National Symposium on Hydrology
Dec.16-18,1987, N.I.H..Roorkee

ASSESSMENT OF FOREST INFLUENCE ON GROUND WATER REGIME

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ABSTRACT

Researchers have been trying for past several decades to ascertain the hydrological importance of forests. As watershed experiments are generally long term and expensive, and need a high degree of trained manpower, most research evidence in this field comes from the temperate, industrialised countries. Yet even in developed countries role of forests as far as it affects hydrologic parameters in general and ground water regime in particular remains a matter of scientific investigation. The studies carried out so far regarding influences on ground water do not give coherent results. In forested watersheds on one hand, it is advocated that due to improved conditions of soil surface and soil structure the ground water regime would improve owing to better recharge conditions while on the other due to high rate of evapotranspiration of forests, the water table is considered to be adversely affected.

Use of a mathematical modelling approach has been suggested in the present paper to study the influence of forests on ground water regime. The approach is based on a solution given by Hantush (1967) to find out position of water table in an unconfined aquifer with known values of recharge rate and aquifer parameters. Based on limited number of studies done on evapotranspiration and recharge rates in forested basin in the country, these values were assumed to find out effects of forests on water table regime. It was found that due to better recharge conditions the water table rose during rainy season but in non-rainy season the water table declined as a result of forests. The effects of forests were predominent only in and around forested region. There is a vast scope to further improve the results by using more realistic data.

1.0 INTRODUCTION

The habitable surface area of our globe remains more or less fixed. The number of people that inhabits it, on the other hand, is on a fast increasing trend. Those charged with the management of the earth's natural resources must, therefore, be aware of the likely consequences of their actions, so that each unit area of precious land will produce the optimum yield of its resources. Water is only one of these resources and is the prime mover. Food, fiber, and space for habitation, recreation and industry are others. The use of land for one purpose may make it unusable for others. However, forested land, which covers 30% of the earth's surface, is generally capable of yielding a variety of products. A wide range of claims have been made about the miraculous benefits of trees, whether in rows, groves, or forests. It is alleged that they can stop floods, make rain, provide fuelwood, yield fodder, produce resins, provide food, renew springs and wells, prevent erosion, shelter and feed wildlife, keep sediment out of

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rivers, lakes and reservoirs, release water during the dry season, enhance landscape beauty, supply commercial wood products such as timber and biomass for energy, and protect gene pools of biotic diversity (Hamilton, 1985). However, it may worthwhile examining these issues in greater depth by carrying out systematic studies before drawing any conclusions. Unfortunately, the studies so far conducted in these directions have been mainly concentrated on small watersheds and as such results so obtained can't be extrapolated to larger basins. An attempt has, therefore, been made in the present paper to describe a methodology to investigate effects of forests on ground water regime with the help of a mathematical model.

2.0 HYDROLOGIC ROLE OF FORESTS

The important compoents of a forest from hydrological point of view are canopy, leaf litter and humus with dense roots. Interception, surface ponding and detention, obstruction of the surface runoff by leaf litter, mulch, debris, storage of water by humus and organic matter, dead root and burrows of organisms are the effects of forest cover on hydrology of the basin. Leaf litter and humus act as a cushion against the impact of rain drop and provide temporary pondage as the rich organic content of the dense leaf litter helps in high infiltration and soil moisture storage. Water holding capacity of humus is several times its weight and the presence of organic matter improves the soil structure. The leaf litter and humus is high in temperate subtropical zone and low in tropical zone. Hence, good cover, high organic matter, ramified root system and protective-cum-productive vegetation as found in a forest catchment regulates the streamflow. Thus the important components of a forest which influence hydrology of a catchment are canopy (including top storey, underwood, and undergrowth), density, leaf litter and humus with dense roots. Researchers have been trying for past several decades to ascertain the hydrological importance of forests. As regards to forest influences on rainfall, the majority of researchers have concluded that forests did not affect rainfall on a regional scale. In coastal fog belts, the forests have been found affecting rainfall by intercepting moist air masses. The interception losses in forested catchments are function of types of forests, precipitation characteristics and climate. The evapotranspiration losses in forested catchments are higher than other types of land uses. The infiltration characteristics of forested soils are better than other soils due to increased amount of organic matter and protection of soil by vegetal cover. Forest influences on ground water regime have not been studied in a systematic manner and therefore need careful investigation. The annual water yield from a watershed gets increased following forest removal due to reduction in ET losses. The effects of forests are limited to moderate and flash floods. The cutting of forests results in more soil loss.

3.0 FORESTS AND GROUNDWATER

Forest influences on ground water storage can be estimated from evapotranspiration and discharge relationships. Many research projects carried out in the USA, Switzerland and Japan have attempted to show the influence of forests on underground water tables. The findings have not been very coherent as the American studies claim that water tables collapse as a result of deforestation or forest fire; while Swise studies seem to indicate no effects on water table with forest cover changing to grass (Rakhamanov, 1960; Penman, 1963). In France, during the late eighteenth century and early nineteenth century, the writers, members of the French Royal Academy of Agriculture made it clear that because of deforestation carried out following the sale of properties belonging to the church and aristocracy at the time of Frech Revolution, numerous fountains dried up and rivers decreased in volume. However, there have also been instances when clearing of forest did not have any significant effects on ground water sources of fountains in France. Hence, there does not seem any historical evidence of any direct influence of deforestation on the lowering of water tables (Guillerme, 1980). Eckholm (1976) and Sharp and Sharp (1982) have opined that logging of tropical forest watersheds had caused wells, springs, streams, and even major rivers to cease flowing, at least during the dry season. There have been opinions that roots of forest trees exhibit 'Sponge' effect that soaks up water in the wet periods and let it release slowly and evely in the dry season to keep water supplies adequately restored. Such opinions are difficult to believe especially in light of the fact that small watershed cutting experiments have universally given increased total water yield over the year and some cutting experiments have shown increases in ground water levels (Hamilton and King, 1980, Bosch & Hawlett 1982 and Boughton, 1970). Reforestation of upland watersheds has been advocated partially on the grounds that it will induce dry season stream flows and raise ground water well levels and restore the reliability of springs (World Bank, 1978). The Leader of Chipko movement claims that tree planting particularly the broad leaved varieties creates water (World Water, 1981). However, most well conducted experiments have shown that reforestation reduced streamflow year round (Van Lill et al., 1980). Lowering of ground water levels has usually followed reforestation (Holmes and Wronski, 1982). In India, significant efforts have not been made to study effects of forests on ground water. The F.R.I. has conducted some studies with Blue gum to this effect in Nilgiri hills. The study involved monitoring of two small natural watersheds, one predominently under blue gum and another under grass. The analysis of ground water level data recorded in both watersheds showed a fall of 29 cm in water table in grassland and 70 cm in blue gum during study period which were statistically not found significant (Francis H. Raj et al., 1986). Samraj (1984) has observed that plantation of Eucalyptus tree in Nilgiris has resulted in significant lowering of base flows. Singhal et al., undated have reported that there is no scientific basis in the popular fallacy that eucalyptus lowers the underground water table. However, its water consumption has been stated to be more as compared to other slow growing species.

4.0 FOREST INFLUENCES MODEL

The influences of forests on ground water regime is possible mainly because of some factors like deep rooting characteristics, higher water requirements, improvement in soil structure etc. The main components that will differ in carrying out water budgeting of a forested and a non-forested region will be recharge rate and rate of evapotranspiration. Attempts have been made by various researchers to find out rise in water table as a result of recharge from surface. Bianchi and Muckel (1970) have developed a dimensionless graph defining the rise and horizontal spread with time of a water table mound beneath a square recharge area.

Hantush (1967) developed an equation to predict rise and fall of ground water mounds in an unconfined aquifers in a rectangular basin as given below:

$$h_{x,y,t} - H = \frac{V_a t}{4f} \{F[(W/2 + x)n, (L/2 + y)n]$$

$$+ F[(W/2 + x)n, (L/2 - y)n]$$

$$+ F[(W/2 - x)n, (L/2 + y)n]$$

$$+ F[(W/2 - x)n, (L/2 - y)n]\} \qquad ...(1)$$

where,

$h_{x,y,t}$ = height of water table above impermeable layer at x,y and time t

H = Original height of water table above impermeable layer

V_a = arrival rate of water at watertable from infiltration basin

t = time since start of recharge

f = fillable porosity $(1 > f > 0)$

L = lenght of recharge basin (in y direction)

W = width of recharge basin (in x direction)

n = $(4\ t\ T/f)^{-1/2}$

$F(\alpha,\beta)$ = $\int_0^1 \operatorname{erf}(\alpha\tau^{-1/2}) . \operatorname{erf}(\beta\tau^{-1/2}) d$

The values of function F have been tabulated by Hantush. The left hand side in equation (1) gives the rise or fall in the water table positions as the case may be.

The main factor on which the replenishment of ground water depends is the amount of rainfall and its distribution. As is known the rainfall in the country is highly varying with space and time. About 75% of total precipitation occurs during monsoon months (June-September) and rest eight months (October-May) receive only 25% total rainfall. Therefore, rainfall recharge is also a time varying process. Another important factor that will affect rainfall recharge is land use conditions at the surface. As has been discussed earlier in forested land the recharge conditions get improved due to better soil structure, deep rooting characteristics and improved surface conditions. However, at the same time the loss of water due to increased evapotranspiration demand gets increased in forested regions. In order to analyse the net effect of forests on ground water regime it may be worthwhile to carry out detailed analysis taking into account the effects of forests on recharge rate as well as ET demand of the region.

For such analysis let's assume time steps be discretised into time steps of uniform size. The excess recharge rate (due to forested conditions) be assumed as $R_e(\gamma)$, $\gamma = 1, n$: where n is total time steps. The response of the aquifer at coordinate (x,y) at time m due to unit recharge rate per unit area occuring during the first unit time period only is given by:

$$\partial(x,y,m) = \frac{1.m}{4f} [F \{ (w/2 + x)m, (L/2 + y)m \}]$$

$$- \frac{1.(m-1)}{4f} [F \{ (w/2 + x)(m-1), (L/2 + y)(m-1) \}]$$

$$\text{for } m > 2 \qquad \ldots(2)$$

and,

$$\partial(x,y,1) = \frac{1}{4f} [F \{ (w/2 + x), (L/2 + y) \}] \qquad \ldots(3)$$

The water table rise/fall at coordinate (x,y) at the end of time step'n' due to time variant recharge is given by:

$$S_1(x,y,n) = \sum_{\gamma=1}^{n} (x,y,n-\gamma+1)\ R_e(\gamma) \qquad \ldots(4)$$

Considering the net evapotranspiration due to forests is $ET(\gamma), \gamma=1,n$. Therefore, fall in water table due to evapotranspiration of forests will be :

$$S_2(x,y,n) = - \sum_{\gamma=1}^{n} ET_{(\gamma)} \quad (x,y,n-\gamma+1) \qquad \ldots(5)$$

Therefore, the resultant water table rise/fall will be given by:

$$S(x,y,n) = S_1(x,y,n) - S_2(x,y,n) \qquad \ldots(6)$$

In order to demonstrate the use of this methodology a square sub-basin (100 sq.km. area) has been assumed with forest land use as shown in figure 1. The basin is assumed to have an unconfined aquifer of 1000 m thickness, 1 m/day hydraulic conductivity, storage coefficient(S) of 0.001 and transmissivity (T) of 1000 m^2/day. The total annual rainfall in the region was assumed as 1000 mm with 75% occuring during monsson season (June-September). It was further assumed that due to forested conditions 25% of rainfall gets additionally recharged as compared to non-forested conditions. Therefore, fraction increase in recharge rate was taken 0.047m/month in monsson season and 0.0003 m/month in non-monsoon months. Further, the monthly ET rate of forests was assumed as 7 cm/month. Assuming forests evaporate 50% more water than non-forested land, the fraction increase in ET due to forest was taken as 0.035 m/month in monsoon season and 0.0175 m/month in non-monsoon season. These assumptions have been based on realistic data as reported by various researchers.

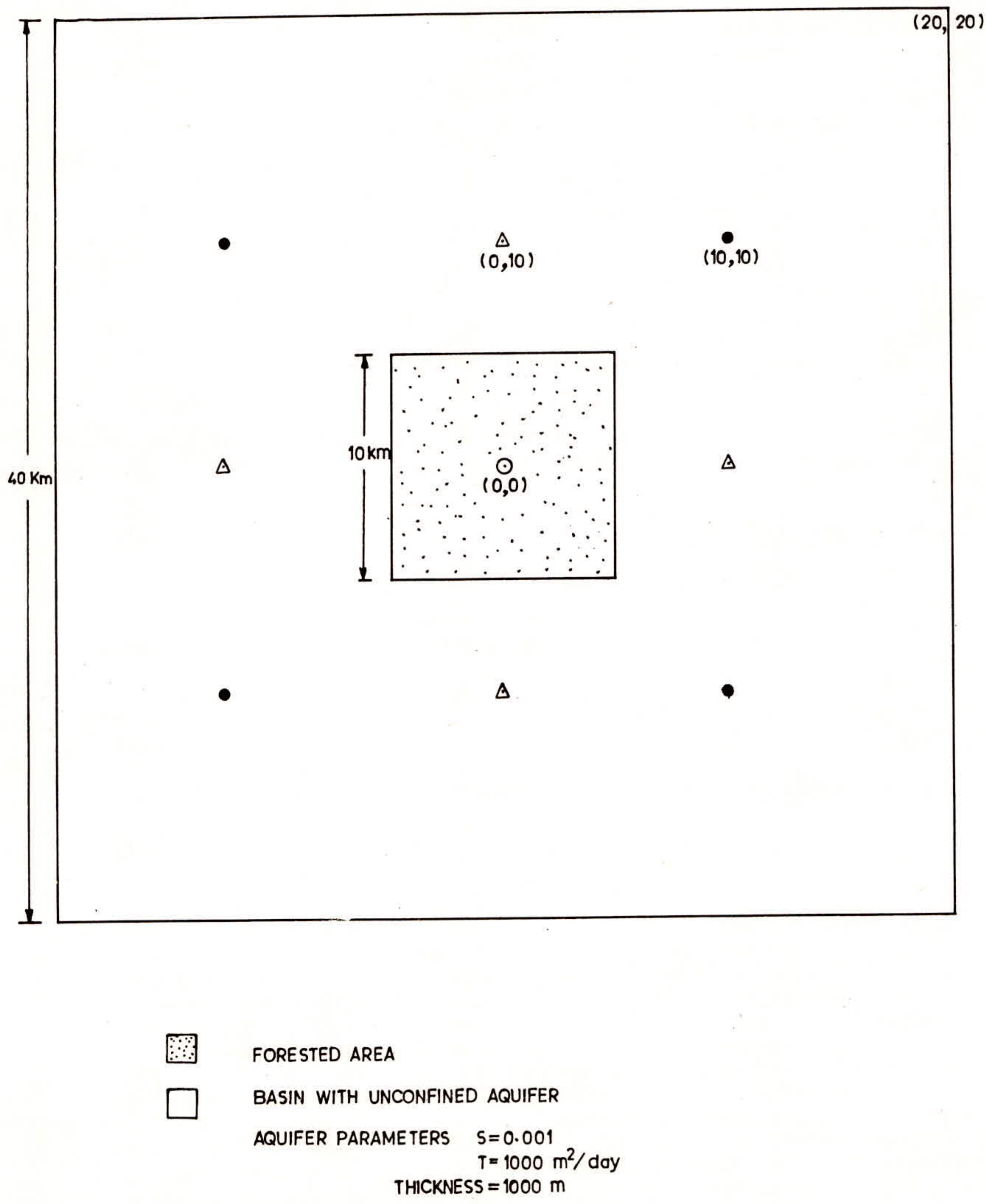

FIG. 1 - FOREST SUB BASIN IN A BASIN

With these values of recharge and evapotranspiration, the response of aquifer was calculated using above described methodology. The positions of water table at various coordinates for 12 months was calculated and have been given in table 2. The water table behaviour as obtained at some of the coordinates is shown in figure 2. It can be seen from table 1 that at the centre of the basin coordinate (0.0) there has been a steep variation in ground water table. However, away from the centre the fluctuation in water table keeps reducing and it tends to get parallel to x-axis which shows not much change in water table positions throughout the year at the extreme ends of the basin. From figure 2, it is evident that during rainy season due to better recharge rates the water table comes up which recedes later during non rainy season. It may also be said that had the region been denuded, the ground water built due to surface recharge would have flown to other basins as ground water is always in a dynamic state. It may further be mentioned that the effect on ground water table as shown in figure 2 represents only the one which takes place due to fraction increase in recharge rate due to forests. However, actual position of water table will be found by adding these computed values of water table positions with the ones that would take place in non-forested conditions. The major limitation in adopting this methodology comes in generating realistic data in respect of percentage increase in recharge and ET rates as compared to non-forested conditions. Also obtaining values of ET losses on monthly basis for various land uses requires lot of experimentation.

CONCLUSION

Forest influences on ground water regime has been a controversial issue. While on one hand due to improved soil structure conditions, the forests contribute in building ground water storage, on the other hand due to their higher ET requirements the ground water storage is expected to be affected. An attempt has been made in the paper to find out water table positions as affected by forests. The results indicate an increasing trend in water table in rainy season when the recharge component is predominent. The results can further improve by carrying out similar analysis with more realistic data for smaller time interval. The values assumed in the present study have been based on studies conducted by researchers in various parts of the country.

ACKNOWLEDGEMENT

The author wishes to thank Dr.Satish Chandra, Director, National Institute of Hydrology, Roorkee for his encouragement during the course of the study. Sincere thanks are due to Dr.G.C.Mishra, Scientist 'F' who has rendered valuable guidance for carrying out the study.

Table - 1

Positions of water table at various observation points (in m)

Month	Observation points as in Fig.1				
	(0,0)	(0,10)	(0,20)	(10,10)	(20,20)
June	1.2	0.60	0.006	0.31	0.006
July	2.4	1.21	0.012	0.61	0.012
August	3.6	1.81	0.018	0.91	0.018
September	4.79	2.41	0.026	1.22	0.024
October	3.06	1.54	0.021	0.78	0.015
November	1.33	0.68	0.020	0.35	0.007
December	-0.45	-0.20	0.025	-0.087	-0.0015
January	-2.24	-1.08	0.034	-0.52	-0.0097
February	-4.03	-1.96	0.043	-0.96	-0.0176
March	-5.81	-2.84	0.049	-1.40	-0.0253
April	-7.57	-3.72	0.048	-1.83	-0.0326
May	-9.27	-4.58	0.039	-2.26	-0.0396

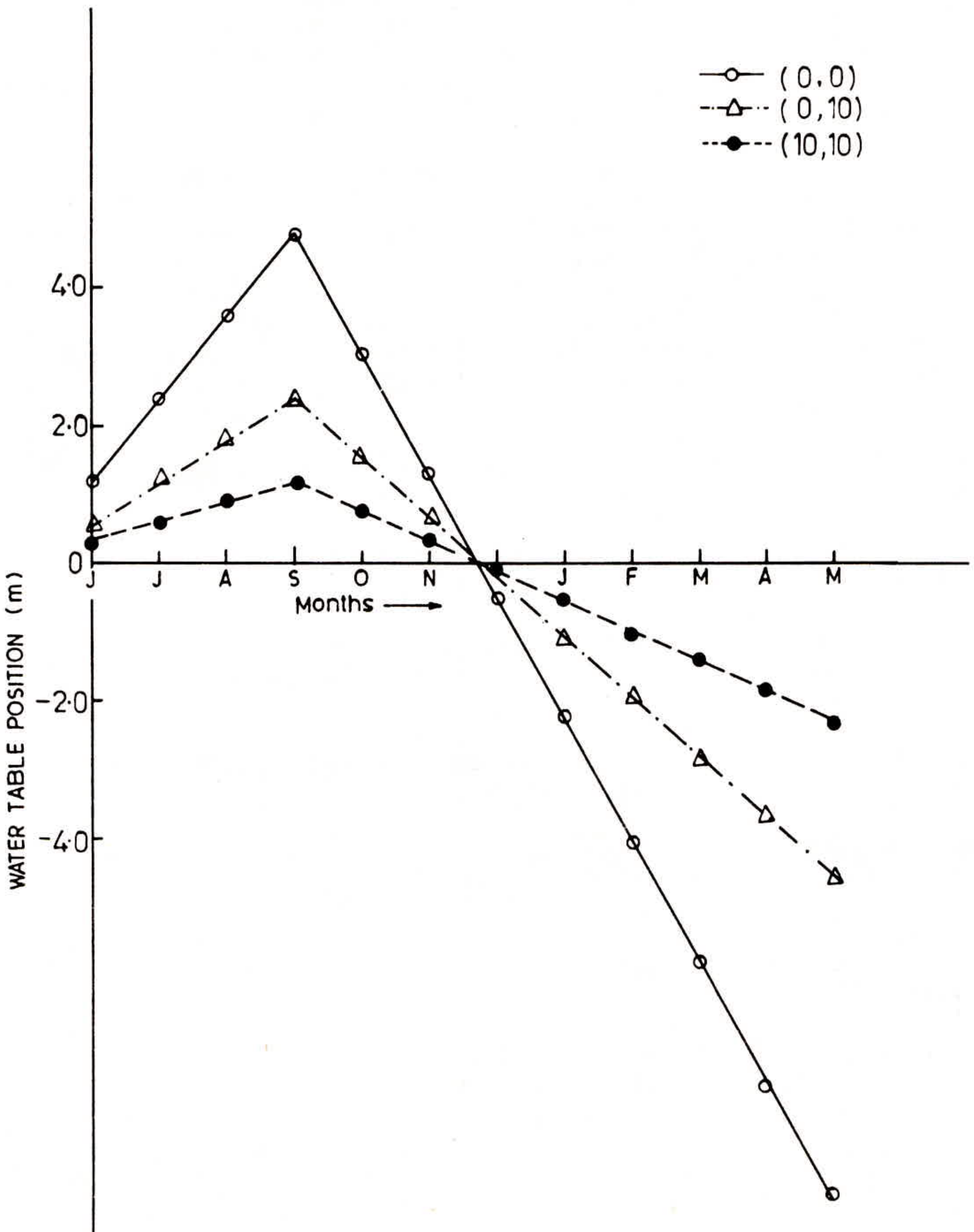

FIG. 2 - WATER TABLE POSITIONS AT VARIOUS OBSERVATION POINTS

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