom, P.(1966),'Unsteady groundwater flow near a willow ring in hummocky moraine', J.Hydrology, V.4,pp.38-62.

8. Meyboom,P (1967),'Mass-transfer studies to determine the groundwater regime of permanent lakes in hummocky moraine of western Canada', J.Hydrology,V.5, pp.117-142.

9. Morel-Seytoux, H.J. (1975),'A combined model of water table and river stage evolution', Water Resources Research, V.11, n.6.

10. Morel-Seytoux, H.J., and Daly,C.J.(1975),'A discrete kernel generator for stream-aquifer studies',Water Resources Research, V.11,n.2 pp.253-260.

11. Proceedings of International Symposium on ground water,Bulgaria,1982.

12. Rao,N.B.(1981),'Interaction of Large depression storage and an aquifer' ,M.E. (Hydrology)thesis, Univ.of Roorkee, Roorkee, 58 pp.

13. United Nations (1980),'Ghaggar river basin mathematical model', UNDP report for Govt of India, 149 pp.

14. Winter, T.C.(1976),'Numerical Simulation analysis of the interaction of lakes and ground water', USGS Prof. paper 1001,45 pp.