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Final Report

SOIL WATER MOVEMENT IN SEMI-ARID CLIMATE - AN ISOTOPIC INVESTIGATION

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1.0 Introduction

We have been studying the phenomenon of groundwater recharge in the Sabarmati Basin, Gujarat, for the last few years by means of radioisotopic and conventional methods (Datta et al 1979, a; 1980, b; Bhandari et al, 1982 and Gupta and Sharma, 1984). Our studies indicated that groundwater recharge in the semi-arid regions is a complex phenomenon, depending not only on the amount and intensity of rainfall but also on the climate and soil texture.

In this report we present results of tritium tagging experiments in the Thar Desert, Rajasthan (Fig. 1) and compare these with the results obtained at Ahmedabad (23.0°N, 72.6°E), a region of about three times higher rainfall than the Thar Desert but still on the fringe of the desert in the semi-arid region of NW India.

2.0 Project Area : Geology and Climate

Fig. 1 shows the locations of stations established for this study in the Thar Desert. The area not covered by dune sands represents the rocky desert with a thin (3-4 m) soil cover. The rock type in the region around Jodhpur are pre-Cambrian granites of the Aravalli system

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while those near Chandan and Jaisalmer are low grade metamorphic sedimentary rocks of "Lathi" formation.

The long term (1901-50) monsoon mean rainfall (June-September) in the Thar Desert is about 32.8 cm at Jodhpur and about 15.2 cm at Jaisalmer, the co-efficient of variation of rainfall being in the range of 55-70% in the region between Jodhpur and Jaisalmer (Gupta and Prakash, 1975). In comparison, the long term (1901-73) mean annual rainfall at Ahmedabad is 77.4 cm (UNDP, 1976) with a co-efficient of variation of about 40%.

Table 1 gives the average values (for the period 1960-69) of monthly mean temperature (Maximum and Minimum) precipitation and relative humidity (at 08.30 and 17.30 hr. local time) for the three locations, Jodhpur, Jaisalmer and Ahmedabad (data supplied by India Meteorological Department). Fig. 2(a), taken from UNDP (1976), gives the long term monthly estimate of potential evaporation at Jodhpur by Penman and Thorntwaite methods. The observed values by the Class-A Pan (wire mesh type) are also given. Fig. 2(b) taken from Gupta (1984), gives the same for Ahmedabad.

Experimental Details and Methodology

Nine experimental stations (RS 1-9) were established in the Thar Desert in September 1982, RS 1 to RS 5 at/around Jodhpur, RS 6 and RS 7 on the stabilized sand dune at Dhandhania, about 55 km NW of Jodhpur, RS 8 at Dhechu on a dune about 100 km NW of Jodhpur. The field station RS 9 was established at Chandan, about 40 km east of Jaisalmer (Fig.1).

The field details at the time of injection/s... ng at these field sites are given in Table 2. It may be notec... we could not sample two of the sites RS 7 and RS 8. The ... RS 7 is located about 100 m away from RS 6 at nearly the sa... elevation on the sand dune at Dhandhania. RS 8 is located at the base of the stabilized sand dune near village Dhechu. A hard clay/kankar bed was encountered at about 1 m at both these locations and the sampling had to be abandoned.

3.0 Experimental Details and Results

The details of the tritium tagging method for estimating the soil moisture movement are given in a recent paper by Gupta and Sharma (1984). Briefly, tritiated water (approx. 2 ml, activity 10 μCi/ml) was injected at a depth of 0.75 m below the ground surface, usually 3-4 sets at any given station. An auger was used for sampling the soil in steps of 10 cm.

The soil moisture was extracted by a batch distillation system under vacuum fabricated especially for this study. The moisture content was measured gravimetrically. After a site was sampled upto the desired depth, in situ soil density was measured by the sand logging method. For the study region, the in situ soil density varied from about 1.75 to 2.25 g cm^{-3}.

The net moisture transfer, M, has been obtained using

$$M = m . D . x \quad \ldots \quad (1)$$

where m = moisture content (g per g of the field soil)

D = in situ density of the field soil ($gm. cm^{-3}$)

x = observed displacement (in cm) of the tagged layer, given by the depth difference between the depth of injection (75 cm) and position of the Centre of gravity (C.G) of the tracer activity profile.

In actual practice, as there is variation of both 'm' and 'D' with depth, the computation of 'M' is done for each 10 cm depth interval for which both 'm' and 'D' are available.

Figs. 3-9 show the observed depth profiles of tritium activity as well as moisture content at seven of the isotopic investigation field station RS 1-5, RS 6 and RS 9 established in the Thar desert. It may be noted that the moisture content of the soil is low in these regions, about 2-6 % only as compared 5-15 % Ahmedabad (Fig. 10) and other stations in Gujarat (Bhandari et al, 1982).

From Table 2, it is seen that the three stations RS 1, RS 4 and RS 5 at the Central Arid Zone Research Institute (CAZRI) campus at Jodhpur show fractional recharge in the range of about 8-12 %. The two stations RS 4 and RS 5 which are about 50 m apart in the same field show close agreement in the fractional recharge values, being 7.6% 7.9 % respectively at these two stations.

The site RS 1 (barren plot) about 500 m away from the location of RS 4/5 in the CAZRI campus shows a higher recharge (11.7 %) as compared to nearby RS 4 and RS 5 locations (cultivated plots). The difference could be due to consumptive use of soil moisture by plants over and above the drip irrigation at RS 4.

For the station RS 2 at Subhavoton Ki Dhani on the outskirts (about 3 km) of Jodhpur the fractional recharge value of 10.1 % is of the same order as for the stations RS 1, 4 and 5 at CAZRI campus, Jodhpur. However, between RS 2 and RS 3, within about 100 m distance of each other the slightly higher recharge at RS 3 (12.0 %) could be due to absence of any vegetation and/or slight depression of the tritium injection site resulting in a ponding of water after a rainfall event, as was noticed during the sampling.

The station RS 6 at the stabilized sand dune at Dhandhania which has almost the same type of topsoil as at Jodhpur, has a prominently low recharge value (5.6 %). The exact rainfall data for this station is not available in the absence of a raingauge station in the vicinity. We have, therefore, used the rainfall data of Jodhpur. However, as can be seen from the contours of annual rainfall, as given in Gupta and Prakash (1975), the variation of rainfall between Jodhpur and Dhandhania is about 5 cm, which gives us confidence in using the rainfall data of Jodhpur for this site. Thus the low values of fractional recharge at RS 6 could be ascribed to the surface slope (about 5^{o}) resulting in higher run-off.

The station RS 9 at CAZRI campus at Chandan shows a higher recharge ($>$ 13.5 %). This site could not be sampled beyond 130 cm depth due to collapsing of the auger hole as a result of loose sand (low moisture content). However, a clear peak of tracer can be seen from Fig.9 and can be taken as the position of C.G. of the profile. In such a case in the absence of the complete tracer acticity profile, the fractional recharge estimated is the lower limit. The site has a thin layer of shifting loose sand with no vegetation cover and the observed high recharge value probably is due to high rate of infiltration through the sand.

Thus, the results of our experiments indicate significant recharge in the range 6–14 % of rainfall as against the average recharge of 14.5 % (range being from 5–35 %) in the alluvial parts of the Sabarmati basin, Gujarat (Gupta and Sharma, 1984). The control of various factors giving rise to the observed variability is also indicated.

4.0 Mechanism of Soil Water Movement

In the previous discussion, it has been implicitly assumed that the tracer is carried downward or upward in response to the soil moisture movement. With a view to document the tracer behaviour over a long period of time, a special study was undertaken at Ahmedabad.

A set of 8 tritium injections were made 1 m apart from each other in a non-irrigated agricultural field at Thaltej (23.0° N, 72.6° E) on the outskirts of Ahmedabad. Table 3 and Fig. 10 give details of the results of periodic sampling (one by one) of the 8 injection points during the two year period 6.8.1977 – 16.10.1979.

The case I (Fig. 10 and Table 3) giving the results of sampling of the first injection point on the same day of injection (6.8.1977) shows no displacement of the tracer peak and consequently no net moisture transfer, in the absence of any precipitation on that day. Case II, obtained by sampling the second injection point on 17.8.1977, eleven days after the injection, shows a downward displacement of 12 cm (Table 3) of the tracer in response to precipitation of 18.4 cm during the 11 day interval. The tracer peak for the case III on 9.9.1977 is found to be at 89 cm, i.e. a net downward displacement of 14 cm from the depth of injection in response to the total precipitation of 25.6 cm during the interval between injection and sampling. For the Cases IV and V, obtained on 10.12.1977 and 12.4.1978 respectively, there was negligible precipitation input (0.9 cm) from the date of Case III. The tracer peak for these samplings show upward displacement of 10 cm and 20 cm respectively, in response to progressive evapotranspiration. The net upward moisture transfer between the depth of injection and tracer activity peak, using equation (1), for the cases IV and V are found to be -2.0 and -3.7 cm respectively.

Case VI, corresponding to sampling on 25.10.1978, indicates the tracer peak at 96 cm depth, a displacement of 41 cm, from the previous position(on 12.4.1978), in response to 65.3 cm of rainfall during the interval 12.4.1978 to 25.10.1978.

For the Case VII, obtained on 13.6.1979, there is no shift in the position of the C.G. of the tracer profile which remains at the same position as for Case VI. However, there is a considerable depletion of soil moisture for the top 60 cm layer in response to evapotranspiration. For the Case VIII on 16.10.1979 there is a further downward displacement of 5 cm of the tracer in response to 53.5 cm of rainfall between these two samplings. A closer look at the moisture profiles for the two Cases VII and VIII shows that there is a considerable build up of the soil moisture at all the depths sampled and it appears that the displacement of the tracer occurs only after the soil moisture deficit is first satisfied. The net groundwater recharge for the two year period between Case I and Case VIII is 8.9 % of the total rainfall.

The above examples clearly illustrate that the soil moisture movement occurs in pulses after an infiltrating sheet of water after a rainfall event satisfies the soil moisture deficit. Based on the above understanding of the soil water movement, we have developed a simplified evapotranspiration-run-off model to estimate the fraction of annual precipitation that would be available for groundwater recharge after accounting for the run-off and evapotranspiration processes.

Several evapotranspiration formulae such as Penman's, the Thorntwaite method and others are available (see Grant, 1975). Often, they cannot be used for want of necessary soil and meteorological data. Even when the required data is available, evapotranspiration estimates using different formulae differ by as much as 50 to 100 % (Fig. 2,a and b). It was therefore felt that it is necessary to develop simple evapotranspiration models and calibrate these with measurable quantities such as pan evaporation data or groundwater recharge estimated using soil water tracing studies. One thing, however, is clear that temperature, relative humidity and the availability of soil moisture, have a first order effect on actual evapotranspiration.

It was observed that there exists an approximate similarity of distribution of average monthly evapotranspiration E (t), and saturation deficit, V (t), in the atmospheric moisture at two lysimeter stations, Sindorf and Libergerhof in West Germany (Esser,1980). We can therefore assume (Thoma et al, 1979), that

$$E(t) \propto V(t) \text{ or } E(t) = K.\ V(t) \qquad .. \quad (2)$$

with

$$V = P_s(T).\ (1-h) \qquad .. \quad (3)$$

where $P_s(T)$ is the saturation vapour pressure of atmospheric moisture at average temperature (T) of the appropriate month, and h is the average relative humidity (fractional) of the appropriate month. The proportionality constant, K, called evapotranspiration constant (mm. $month^{-1}$, $torr^{-1}$) is determined by the condition that long term integration of equation (2) is equal to long term total potential evapotranspiration. Actual evapotranspiration equals potential evapotranspiration if precipitation in a given month exceeds sum of potential evapotranspiration and soil moisture deficit of previous month, if any.

Under European conditions, where precipitation (either rain or snowfall) occurs almost round the year and temperatures are low, the actual evapotranspiration can approximately be taken the same as potential evapotranspiration given by equation (2). However, under Indian conditions there is a large discrepancy in the values of actual and potential evapotranspiration (except for the 2-3 months of rainy season), the actual evapotranspiration being much less than potential evaporation as there is simply no water available for evaporation. Therefore, if the precipitation is not sufficient to satisfy the soil moisture deficit or there is continued aridity, actual evapotranspiration is estimated by an exponential relation between aridity and soil moisture deficit such as Thorntwaite graph (Fig. 11, taken from Szalay, 1972). In using the Thorntwaite graph, the difference (P (t) - E (t)) is computed for all the months. It is followed by the computation of summation of the successive negative values. From the successive negative totals $\sum (P(t) - E(t))$; the value of change in the moisture capacity/water holding capacity of the soil is computed for an assumed total water holding capacity of the soil (100 to 500 mm ; average 300 mm). Actual evapotranspiration for the month with aridity is then given by the change in soil moisture capacity. Further if the precipitation excess after fulfilling the requirement of soil moisture storage and potential evapotranspiration during the month is higher than 50 mm (this number can be estimated from rainfall run-off relation for a given catchment area and depends essentially on the slope of the terrain and is smaller for sharply undulating terrain), the excess is lost as run-off. Precipitation excess upto 50 mm for any month results in groundwater recharge according to the mechanism discussed subsequently.

Unfortunately because of the non-availability of temperature and relative humidity data for the study area, have not been able to apply this model for simulation of the present results. However, the groundwater recharge estimated at two stations, Ahmedabad and Idar (23.9° N, 73.0° E) using the above model are shown in Table 4. These compare reasonably well with the data of tritium tagging studies in the Sabarmati basin (Gupta and Sharma, 1984). Datta et al (1979, b; 1980, b;), Thoma et al (1979) and Gupta (1983) have described a conceptual model involving a pulsed movement through a series of hypothetical boxes (mixing cells) sub-dividing the soil column for describing the movement of tracer through the unsaturated zone.

Briefly in the model the soil is assumed to be made up of a series of inter-connected expandable boxes with its moisture content at field capacity. The average field capacity of the entire soil column is assumed to be equal to the observed average moisture content of the soil profile. A fraction of monthly precipitation (total precipitation less estimated evapotranspiration and run-off) with its tracer content is then allowed to pass through the inter-connected series of boxes is small pulses of equal size. It can be easily shown that the process of mixing of an advancing recharge pulse in successive boxes of equal size, H, mathematically simulates the dispersion process according to the relation $D = H^2F/t$ where H is the size of each box, F the fraction representing the size of the recharge pulse in terms of the box size and t the time step of iteration, i.e. the interval at which successive recharge pulses are added to the system. A recharge pulse during transit through the boxes undergoes a change in its tracer concentration by mixing with the fluid in each box and leaving the trailing box at its assumed field capacity. The size of the advancing recharge pulse may be reduced or it may completely exhaust itself before reaching the water table depending on the moisture content of the soil column at the end of the previous evapotranspiration cycle.

The above two models in combination represent our basic understanding of the evapotranspiration, run-off and soil moisture movement processes in the arid regionds of Thar desert. Our studies also indicate that even in a very low rainfall region the groundwater recharge can be quite substantial, amounting to about 7-15 %.

FIGURE CAPTIONS

Fig.1	Schematic map of Thar desert, western Rajasthan showing the isotopic investigation sites.
Fig.2 (a)	Monthly mean long term average pan evaporation and potential evaporation data at Jodhpur (after UNDP, 1976).
Fig. 2 (b)	Same as that in Fig. 2(a) at Ahmedabad (after Gupta, 1984).
Fig. 3	Tracer activity profile and the soil moisture content for the station RS 1 at CAZRI Campus, Jodhpur.
Fig. 4	Same as in Fig. 3 for the station RS 2 at Village Subhavaton Ki Dhani on the outskirts of Jodhpur.
Fig. 5	Same as in Fig. 3 for the station RS 3 at village Subhavaton Ki Dhani on the outskirts of Jodhpur.
Fig. 6	Same as in Fig. 3 for the station RS 4 at the CAZRI Campus, Jodhpur.
Fig. 7	Same as in Fig.3 for the station RS 5 at the CAZRI Campus, Jodhpur.
Fig. 8	Same as in Fig. 3 for the station RS 6 at the stabilized sand dune near village Dhandhania.
Fig. 9	Same as in Fig. 3 for the station RS 9 at CAZRI Campus, at Chandan.

Fig. 10 Tracer activity and the moisture content profiles obtained by successive sampling (I to VIII) of the 8 injection points at Thaltej (Station Code 37), near Ahmedabad during the period 1977-1979 (after Bhandari et al, 1982).

Fig. 11 Thorntwaite graph for estimating the effect of aridity on soil moisture depletion (after Szlay, 1972).

LIST OF TABLES

Table 1a: Average values (for the period 1960-69) of monthly mean temperature (°C) at Jodhpur, Jaisalmer and Ahmedabad

		Jodhpur Max./Min. (°C)		Jaisalmer Max./Min. (°C)		Ahmedabad Max./Min. (°C)	
January	..	25.32	9.01	24.18	7.01	28.55	11.68
February	..	29.04	12.3	28.21	10.31	31.98	14.12
March	..	33.91	17.70	33.15	15.52	35.90	18.68
April	..	38.26	22.58	37.17	20.19	39.58	23.06
May	..	41.63	26.47	41.63	24.3	41.80	26.01
June	..	40.2	27.94	40.62	25.03	38.80	26.97
July	..	36.82	26.97	38.40	25.46	33.58	25.82
August	..	34.43	25.56	36.43	22.44	32.02	24.87
September	..	35.70	24.36	36.75	23.91	33.64	24.15
October	..	36.85	20.18	36.44	20.0	36.44	20.49
November	..	31.88	15.35	30.95	13.11	33.75	16.83
December	..	26.91	11.01	25.10	8.53	30.00	13.48

Table 1b: Average values (for the period 1960-61) of monthly mean precipitation (mm) at Jodhpur, Jaisalmer and Ahmedabad

		Jodhpur (mm)	Jaisalmer (mm)	Ahmedabad (mm)
January	..	0.73	0.89	2.63
February	..	2.94	2.90	0.15
March	..	14.7	5.62	2.70
April	..	0.86	3.46	1.68
May	..	6.92	4.35	2.86
June	..	21.94	20.75	74.81
July	..	114.55	52.02	276.50
August	..	94.80	26.22	139.04
September	..	50.95	12.59	142.09
October	..	2.83	0.0	2.26
November	..	0.58	0.09	6.46
December	..	0.96	2.74	1.99

Table 1c: Average values (for the period 1960-69) of monthly mean relative humidity (%) at Jodhpur, Jaisalmer and Ahmedabad

	Jodhpur		Jaisalmer		Ahmedabad	
	8.30	17.30	8.30	17.30	8.30	17.30
January ..	49.1	24.1	55.8	35.0	52.4	25.4
February ..	41.9	22.6	50.5	30.2	46.3	18.6
March ..	35.3	15.2	43.9	25.7	45.3	16.5
April ..	33.4	15.4	47.2	27.6	55.7	15.7
May ..	40.2	16.5	53.4	23.6	57.3	18.6
June ..	61.6	29.5	61.6	28.8	72.2	41.1
July ..	73.6	52.8	65.1	40.8	84.3	64.7
August ..	79.5	56.3	71.9	49.6	86.6	68.1
September ..	72.3	45.6	64.0	45.3	81.0	55.7
October ..	45.2	22.2	53.8	36.8	59.4	31.5
November ..	42.7	24.8	50.8	35.7	49.1	30.0
December ..	49.2	30.6	56.5	36.3	53.3	30.2

Table 2: Details of field site and tritium tagging experiment conducted at the isotopic investigation stations established in the Thar Desert, Rajasthan

Station Code	Station Name	Details of the location	Soil type (median grain size of top 0.5m layer, u m)	Date of Injection	Date of Sampling	Net moisture transfer (cm)	Water input** (cm)	Fractional recharge (%)
RS-1	Jodhpur	CAZRI* campus. Barren land, sparsely planted desert plants exist at the site. RS-1 is about 500 m away from the location of RS-4/5	(150 µm)	7.9.82	24.7.83	2.57	21.88	11.7
RS-2	Subhavaton ki Dhani	Pasture land in the Doki-Pal basin on the outskirts of Jodhpur. Seasonal grass cover 0.5 m in height at the time of injection	(190 µm)	7.9.82	25.7.83	2.21	21.88	10.1
RS-3	Subhavaton ki Dhani	Same as RS-2 on a barren part of the land located in a slight depression, about 100 m from RS-2	(210 µm)	7.9.82	2.8.83	4.68	38.91	12.0
RS-4	Jodhpur	Experimental field of CAZRI in the CAZRI campus, Cowpeas crop under drip irrigation (no return seepage of irrigation water with this type of irrigation)	(185 µm)	7.9.82	24.7.83	1.66	21.88	7.6
RS-5	Jodhpur	Experimental field of CAZRI in the CAZRI campus, rainfed Guvar (a kind of beans) raised in the field RS-5 is about 50 m away from RS-5 in the same field.	(210 µm)	7.9.82	24.7.83	1.74	21.88	7.9
RS-6	Dhandhania	Stabilized sand dune near village Dhandhania 55 km from Jodhpur on Jodhpur-Jaisalmer State Highway, sparse shrub cover over the dune station is on the wind-ward side of the dune at a surface slope of about 5°.	(225 µm)	8.9.82	31.7.83	2.18	38.91	5.6
RS-9	Chandan	CAZRI Campus at Chandan, about 40 km from Jaisalmer on Jodhpur-Jaisalmer State Highway. Stabilized sand dune with a thin cover of shifting sands	(225 µm)	9.9.82	30.7.83	2.23	16.49	13.5

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**Water input being only the precipitation between the dates of injection and sampling; irrigation input being zero at all the sites.

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**Water input being only the precipitation between the dates of injection and sampling; irrigation input being zero at all the sites.

Table 3. Results of multiple sets of injection at Thaltej, Station Code-37 (Injection depth = 75 cm)

Inj. No.	Date of Injection	Date of Sampling	Displacement of tracer peak (cm)	Water input (Precipitation) (cm)	Net downward moisture transfer (cm)	Fractional Recharge (%)
1.	6.8.77	6.8.77	0.0	0.0	0.0	0.0
2.	6.8.77	17.8.77	+12.0	18.4	2.85	15.5
3.	6.8.77	9.9.77	+14.0	25.6	3.40	13.3
4.	6.8.77	10.12.77	-10.0	26.5	-2.0	-
5.	6.8.77	12.4.78	-20.0	26.5	-3.7	-
6.	6.8.77	25.10.78	+21.0	91.8	7.23	11.1
7.	6.8.77	13.6.79	+21.0	96.6	6.31	9.0
8.	6.8.77	16.10.79	+26.0	150.1	10.97	8.9

Table 4: Estimates of groundwater recharge using evapotranspiration-runoff model and tritium tagging method at Ahmedabad and Idar, in Gujarat

Year	Precipitation (mm)	Recharge based on soil moisture storage capacity				Recharge based on tritium tagging experiment % rainfall
		300 mm		200 mm		
		(mm)	% Rainfall	(mm)	% Rainfall	
Station: Ahmedabad						
1976	1026	90.1	8.8	110.3	10.8	
1977	1252	100.3	8.0	122.8	9.8	Average of 1977-79
1978	700	69.4	9.9	95.8	13.7	
1979	600	63.6	10.6	79.3	13.7	
Mean	894	80.9	9.0	102.1	11.4	8.9
Station: Idar						
1971	552	75	13.6	103	18.7	
1972	349	13	4.0	65	18.6	
1973	1377	155	11.3	163	11.8	
1974	321	9	2.8	57	17.8	
1975	1252	145	11.6	152	12.1	
1976	1098	133	12.1	169	15.4	
1977	1196	195	11.3	173	14.5	
1978	855	111	13.0	144	16.8	
1979	510	64	12.5	111	21.8	Average of 1978-79
1980	785	102	13.0	144	16.3	
1981	739	93	12.6	120	16.2	
Mean	821	94	11.5	126	15.3	11.9

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rain or snowfall) occurs almost round the year and ... are low, the actual evapotranspiration can approximately be

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in terms of the box size and t the time step of iteration,

Thoma, G. Esser, N., Sonntag, C., Weiss, W., Rudolph, J., and Levene, P., (1979). New technique of in situ soil moisture sampling for environmental isotope analysis : applied at Pilat sand dune near Bordeaux, in Isotope Hydrology, 1978, Vol. II, IAEA, Vienna, pp. 753-768.

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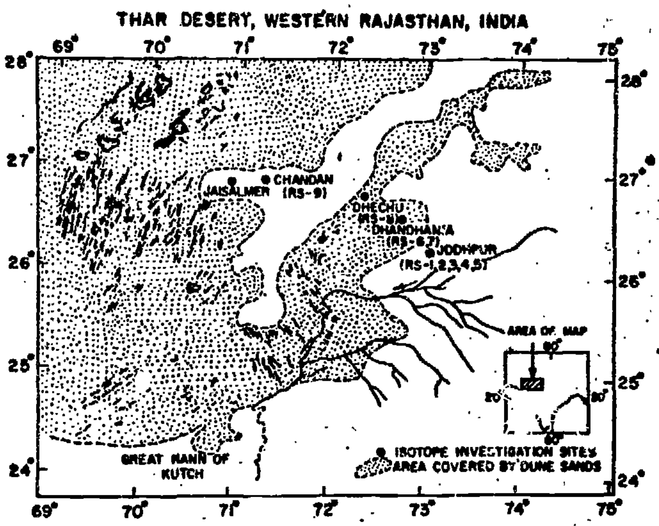

THAR DESERT, WESTERN RAJASTHAN, INDIA
69°
70°
71°
72°
73°
74°
75°
28°
27°
26°
25°
24°
CHANDAN
JAISALMER (RS-9)
DHECHU
DHANDHANIA
(RS-6,7)
JODHPUR
(RS-1,2,3,4,5)
AREA OF MAP
GREAT RANN OF
KUTCH
ISOTOPE INVESTIGATION SITES
AREA COVERED BY DUNE SANDS

Fig. 1

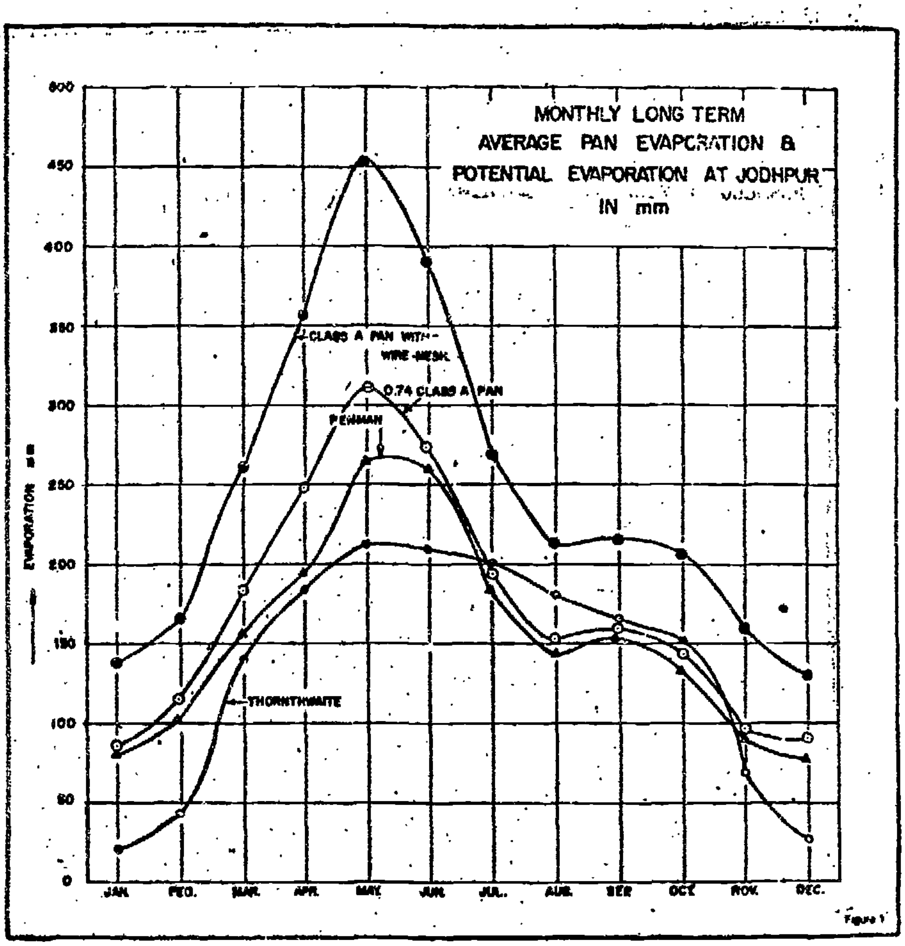

MONTHLY LONG TERM
AVERAGE PAN EVAPORATION &
POTENTIAL EVAPORATION AT JODHPUR
IN mm
CLASS A PAN WITH WIRE MESH
0.74 CLASS A PAN
PENMAN
THORNTHWAITE
EVAPORATION mm
500
450
400
350
300
250
200
150
100
50
0
JAN.
FEB.
MAR.
APR.
MAY
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.

Fig. 2 (a)

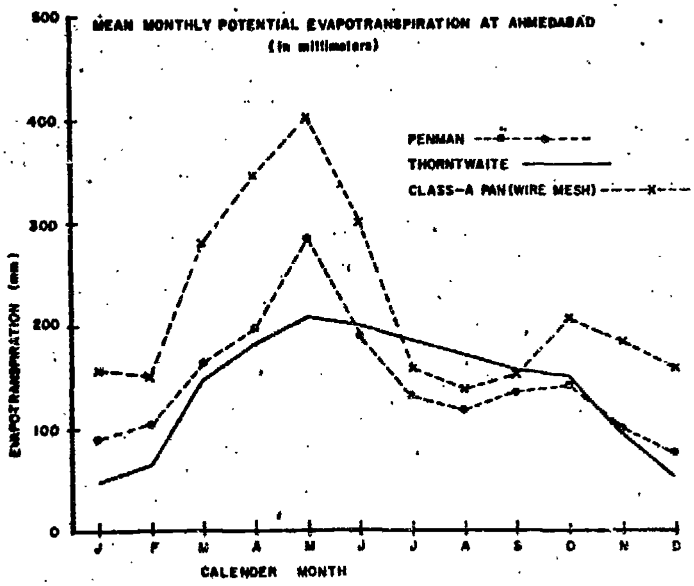

MEAN MONTHLY POTENTIAL EVAPOTRANSPIRATION AT AHMEDABAD
(in millimeters)
PENMAN
THORNTWAITE
CLASS-A PAN (WIRE MESH)
EVAPOTRANSPIRATION (mm)
500
400
300
200
100
0
J
F
M
A
M
J
J
A
S
O
N
D
CALENDER MONTH

Fig. 2 (b)

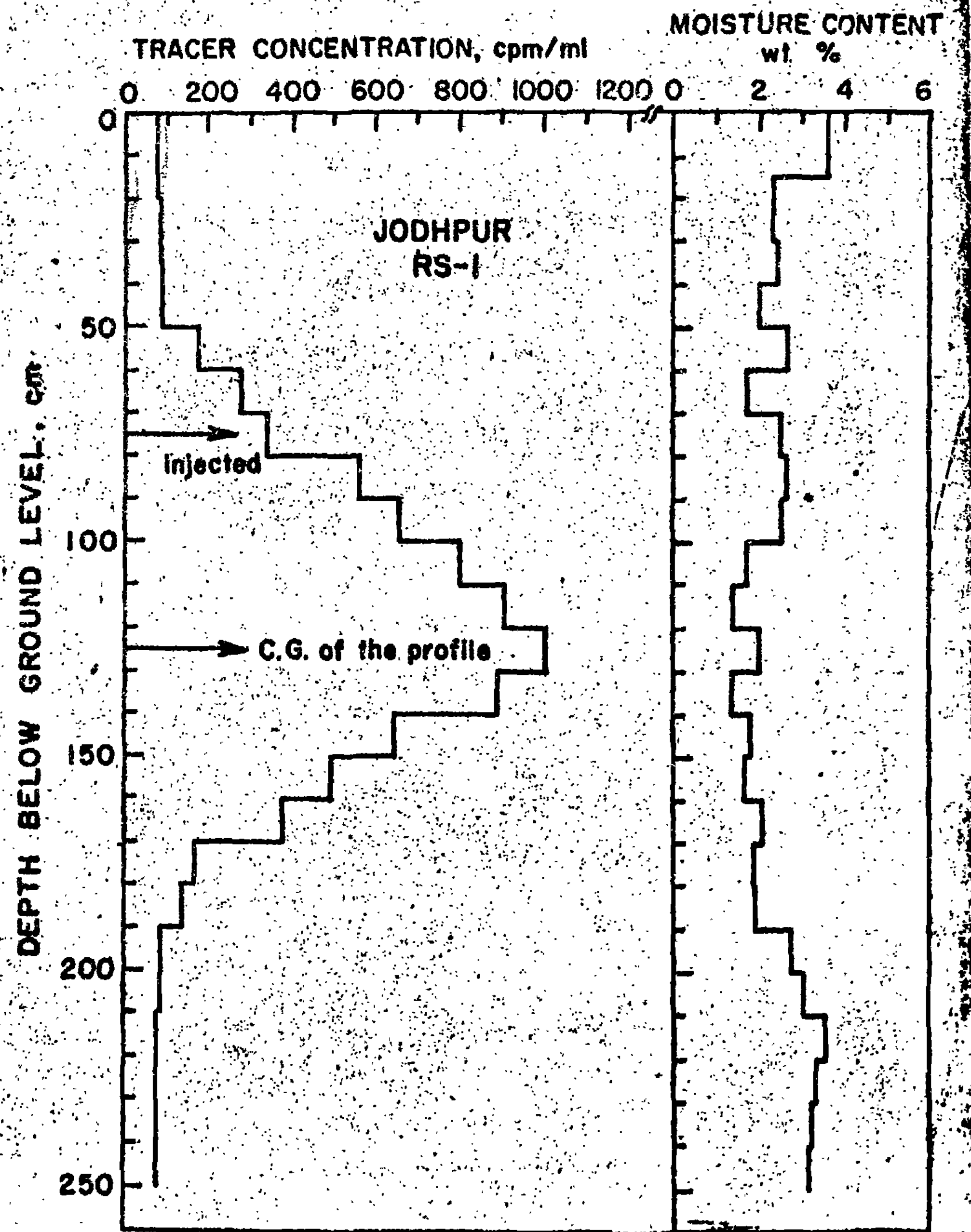

TRACER CONCENTRATION, cpm/ml
0
200
400
600
800
1000
1200
MOISTURE CONTENT
wt %
0
2
4
6
JODHPUR
RS-I
Injected
C.G. of the profile
DEPTH BELOW GROUND LEVEL, cm
0
50
100
150
200
250

Fig. 3

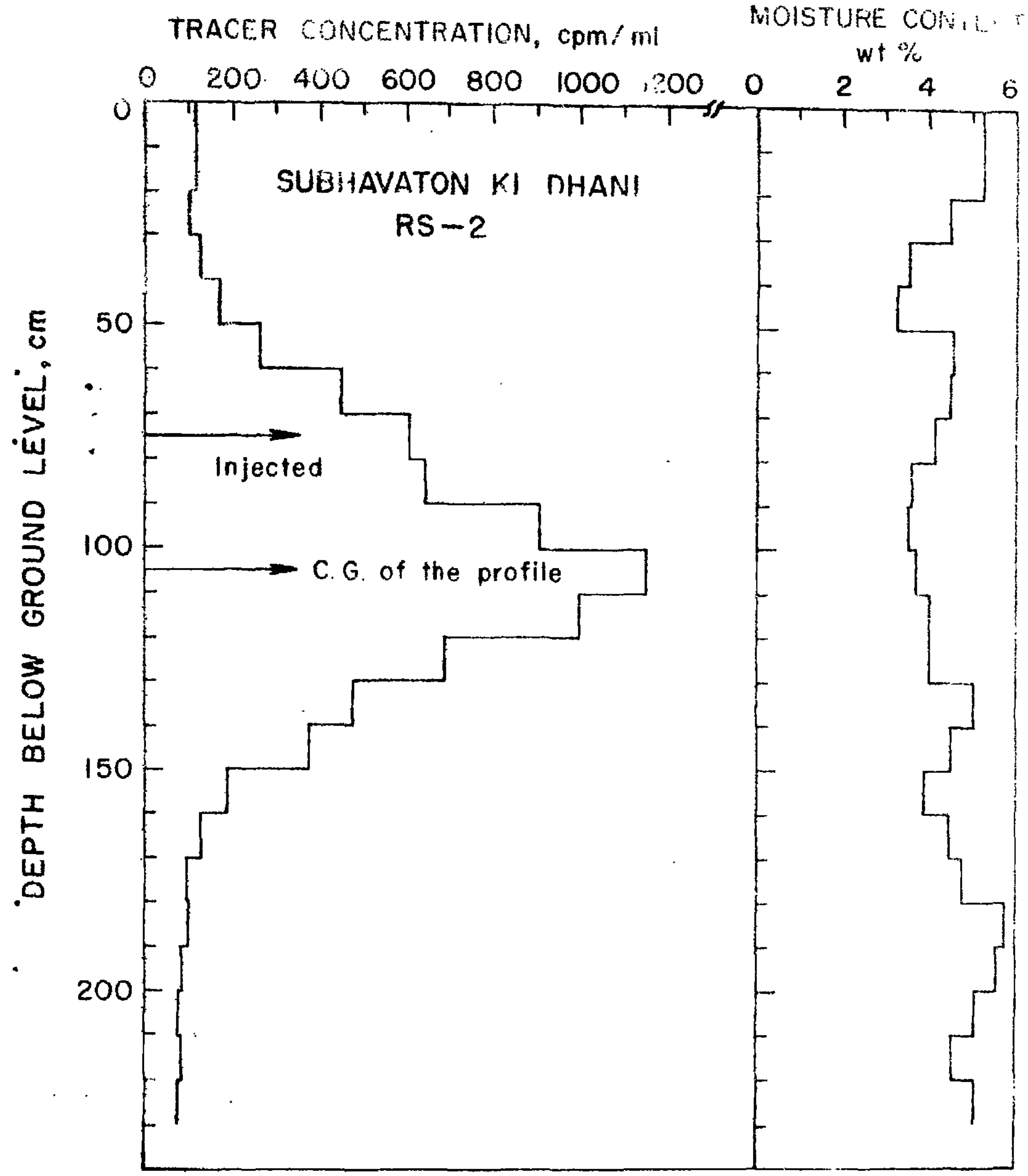
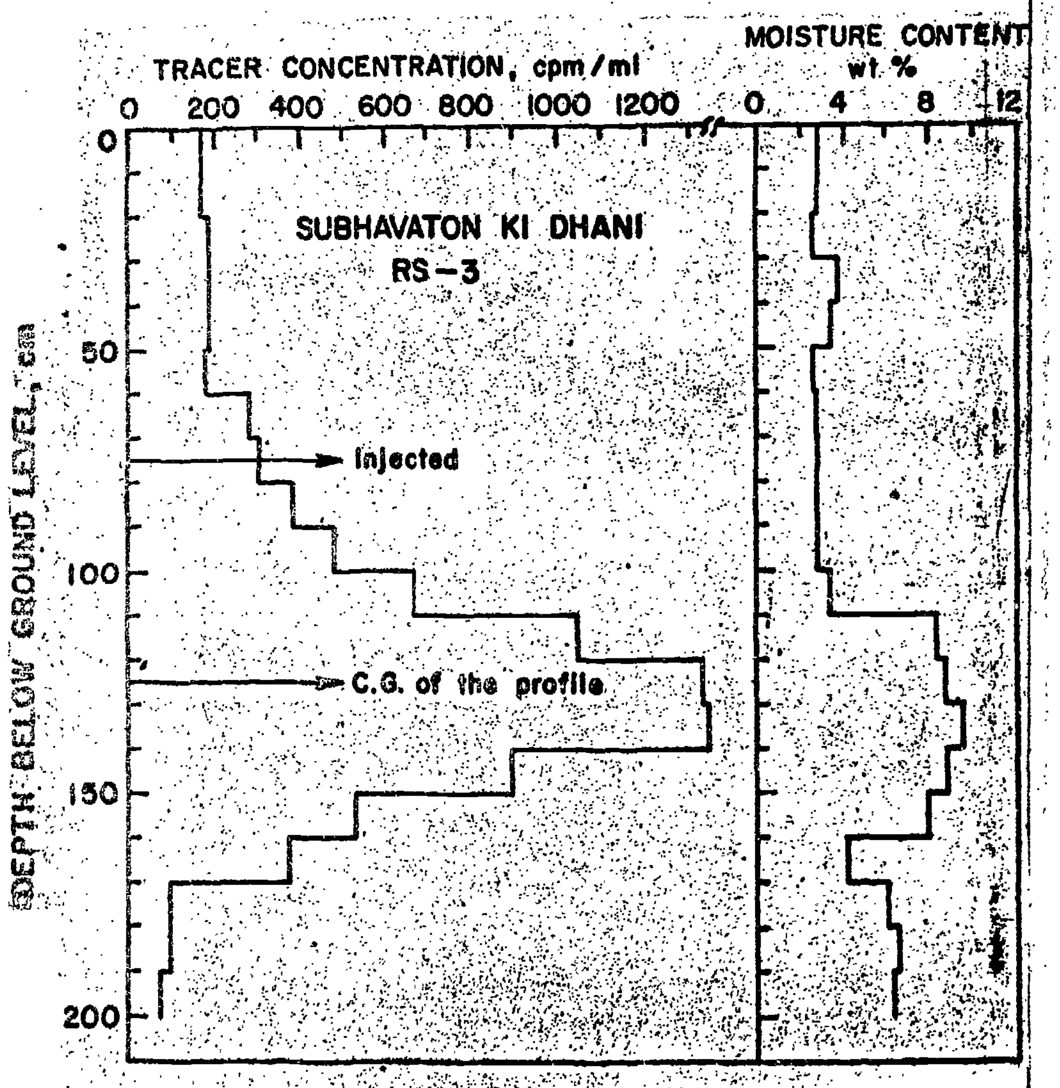

TRACER CONCENTRATION, cpm/ml
0
200
400
600
800
1000
1200
MOISTURE CONTENT
wt %
0
2
4
6
DEPTH BELOW GROUND LEVEL, cm
0
50
100
150
200
SUBHAVATON KI DHANI
RS-2
Injected
C.G. of the profile

Fig. 4



TRACER CONCENTRATION, cpm / ml
0 200 400 600 800 1000 1200
MOISTURE CONTENT
wt %
0 4 8 12
SUBHAVATON KI DHANI
RS-3
Injected
C.G. of the profile
DEPTH BELOW GROUND LEVEL, cm
0
50
100
150
200

Fig. 5

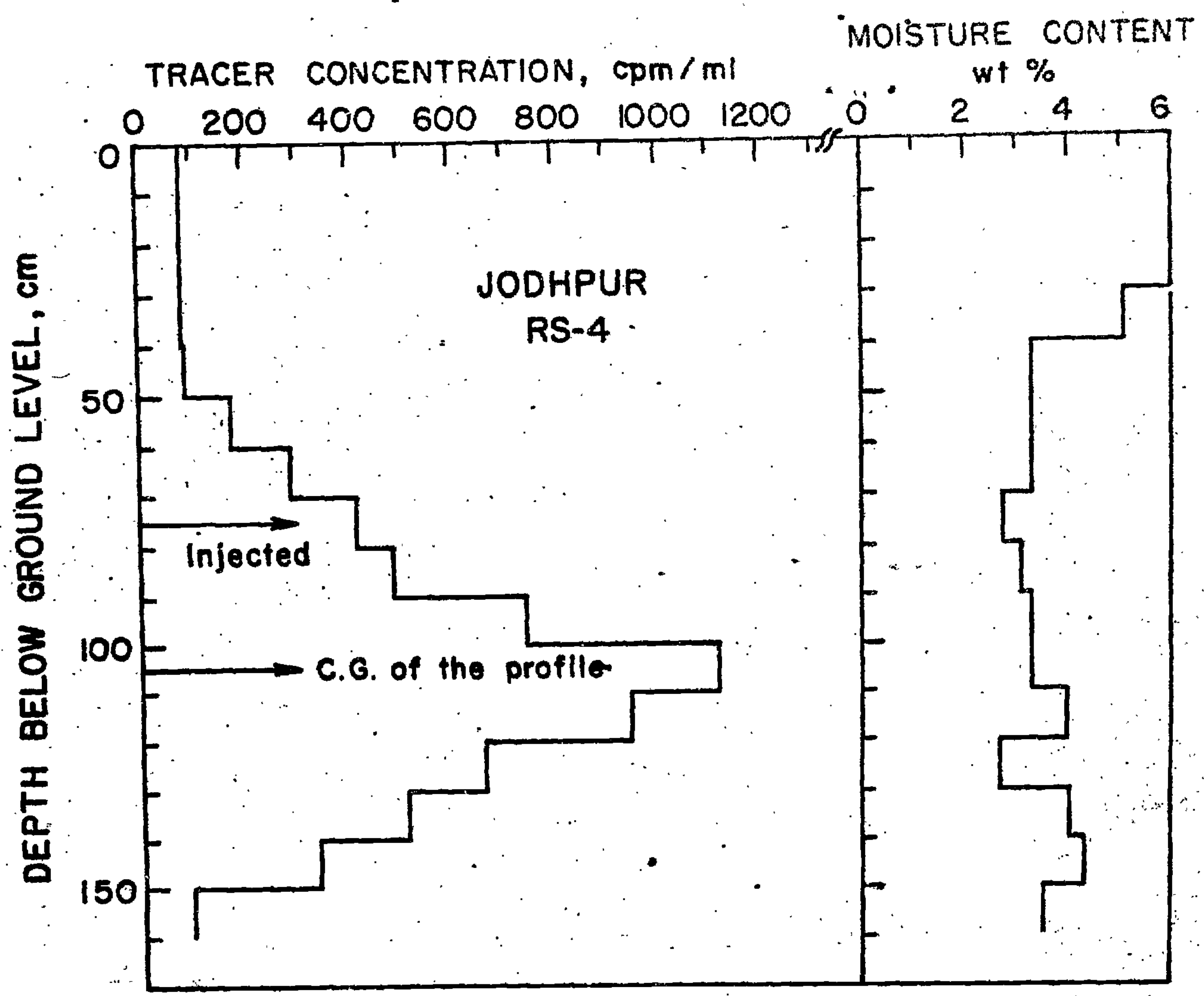

TRACER CONCENTRATION, cpm/ml
0 200 400 600 800 1000 1200
MOISTURE CONTENT
wt %
0 2 4 6
DEPTH BELOW GROUND LEVEL, cm
0
50
100
150
JODHPUR
RS-4
Injected
C.G. of the profile

Fig. 6

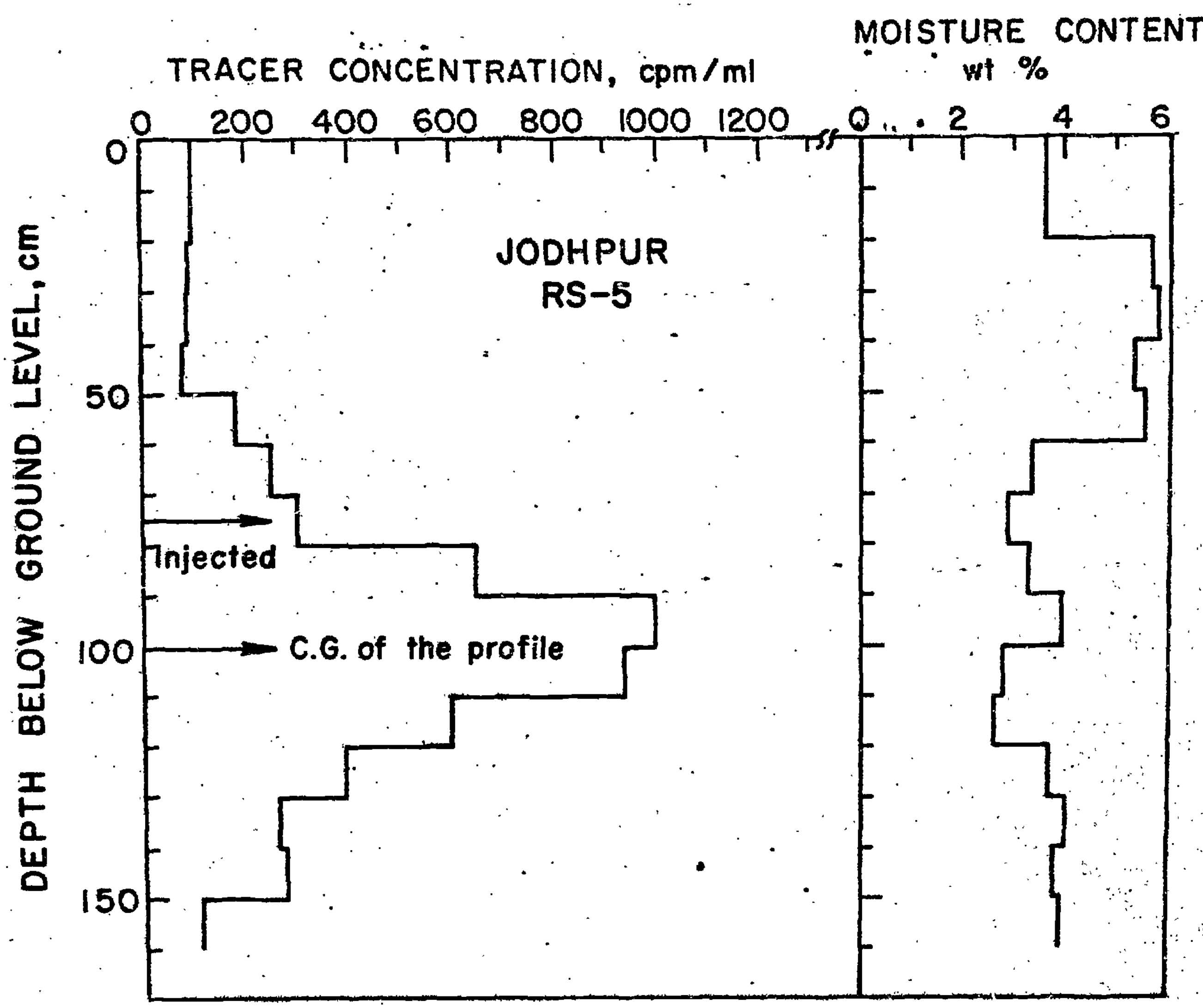

TRACER CONCENTRATION, cpm/ml
MOISTURE CONTENT
wt %
0 200 400 600 800 1000 1200
0 2 4 6
DEPTH BELOW GROUND LEVEL, cm
0
50
100
150
JODHPUR
RS-5
Injected
C.G. of the profile

Fig. 7

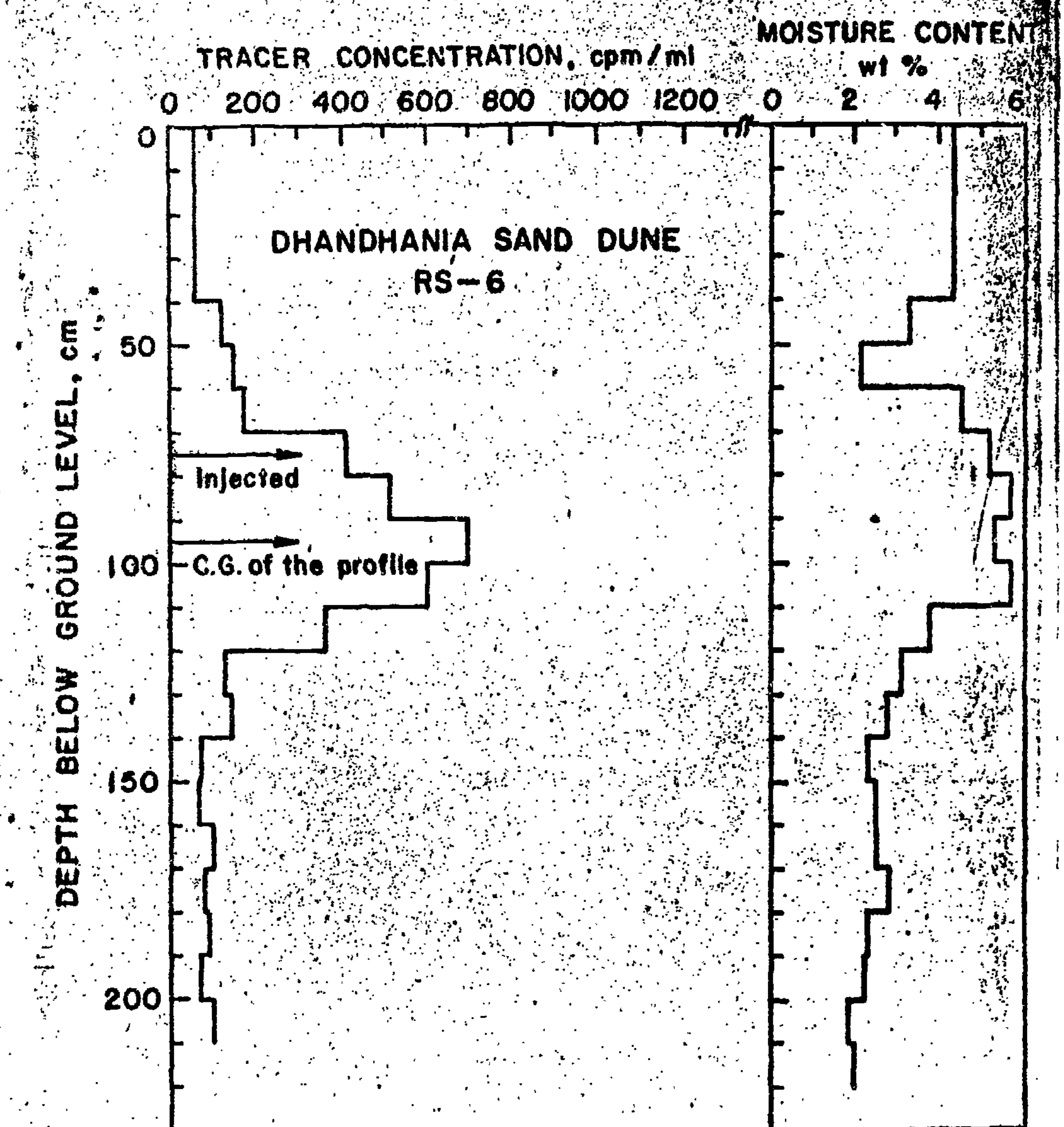

TRACER CONCENTRATION, cpm/ml
0 200 400 600 800 1000 1200
MOISTURE CONTENT wt %
0 2 4 6
DHANDHANIA SAND DUNE
RS-6
Injected
C.G. of the profile
DEPTH BELOW GROUND LEVEL, cm
0
50
100
150
200

Fig. 8

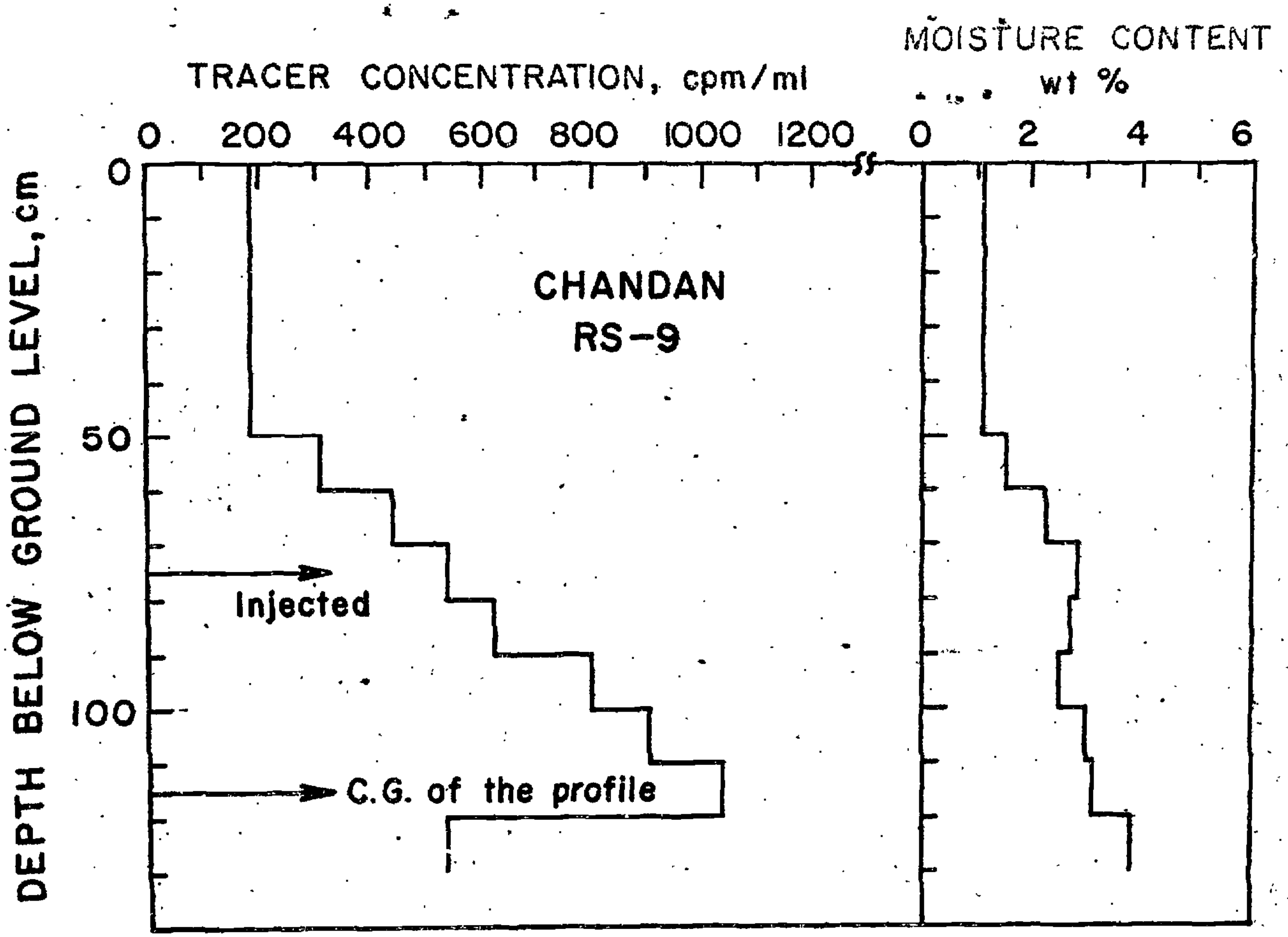

TRACER CONCENTRATION, cpm/ml
MOISTURE CONTENT wt %
0 200 400 600 800 1000 1200
0 2 4 6
DEPTH BELOW GROUND LEVEL, cm
0
50
100
CHANDAN
RS-9
Injected
C.G. of the profile

Fig. 9

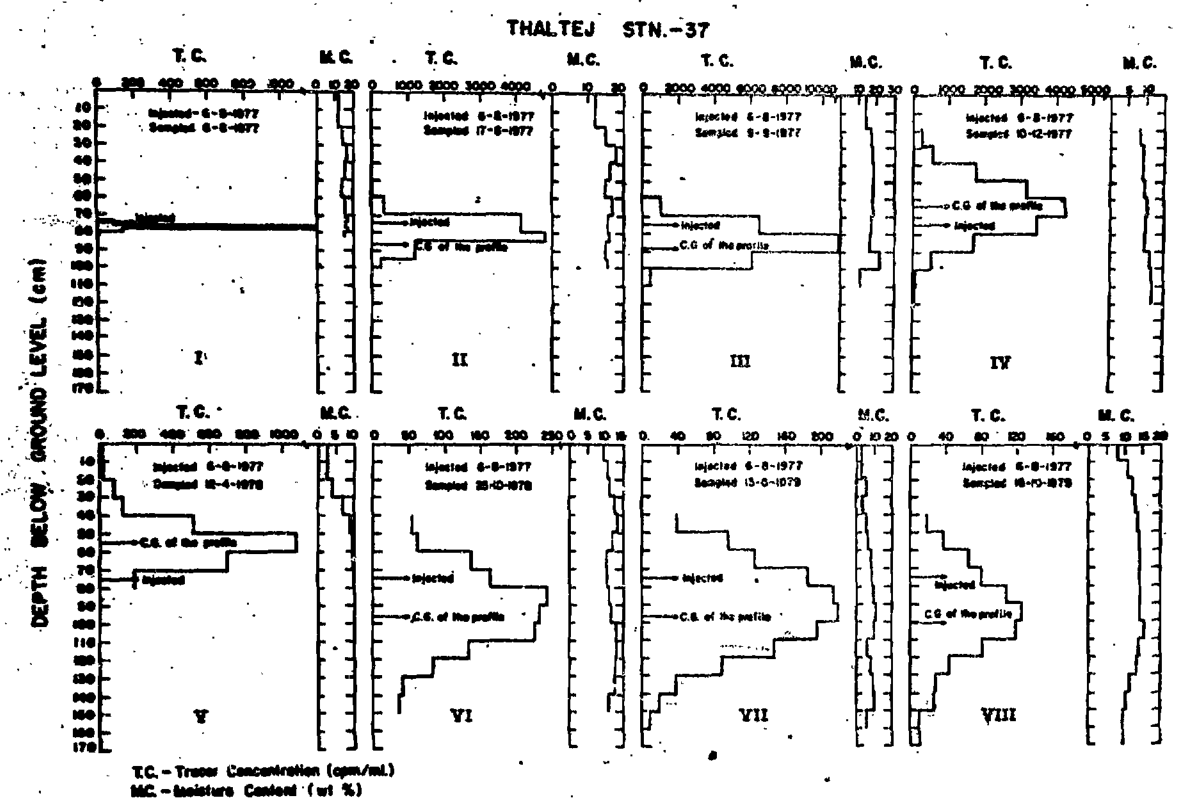
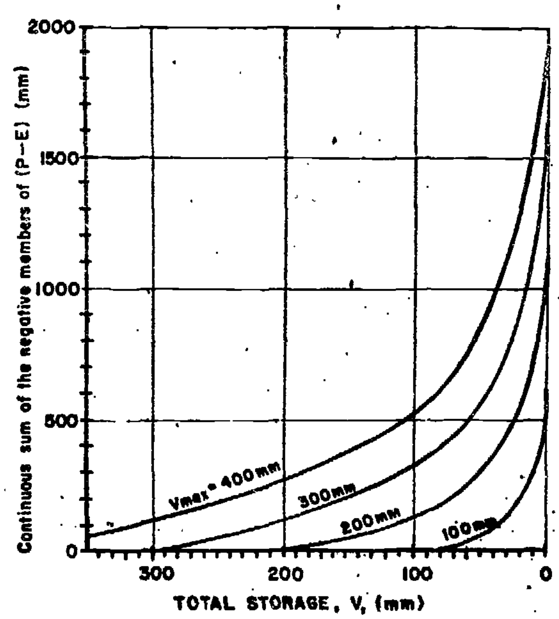

THALTEJ STN.-37
T.C.
M.C.
DEPTH BELOW GROUND LEVEL (cm)
Injected 6-8-1977
Sampled 6-8-1977
Injected 6-8-1977
Sampled 17-8-1977
Injected 6-8-1977
Sampled 9-9-1977
Injected 6-8-1977
Sampled 10-12-1977
Injected 6-8-1977
Sampled 18-4-1978
Injected 6-8-1977
Sampled 25-10-1978
Injected 6-8-1977
Sampled 13-6-1979
Injected 6-8-1977
Sampled 16-10-1979
Injected
C.G. of the profile
I
II
III
IV
V
VI
VII
VIII
T.C. - Tracer Concentration (cpm/ml.)
M.C. - Moisture Content (wt %)

Fig. 10



2000
1500
1000
500
0
Continuous sum of the negative members of (P−E) (mm)
300
200
100
0
TOTAL STORAGE, V, (mm)
Vmax = 400mm
300mm
200mm
100mm

Fig. 11