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HYDROLOGICAL STUDIES OF PARDA SPRING IN NAINITAL

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INDIA
1990-91

PREFACE

Spring water has been used for the community from quite a long time. It has been reported that urban centres of Roman Empire were supplied with spring water through eleborate aqueduct. Spring water is relatively clean and provide for the water requirement of rural populace in remote hilly areas. But the hydrological modelling of spring flow domain in order to harness spring flow has started only two-three decade ago.

An unsteady one dimensional mathematical model of spring flow domain has been made by hydrologically decomposing the flow domain into two sub-domains: i) recharge zone, and ii) transition zone. With the help of the model, recharge to the spring flow domain and live storage in the spring and spring flow can be predicted for time variant recharge.

The model has been applied to Parda spring in Nainital for which several years of spring flow and rainfall data are available. This is the first attempt to apply a developed model on spring flow on a spring in India. Results obtained are reported in this report.

This report entitled: 'Hydrological Studies of Parda Spring in Nainital' is part of the work programme of Ground Water Assessment Division of the Institute. The study was carried out by Shri A K Bhar, Scientist 'E' under the guidance of Dr. G C Mishra, Scientist 'F'.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

The springflow models which are hitherto available are based on the assumption of lumped recharge in the recharge zone of a spring.But in reality recharge to a spring is variable with time. With the help of the existing models of the springflow, the prediction of volume of live reserve inside the spring is only possible for lumped recharge A mathematical model for analysing the unsteady flow from a spring has been developed accounting variable recharge. The springflow domain has been hydrologically decomposed into two domains,-i)recharge zone,and ii)transition zone.The spring's threshold point lies at the end of the transition zone.In the recharge zone,the flow has been assumed to be only in the vertical direction and in the transition zone the flow has been assumed to follow Dupuit-Forchheimer assumptions and the flow is in the horizontal direction. For solving the problem, the unsteady state has been assumed to be succession of steady states.

With the help of the present model, recharge to the spring flow domain, and live storage in the spring and springflow can be predicted for time variant recharge.

The model developed is applied to Parda spring, Nainital for which several years of springflow and rainfall data are available. These data have been used to calibrate and test the model.

HYDROLOGICAL STUDIES OF PARDA SPRING IN NAINITAL

1.0 INTRODUCTION

Springs are natural and important source of water for remote hilly terrain where other conventional water resources are difficult to develope. Spring could serve as a dependable source of drinking water and for other uses in hilly areas.

Springs are part of ground water resources of an area. A spring emerges at ground surface through a threshold point where the drawdown is constant till the spring is active. A few small springs emerging from an area indicate the presence of thin aquifer of poor transmissivity whereas frequent large springs in an area are indicator of thick transmissive aquifers.There are many configuration of the springs in nature depending on various combinations of geologic, hydrologic, hydraulic, pedologic and climatic controls.Size of the spring could vary from small trickle to large stream which can cater for the requirement of a large city.

There are many springs in the Himalayas,Western Ghats and other places in India.So far there is no systematic study of the springflow for developing these springs as dependable and sustainable source of water for rural population in remote hilly areas.

The work on the hydrologic modelling of spring is limited and the available models are based on assumptions of lumped recharge to the springflow domain. However, the recharge from precipitation to the flow domain of a spring is always time variant. But, the existing models can predict the live storage in the spring for lumped recharge .These limitations are taken care of in the present model .In the present study ,the unsteady flow from a spring has been analysed considering variable recharge .

The model has been applied to Parda spring, Nainital for which several years of springflow and rainfall data are available. These data are used to calibrate and test the model and recharge to spring and spring outflow are predicted

2.0 BRIEF DESCRIPTION OF THE MODEL USED

2.1 Review

A mathematical model for analysing the unsteady flow from a spring has been developed to take into account the variability in recharge(Fig.1).The springflow domain has been hydrologically decomposed into two domains;-(i)recharge zone and (ii)transition zone.The spring's threshold point lies at the end of the transition zone. In the recharge zone, the flow has been assumed to be in vertical direction and in the transition zone,the flow has been assumed to satisfy Dupuit-Forchhemier conditions. For solving the problem, the unsteady state has been assumed to be succession of steady state.An expression for spring discharge due to an instantaneous recharge in the recharge zone has been derived by Bhar(1989) and the expression is given by;

$$Q(t)=\frac{WTN}{L_1\phi}\left(e^{-WTt/AL_1\phi}\right) \qquad ...(1)$$

where

T = Transmissivity of the aquifer in the vicinity of the spring,
ϕ = Aquifer storativity,
L_1 = Length of the transition zone,
N = Instantaneous recharge quantity per unit area to aquifer,
A = Area of recharge zone,
W = Width of the spring's opening,and
t = Time since the instantaneous recharge commenced.

Eq(1) is similar to the equation $Q=Q_0e^{-t/t_0}$ which has been derived by Mandel and Shiftan (1981).A conceptual Unicell model has been used by Mandel and Shiftan to derive the equation.

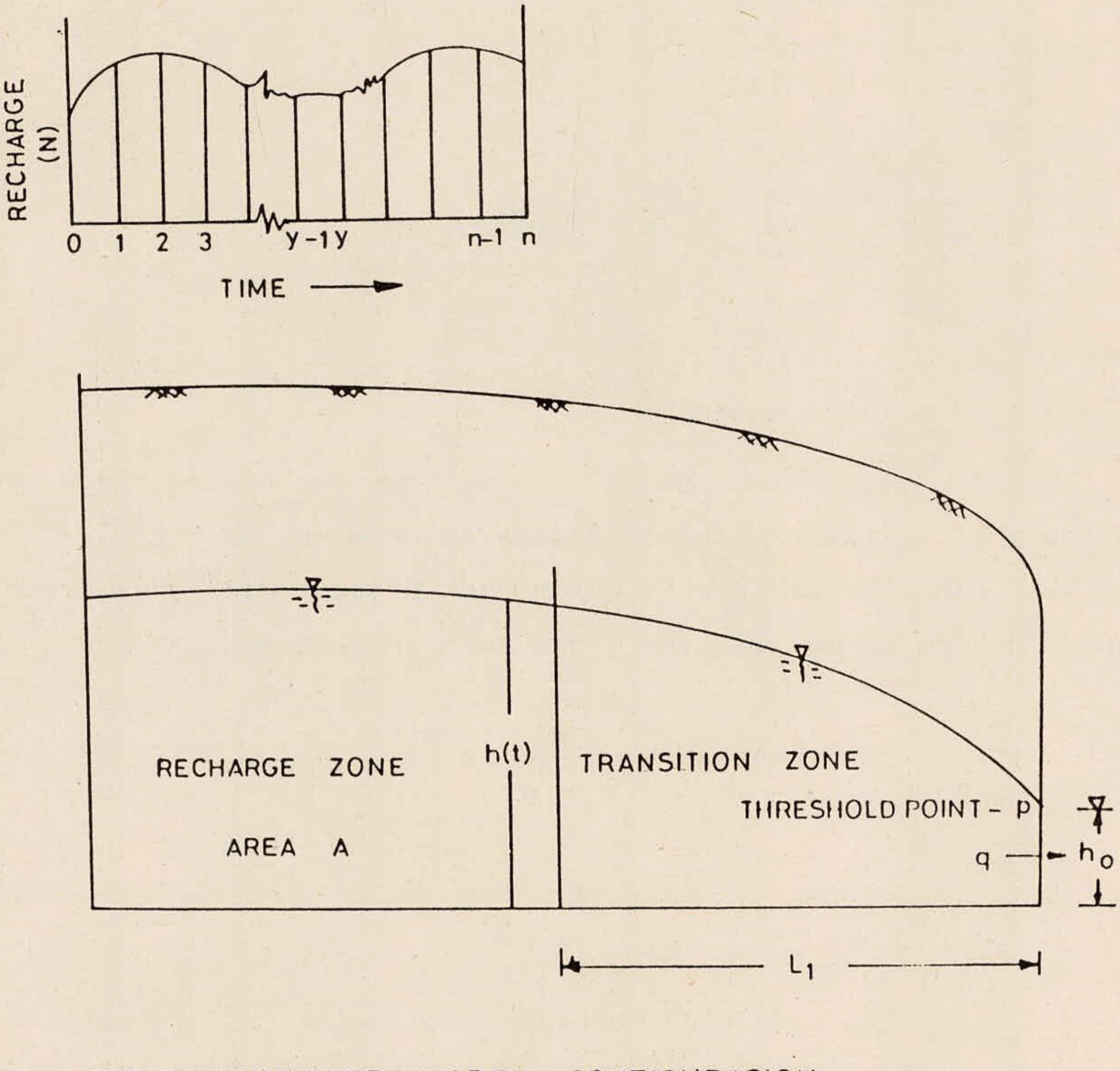

FIG. 1 - PROPOSED MODEL CONFIGURATION

2.2 Depletion time(t_o)

Comparing equation (1) to the pattern of $Q = Q_o e^{-t/t_o}$ of Unicell model of spring (Mandel and Shiftan, 1981) where t_o is the depletion time,

$$t_o = \frac{A\phi L_1}{W T} \qquad ...(2)$$

and

$$Q_o = Q(o) = \frac{WTN}{L_1\phi} = \frac{WATN}{AL_1\phi} = \frac{WRT}{AL_1\phi}$$

where

R = AN = Total recharge

The depletion time of a spring can be found from the semilog plot of the dry season discharge of a spring(Fig.2).

The volume of water, V(t), which is present in the dynamic storage of the spring at time t can be expressed as

$$V(t)=\int_t^{\alpha} Q(t)dt = \int_t^{\infty} \frac{WTN}{L_1\phi} e^{-WTt/AL_1\phi} dt$$

$$= W A N \left[e^{- WTt/AL_1\phi} \right]$$

$$= W R \left[e^{- WTt/AL_1\phi} \right].$$

Also the live storage of ground water at time, t, that maintains spring discharge, is equal to product of depletion time and outflow rate of the spring at that time. The live reserve at time, t, in the spring flow domain is, therefore, equal to $Q(t).t_0$.

Using eqs.(1) and (2), the following expression for live storage has been derived;

$$Q(t).t_o = \left[\frac{W TN}{L_1\phi} e^{- WTt/AL_1\phi}\right]\left[\frac{AL_1\phi}{W T}\right]$$

$$=A N e^{- WTt/AL_1\phi}$$

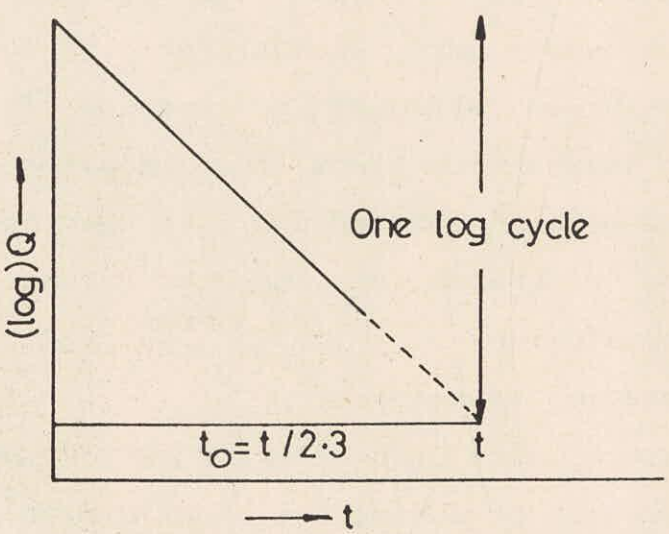

Fig. 2. DETERMINATION OF DEPLETION TIME (t_o)

Thus, the validity of the expression for the depletion time given in eq.(2) which incorporates the hydrogeological parameters and the geometry of the aquifer, is verified.

The variation of spring discharge with time can be plotted in a semilog paper (discharge being in log scale). The slope of such a plot will provide the depletion time, t_o. It is likely that the slope of the discharge time plot will vary. Any change in the slope of the line from year to year is indicative of interference in the groundwater system. A progressive flattening and steepening of the slope indicate the replenishment of the aquifer in the supposedly dry season(probably due to return flow of irrigation/urban effluent or seepage from reservoirs) and groundwater abstraction from the aquifer respectively. Occurrence of rare natural catastrophe like earthquake can have effect on spring discharge and on the slope of the time discharge line considerably.

2.3 Use of convolution technique

Generally, the recharge occurs over a period of time either during the rainy season or during the snow melt period. In such cases, the model should consider the time variant recharge rate. The conceptual model being linear, the response of the model to a time variant input can be obtained using convolution technique.

The response of a linear system which is initially at rest condition to a unit pulse excitation given to the system during the first unit time step has been designated as the discrete kernel coefficients, $\delta(.)$, (Morel Seytoux and Daly, 1975). In the present case, the unit recharge takes place during unit time period and the discharge of the spring at different time period are the discrete kernel coefficients for the spring. These coefficients are the properties of the spring and are independent of the excitation. Using these coefficients, the spring discharge for variable recharge can be found. The unit step may be one day, one week or one month.

Rewriting the eq.(1) in terms of total recharge, we have,

$$Q = \frac{WT}{AL_1}\left[\frac{R}{\phi}\, e^{-\frac{W\,Tt}{AL_1\phi}}\right] \qquad \ldots(3)$$

Now, let the response of the system to a unit impulse recharge be designated as k(t).

k(t) is given by

$$k(t) = \frac{W\,T}{AL_1\phi}\left[e^{-\frac{W\,Tt}{AL_1\phi}}\right] \qquad (4)$$

The discrete kernel coefficients, $\delta(n)$, is defined as

$$\delta(n)=\int_0^1 k(n-\tau)\,d\tau$$

For variable recharge, the spring outflow is given by

$$q(n) = \int_0^1 k(n-\tau)N(1)\,d\tau + \int_1^2 k(n-\tau)N(2)\,d\tau + \ldots + \int_{\upsilon-1}^{\upsilon} k(n-\tau)N(\upsilon)\,d\tau + \ldots$$

$$+ \int_{n-1}^{n} k(n-\tau)N(n)\,d\tau = \sum_{\upsilon=1}^{n} N(\upsilon) \int_{\upsilon-1}^{\upsilon} k(n-\tau)\,d\tau \qquad (5)$$

The integral in eq.(5) can be put in a more standard format by using the discrete kernel, $\delta(n)$. A change of variable of integration in eq.(5) is the discrete kernel (Morel Seytoux and Daly, 1975) with argument $(n-\upsilon+1)$ and eq.(5) takes the form

$$q(n) = \sum_{\upsilon=1}^{n} \delta(n-\upsilon+1)N(\upsilon) \quad (6)$$

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 the eq.(4) and is given by $\delta(n)$.

$$\delta(n) = \int_0^1 \frac{W\,T}{AL_1\phi} e^{-\frac{W\,T(n-\tau)}{AL_1\phi}} d\tau \quad \ldots(7)$$

After integrating and putting $t_o = \frac{AL_1\phi}{W\,T}$ 'We have

$$\delta(n) = e^{-n/t_o}(e^{1/t_o} - 1) \quad \ldots(8)$$

Thus using the discrete kernel approach, the outflow for the time variant recharge can be computed.

2.4 Inverse problem

The model could be used to solve the inverse problem also.If the outflow from the spring(including during the recharge period) are available,the model can estimate the time variant recharge to the ground water in the springflow domain.This is an important aspect of the model's capability.

The depletion time t_o could be estimated from the semilog plot of the available springflow data.From the estimate of t_o, $\delta(.)$ can be generated using eq.(8) for different time steps. The effect of previous recharge are taken out from the spring outflow and these modified outflows can be put in eq.(6) and the number of equations (depending on time steps)can be solved for $N(\tau)$. $N(\tau)$ is the recharge to ground water in each step.

2.5 General Remarks

The basic assumption of the model that the outflow from the spring is linearly varied with the storage inside the spring, is identical with Bear's assumption for his model (Bear,1979). But the improvement incorporated in the present model are:

1.The flow domain of the spring is hydrologically decomposed in the recharge zone and the transition zone.

2.The model has been made of one parameter,i.e., depletion time (t_0).

3.The model is capable of analysing the case for variable recharge in the recharge domain of the spring.The model can predict the outflow from spring both for wet and dry seasons.

3.0 PARDA SPRING

3.1 Description

Water emanating through cavities and channels in dolomite and limestones give rise to springs such as are seen in Nainital township. Parda spring is one of them and is classified as a karst spring. Sharma(1981) describes Parda spring as controlled by the Nainital fault,but the investigators from Kumaon University consider it as a karst spring (Valdiya and Bartarya,1988) because it is located in karst of dolomite,and is related to the underground channels and cavities.Nainital fault has played a major role in localization of the Parda spring and other springs in the region. But the solution channels and cavities have got opened due to faulting.

3.2 Data available

The monthly springflow data for the Parda spring for 1973-74,1977-78,1980-81,1982-83 to 1985-86 (for 7 years) and monthly rainfall data for two stations in the area viz,Nainital (for 13 years),Nainital observatory (for 10 years) along with some hydrometeorological data are available and is given in Appendix-I,IIA,IIB & III.

3.3 Determination of t_o

The monthly springflow data available are plotted in semilog graph paper (flow in log scale) yearwise and the recession portion of the plots which have been fitted into a straight line, were extended to meet the time axis and depletion time (t_o) for each year were determined (Fig.2). The value of t_o for the years 1982-83 to 1985-86 for which continuous springflow data were available are 5.6 month, 5.2 month, 3.9 month, 6.5 month. Average depletion time (t_o) is taken to be 5.3 months for the Parda spring (Fig.3).

3.4 Water balance of spring flow domain and estimation of recharge to aquifer

3.4.1 By spring water balance

Aquifer replenishment(AR) between the end of one dry season and the beginning of the next one can be estimated by the following equation with the aid of principle of continuity.

$$AR = Q_2 t_o - Q_1 t_o + \int_{t_1}^{t_2} Q \, dt \qquad \ldots(9)$$

where, AR is the aquifer replenishment in the springflow domain; t_1, t_2 are the instances of time at the end of one dry season and the beginning of the next one, and Q_1, Q_2 are the springflow at time t_1, t_2 respectively.

From the springflow data and with the estimated t_o, yearwise aquifer replenishment were calculated using equation (9) for the seven years. The calculated recharge to spring aquifer from rainfall is furnished in Table-1.

3.4.2 From springflow hydrogram

The aquifer recharge due to rainfall has also been estimated as the area bounded by spring flow hydrographs before and after the onset of rainfall for those years. The recession

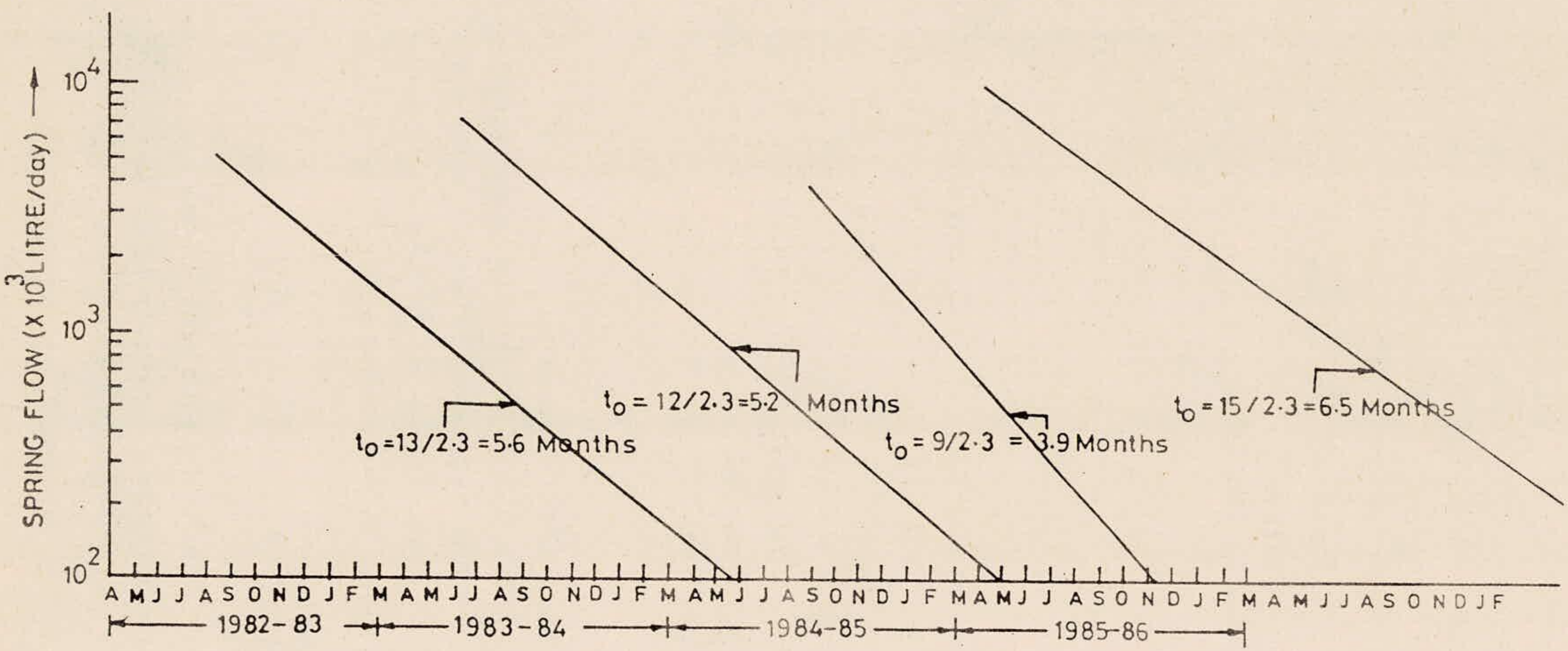

FIG. 3 - DETERMINATION OF DEPLETION TIME FOR PARDA SPRING

curve before and after the onset of rainfall have been extended with the aid of the equation $Q=Q_o\ e^{-t/t_o}$

The estimated values of aquifer recharge by planimetering the area between two hydrographs is given in Table 1. The estimated aquifer recharge by these two approaches tallies fairly well.

Table 1. Calculated recharge to spring aquifer from rainfall

Year	t_1	t_2	t_0 months	Rain-fall t_1 to t_2 (mm)	AR ($\times 10^5$ cu m) by water balance	by planimetering	by $\delta(.)$
1973-74	June'73	oct.'73	5.3	2264.5	6.37	7.68	-
1977-78	July'74	Sep.'74	8.7	1588.9	9.47	9.24	8.63
1980-81	May '80	Sep.'80	6.1	1180.3	9.16	9.00	9.80
1982-83	June'62	Oct.'82	5.6	1507.5	9.24	8.40	11.40
1983-84	June'83	Oct.'83	5.2	N.A.	8.66	7.80	-
1984-85	June'84	Oct.'84	3.9	1449.8	8.26	6.84	7.72
1985-86	June'85	Sep.'85	6.5	2370.9	9.72	10.44	9.94

3.4.3 By the use of discrete kernel

For the estimation of recharge to aquifer the equation (8) could be used to generate $\delta(.)$ (after estimating t_o) for each month for different years. These $\delta(.)$ could be used to estimate monthly recharges (during monsoon period) by using the equation,

$$\Sigma R_i \delta_j = q_i \qquad \ldots (10)$$

where,

R_i = Monthly recharges to be estimated, and

q_i = Springflow measurement available for the respective months minus the portion of springflow caused due to recharge in the preceeding year.

The equation (10) can be written as follows,

$$R_1 \delta_1 = q_1 \quad \ldots (10a)$$

$$R_1 \delta_2 + R_2 \delta_1 = q_2 \quad \ldots (10b)$$

$$R_1 \delta_3 + R_2 \delta_2 + R_3 \delta_1 = q_3 \quad \ldots (10c)$$

$$\ldots \quad \ldots \quad \ldots \quad \ldots$$

As δ_j and q_i are known, R_1, R_2, R_3...etc. could be found out. The sum of such monthly recharges, i.e., R_1, R_2, R_3... is the total recharge to aquifer for an year. Annual recharges to spring aquifer were estimated by generation of δ (.).The estimation is incorporated in Table-1 along with estimated recharge value from other two approaches.A perusal of these values indicate that these are reasonably agreeable.

3.4.4 Operation of the model with continuous springflow data

Out of the available monthly springflow data,the data from April,1982 to March,1986(4 years) are available without any break. This continuous data of springflow has been used to compute the monthly recharges of the corresponding months.As the rainfall usually starts in the month of June and from the perusal of springflow hydrograph, July seems to be the first month after the onset of monsoon to receive perceptible recharge in the aquifer in the vicinity of the spring. So, the springflow for June,1982 has been taken as the end of the recession curve and the conflex point from where the rising curve of the springflow hydrograph starts due to recharge. The recession curve has been extended through June 1982 following the decay curve equation $Q=Q_o e^{-t/t_o}$ and ordinate of the extended curve is taken to be as that portion of the present springflow due to recharge of earlier years. The values of the ordinate was taken out from the present springflow data to obtain the modified monthly springflow (q_m) data arising out of recharge of present year [Fig 4].This modified monthly discharge values are used for computing monthly recharge.

The equation 10(d) can be written in a generalised form

$$[A]\ [B] = [C] \quad \ldots (11)$$

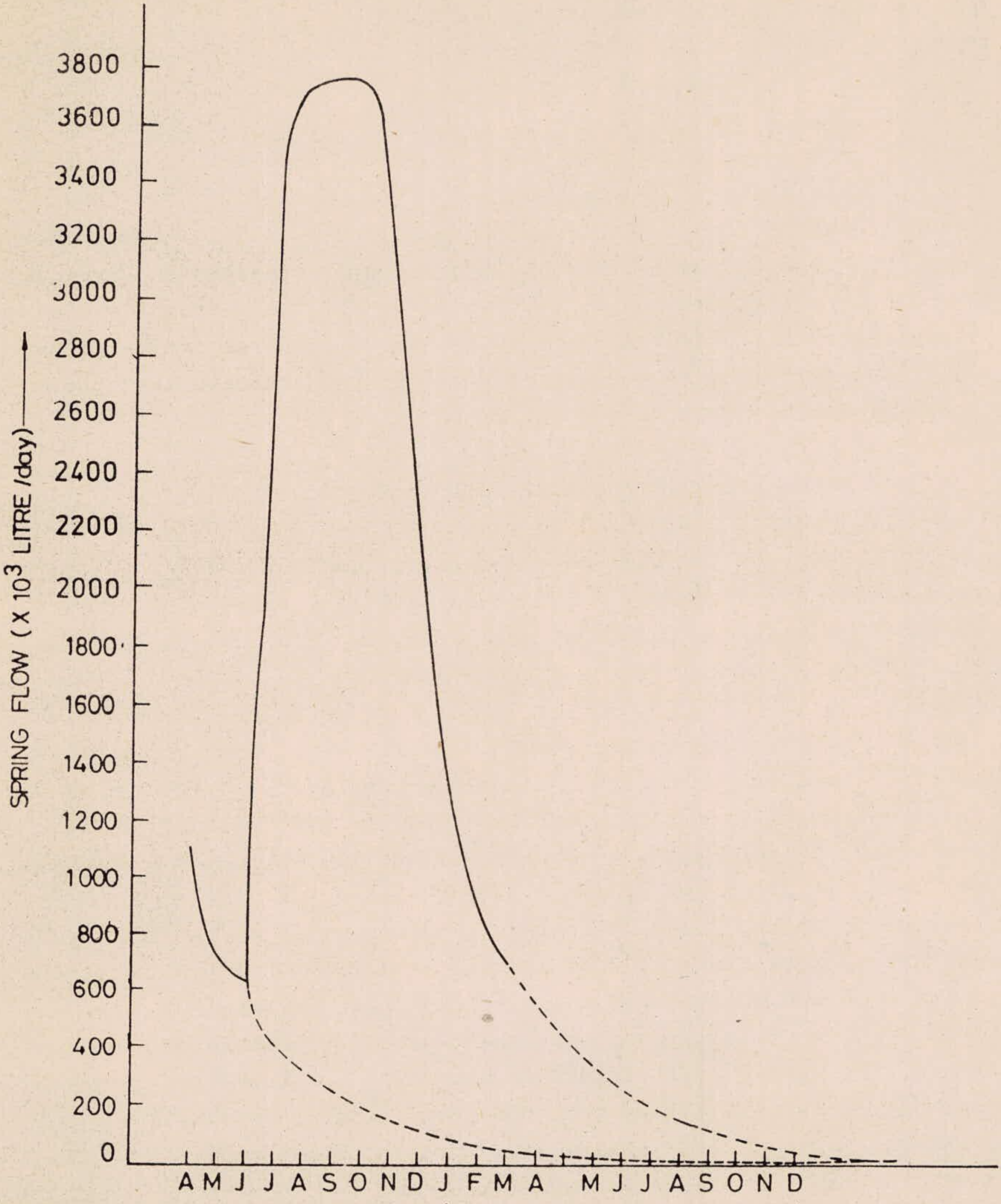

FIG. 4. SEPARATION OF EFFECT OF EARLIER RECHARGE

where,

[A] = Matrix of nxn dimension involving $\delta(.)$

[B] = Matrix of nxn dimension involving monthly recharges, R

[C] = Matrix of nx1 dimension involving monthly modified springflows, q_m

Therefore,

$$[B] = [A^{-1}]\ [C] \qquad (12)$$

So, with monthly springflow data and computed depletion time as inputs, computer program has been developed to generate $\delta(.)$, i.e., [A]. The inverse of the matrix, $[A^{-1}]$ when multiplied by matrix [C]involving modified monthly springflows provide the computed values of monthly recharge to the aquifer in the vicinity of the spring.

Once the monthly recharge is computed, the monthly storage in the spring could be computed easily with simple water balance method.

3.4.5 Generation of springflow data using the model

It was observed from the computed monthly rechrge values that some of the recharge values are abnormally high compared to the expected very negligible or near zero recharge after the cessation of monsoon around October. The modified spring flow values were generated setting the monthly recharge values (q_{mg}) as zero for dry months. A comparison of modified (q_m) monthly springflow values from field measurement and generated monthly modified springflow (q_{mg}) is made in Table 2 and is furnished as a plotting on graph paper in Fig.5.

4.0 RESULTS AND DISCUSSIONS

The modified field data and generated data of monthly springflow for Parda river matched well except for the early months in the year 1985 and 1986. A perusal of springflow data available and is given in Appendix-I reveals that springflow data is constant for April, May and June, 1985 indicating something wrong somewhere in the field data. Also, the monthly springflow data for September and October for 1982 to 1986 are same which also indicates towards the possibility of shortcomings in the

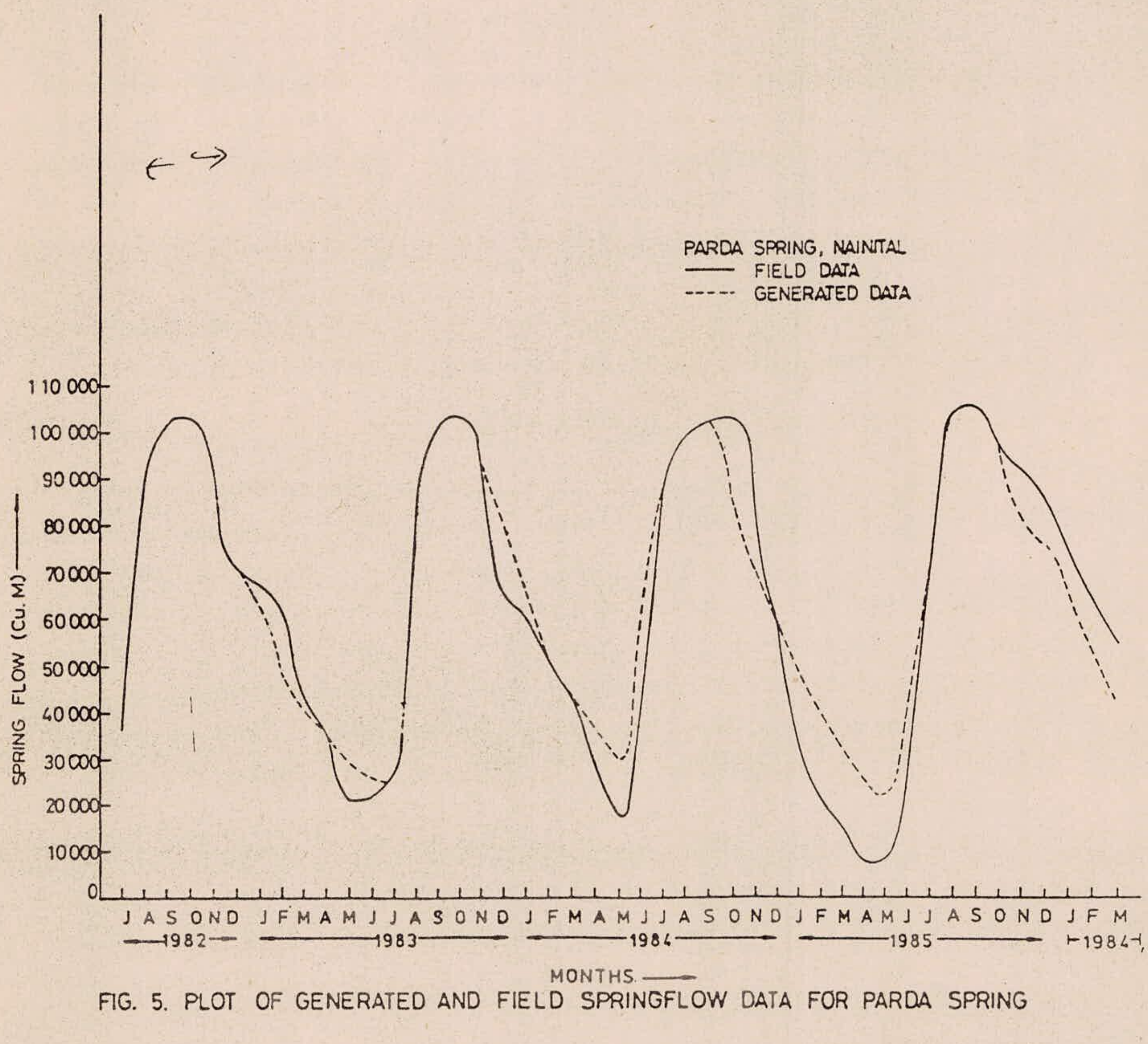

FIG. 5. PLOT OF GENERATED AND FIELD SPRINGFLOW DATA FOR PARDA SPRING

field data. Further effect of local snowmelt during the snow period may induce some recharge during non-monsoon period which will increase the springflow.

Considering all these aspects, it will be better to process the field data to get rid of their inconsistencies and shortcomings. The processed data i.e. the generated data should be used for predicting recharge to the springflow domain.

The monthly computed recharge to the Parda spring using the generated springflow data and using the model are given in Table 2.

Table 2. Comparison of modified springflow from field (q_m) and generated modified springflow data, Parda spring Nainital.

Month and year	Modified springflow in cu.m. from field data	Modified springflow in cu.m. Generated	Computed Recharge ($x10^6$ cu.m)
1982			
July	36244	36244	0.21
Aug	89354	89354	0.34
Sept	101948	101948	0.16
Oct	103831	103831	0.11
Nov	88437	88437	0.14
Dec	71422	73225	0.00
1983			
Jan	66695	60622	0.00
Feb	62444	50188	0.00
Mar	44259	41550	0.00
Apr	36757	34400	0.00
May	20799	30135	0.00
July	26520	26520	0.15
Aug	81793	81793	0.35
Sept	101180	101180	0.19
Oct.	103195	103195	0.11
Nov.	94543	94543	0.53
Dec.	65460	78284	0.00

1984			
Jan.	61198	64822	0.00
Feb.	52194	53674	0.00
Mar.	44012	44443	0.00
Apr.	29400	36762	0.00
May	18049	30408	0.00
July	86608	86608	0.50
Aug.	99674	99674	0.16
Sept.	101948	101948	0.11
Oct.	103831	84416	0.11
Nov.	82050	69900	0.00
Dec.	60490	57878	0.00
1985			
Jan.	34532	47925	0.00
Feb.	21903	39683	0.00
Mar.	17110	32858	0.00
Apr.	8870	27210	0.00
May	9372	22530	0.00
July	67875	67875	0.40
Aug.	104813	104813	0.28
Sept.	106203	106203	0.11
Oct.	97034	97034	0.05
Nov.	91355	80347	0.00
Dec.	85757	75644	0.00
1986			
Jan.	74492	62636	0.00
Feb.	64101	51864	0.00
Mar.	54699	42945	0.00

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Monthly average discharge(x 10^3 litre/day),Parda spring,Nainital

Months	Years						
	1973-74	1977-78	1980-81	1982-83	1983-84	1984-85	1985-86
April	1171.2	1199.8	1084.3	1084.3	1322.7	1084.3	393.1
May	874.5	1084.3	688.0	688.0	774.0	688.0	393.1
June	929.6	1084.3	1891.9	642.9	688.0	642.9	393.1
July	2985.3	1084.3	2985.3	1740.9	1453.7	3419.3	2588.0
Aug	2985.3	3419.3	2985.3	3419.3	3198.2	3763.3	3763.3
Sept	2985.3	3763.3	3763.3	3763.3	3763.3	3763.3	3763.3
Oct	2985.3	3419.3	3763.3	3763.3	3763.3	3763.3	3419.3
Nov	2785.1	2985.3	2985.3	3198.2	3419.3	2985.3	3198.2
Dec	2539.4	2785.1	2223.6	2588.0	2403.8	2223.6	2985.3
Jan	1891.9	2403.8	1740.4	2403.8	2223.6	1322.7	2588.0
Feb	1666.7	2223.6	1593.0	2223.6	1891.9	872.7	2223.6
Mar	1453.7	2055.7	1453.7	1593.0	1593.0	688.0	1891.9

(Source:Kumaon Jal Sansthan Vide Project Report on "Geohydrological Investigation of Gaula Catchment,District Nainital ,Kumaon University,1988)

APPENDIX-IIA

Rainfall data of Nainital

Months	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
	Years											
Jan.	29.5	0.0	0.0	22.8	67.6	0.0	57.6	0.0	0.0	7.6	11.6	160.0
Feb.	0.0	57.5	0.0	0.0	61.0	124.4	2.0	0.0	26.3	111.2	0.0	55.4
Mar.	57.0	14.5	0.0	39.1	50.0	18.5	0.0	0.0	0.0	128.4	97.8	0.0
Apr.	83.7	0.5	0.0	0.0	2.0	37.2	109.1	0.0	14.2	27.1	0.0	77.4
May	338.7	0.0	10.0	34.4	0.0	145.7	197.0	0.0	8.0	8.0	43.0	0.0
Jun.	503.3	156.4	704.2	168.1	0.0	138.9	224.9	0.0	0.0	0.0	279.5	144.9
Jul.	3409.1	499.0	0.0	0.0	0.0	649.1	625.2	0.0	0.0	805.9	617.8	505.4
Aug.	604.1	404.2	590.4	0.0	0.0	766.9	638.7	0.0	0.0	388.5	357.5	719.0
Sep.	366.2	557.5	345.9	0.0	0.0	110.3	325.0	0.0	64.8	407.2	416.8	117.0
Oct.	44.7	5.4	0.0	0.0	16.5	0.0	35.3	0.0	0.0	0.0	20.1	21.2
Nov.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dec.	0.0	0.0	0.0	0.0	0.0	0.0	34.2	0.0	21.1	15.7	12.7	21.2
Total	5436.3	1695.0	1650.5	264.4	197.1	1991.0	2249.0	0.0	134.6	1899.6	1856.8	1821.5

(Source:India Meteorological Department,Poona)

APPENDIX-IIB

Rainfall data of Nainital

(mm)

Months	Year 1983	1984	1985	1986
Jan.	NA	48.5	35.0	34.0
Feb.	NA	142.0	3.5	21.0
March	NA	12.0	0.6	38.0
April	NA	19.0	26.1	107.0
May	NA	3.5	125.5	217.8
June	NA	49.2	312.5	499.0
July	NA	625.3	554.5	715.0
Aug.	NA	178.8	1114.4	394.5
Sept.	629.0	596.5	389.5	162.5
Oct.	73.0	0.0	917.0	12.0
Nov.	0.0	0.0	0.0	0.0
Dec.	20.5	33.5	39.2	78.0
Total		1708.3	3517.8	2278.8

(Source: Project report on "Geohydrological Investigation of the Gaula Catchment, District Nainital, Kumaun University, 1988)

APPENDIX-III

Rainfall data of Nainital Observatory

Months	Year 1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
Jan.	39.0	26.0	72.0	19.2	160.6	2.2	47.3	0.0	88.3	25.0
Feb.	64.0	97.4	63.4	52.0	50.6	120.6	7.1	65.0	109.2	25.8
March	59.0	14.0	39.8	32.4	42.8	26.6	2.4	169.6	88.2	67.4
April	90.2	45.6	0.2	6.0	2.6	35.8	142.6	28.4	41.0	14.0
May	167.2	4.6	0.0	27.5	65.0	170.0	0.0	4.0	64.2	3.2
June	452.6	225.4	1026.4	247.6	453.8	219.8	0.0	312.8	196.5	224.8
July	656.5	1094.8	313.7	0.0	758.5	200.8	0.0	497.3	521.0	444.8
Aug.	659.2	402.0	441.8	0.0	336.0	784.8	626.0	565.1	219.4	247.8
Sept.	451.1	697.3	328.2	0.0	526.6	72.4	0.0	453.6	77.6	259.7
Oct.	270.7	0.0	154.4	0.0	54.9	3.0	32.0	13.2	29.0	0.0
Nov.	41.2	6.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	0.0
Dec.	0.0	2.0	2.0	0.0	0.0	5.6	57.2	0.0	36.0	0.0
Total	2950.7	2615.1	2441.9	384.7	2451.4	1641.6	914.6	2109.0	1495.4	1317.5

(Source: India Meteorological Department, Poona)