

Measurement of Vertical Recharge to Groundwater in Haryana State (India) Using Tritium Tracer

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Downward movement of soil moisture due to rainfall and supplemental irrigation in the unsaturated zone has been followed by tagging a layer of soil with tritiated water at a number of sites in the state of Haryana. The activity apparently moves by a piston type flow. The average recharge for 15 sites during the interval July - November, 1973 has been equivalent to 9 cm of water which is 14% of the irrigation plus rainfall. For 18 sites sampled after two monsoons (July 1973 to December 1974) the average recharge is 19 cm and the fractional recharge is 0.15. Wide variations in recharge values are noted. The most significant factor affecting the fractional recharge is the clay content of the soil.

Introduction

Movement of moisture in an unsaturated zone of soil can be monitored with the help of environmental (bomb-produced) (Smith et al. 1970; Allison and Hughes 1972; Anderson and Sevel 1974; Bredenkamp et al. 1974) as well as artificial tritium (Zimmermann et al. 1966; Blume et al. 1967; Zimmermann et al. 1967; Datta et al. 1973). In most studies the tritium profiles show that the downward movement of water through the unsaturated zone takes place by displacement flow, and without overtaking by new water. Infiltration due to precipitation increases the water content in the upper parts of the unsaturated zone. As soon as the field capacity is exceeded, a zone of gravitational water is produced. The front of this zone starts moving downwards in a piston-type flow.

In a recent paper we (Datta et al. 1973) have reported the results of tritium tracer studies on groundwater recharge in Western Uttar Pradesh. In these alluvial plains the moisture movement below the root zone is essentially by displacement flow. In the present paper we report the results of our studies undertaken in the state of Haryana where semi-arid climatic conditions prevail.

Geohydrological Conditions

The state (Fig. 1) traverses mainly plain area ranging in elevation from 198 m to 298 m above mean sea level. There are five physiographic regions, namely, the Siwalik hill tract (average height 500 m from m.s.l.), the dissected rolling plains in the foot-hills (298 m - 373 m), the upland plains or the Ghaggar Yamuna Doab (220 m - 280 m), the flood plains (190 m - 225 m) and the plains with hills and sand dunes. Streams from north flow south and westward while the flow of streams in the southern part is towards north constituting an internal drainage basin. Groundwater occurs in unconfined, semi-confined and confined conditions. Water table depth varies from 3 to 20 m in eastern part to as deep as 55 m in the western part of the state.

The underlying materials consist of alluvial deposits of Quaternary age. The alluvium, at least that of the shallower horizons, is derived from peripheral erosion, essentially all from the highlands in the north east. These deposits are akin to those found generally throughout the Indo-Gangetic plain and consist of a succession of clay, clay with *kanker* (irregular concretions formed due to the segregation of the calcareous material), sandy to silty clay, silt, fine to coarse sand, and sand with *kankar*. Locally, thin beds of gravel and cemented sands are occasionally present with unconsolidated sand.

The slope of the plain in the northern part of the area from west to east is about 0.19 m/km. While that of the south-western part from west to northwest is about 0.75 m/km. The slope in the southeastern part is at about 0.19 m/km. It appears that sand dunes are more or less fixed in southwest to southeast region and support light vegetation in most places.

The long term records of water levels in the fresh water zone show its decline because of the increased rate of pumping. On the contrary a rise in water levels has been observed in various saline or marginal water areas after the introduction of canal irrigation because the withdrawal of groundwater in such areas is very low.

In 1974 the number of wells has increased to 180,000. Out of these about 32,800 are open wells (dug-wells), 145,000 shallow tubewells owned by cultivators, and 2,200 are the heavy capacity deep tubewells run by the State Corporation. These wells are located in an area of 22,000 sq.km. which has groundwater of fresh and marginal quality (E.C. from 300 to 6,000 micro-mhos/cm at 25°C). The total area of the state is 44,222 sq.km.

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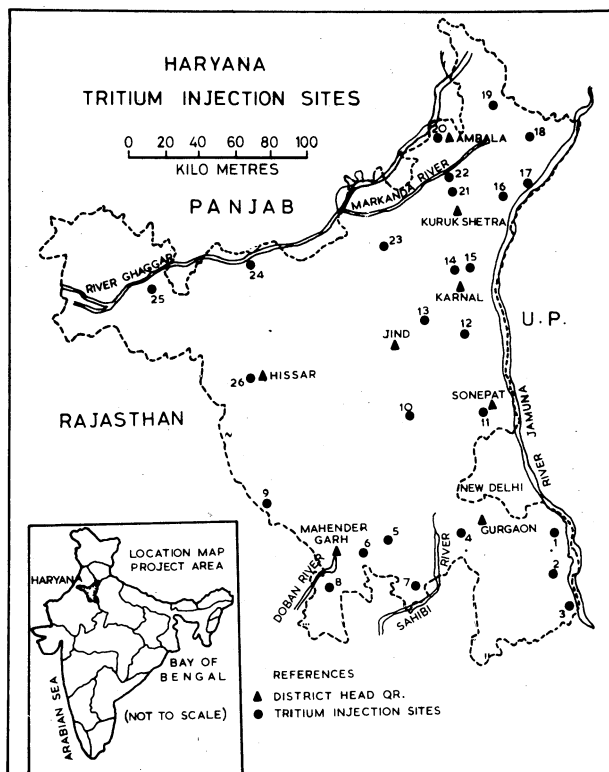


Fig. 1. Index map of Haryana state.

The normal annual rainfall increases from 30 cm in the western part of the state to 100 cm in the extreme north. The normal rainfall in the central part of the region is of the order of 50 cm. The climatic conditions are tropical. A continuous heavy development of groundwater basins is needed. This is possible only if there is adequate groundwater recharge from all sources. It is, therefore, very desirable to determine the amount of vertical recharge in this state.

Experimental

A total of 26 sites spread over the entire state were chosen for tritium injection. Broadly these covered geohydrologically representative areas. The location of injection sites is shown in Fig. 1. In Table I some geohydrological information about each site is given.

A soil moisture layer below the root zone (70 cm deep) was tagged with tritiated water ($10 \mu\text{Ci/ml}$) before the onset of monsoon rains. Our experience from the U.P.

Table 1 - Injection sites for studying recharge in Haryana state

Site	Soil type	Source of irrigation	Ranifall zone (mm)	Depth to watertable (m)	Quality of water	
H- 1	Ballabgarh	Sandy Loam	Tubewell	500-750	6	Fresh
H- 2	Palwal	Loam	Tubewell	500-750	3	Fresh
H- 3	Hassanpur	Loam	Tubewell, Canal	500-750	-	Fresh
H- 4	Pataudi	Loamy sand	Tubewell	300-500	7	Fresh
H- 5	Jatusana	Loamy sand	None	300-500	-	Saline
H- 7	Bawal	Loamy sand	None	300-500	16	Fresh
H- 8	Narnaul	Loamy sand	None	300-500	12	Fresh
H- 9	Loharu	Loamy sand	None	300-500	12	Fresh
H-10	Rohtak	Loam	Tubewell	500-750	5	Fresh
H-11	Sonepat	Sandy Loam	Tubewell	500-750	4	Fresh
H-12	Panipat	Sandy Loam	Canal	500-750	5	Fresh
H-14A	Karnal	Loam	Tubewell	500-750	3	Fresh
H-14B	Karnal	Kaller*	None	500-750	3	Fresh
H-14C	Karnal	Loam	Tubewell	500-750	3	Fresh
H-15	Karnal	Loam	Tubewell	500-750	8	Fresh
H-16	Radaur	Loam	Tubewell	700-1000	8	Fresh
H-17	Yamuna Nagar	Loam	Tubewell	700-1000	4	Fresh
H-18	Bilaspur	Sandy Loam	None	1000	3	Fresh
H-19	Naraingarh	Sandy Loam	Dugwell	1000	4	Fresh
H-20	Ambala	Sandy Loam	Unirrigated	750-1000	3	Fresh
H-22	Jhansa	Loam	Tubewell	500-750	10	Fresh
H-23	Mundri	Loam	Canal	500-750	2	Fresh
H-24	Chimmon	Sandy Loam	Tubewell	300-500	9	Fresh
H-25	Sirsa	Sandy Loam	Canal	300-500	9	Fresh
H-26A	Hissar	Sandy Loam	Canal	300-500	19	Brackish
H-26B	Hissar	Sandy Loam	Canal	300-500	19	Brackish
H-26C	Hissar	Sandy Loam	Canal	300-500	19	Brackish

*Non-fertile land covered with saline efflorescent deposits on the surface

and Panjab experiments suggested some improvement in the injection layout. At each site two sets of injections were made each having five holes (Fig. 2). The modification in the layout and the higher concentration of tritium gave higher counting rates so that the activity could be followed for a longer span of time. Injection work at all the sites was done in June, 1973. Soil samples were collected with the help of a 6 cm hand auger in core sections of 10 cm length from the surface to depths of several meters. Soil analysis of each section of the core was carried out in the laboratory of the Directorate of Groundwater, HMITC, for the determination of sand, silt and clay contents. Total

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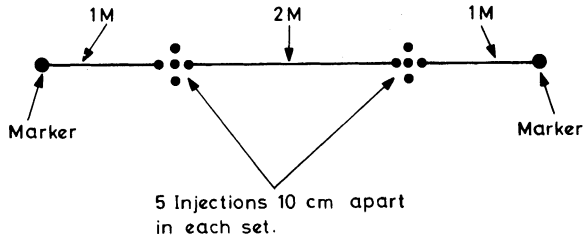


Fig. 2. Layout for tritium injections.

moisture contents of samples were measured on aliquots. Other aliquots were used for tritium measurement. In-situ density measurements of the soil were made at a number of sites. The technique used for tagging the soil moisture layer and the method for bulk density measurements have been described elsewhere (Datta et al. 1973). Tritium content of water extracted from the soil samples were measured by liquid scintillation counting technique. A depth variation of tritium and soil moisture content was thus obtained for all the sites. Recharge was estimated by computing the water contents in a 1 cm² column of the soil lying between the initial position of the tagged layer and the centre of gravity of the displaced tritium activity.

Results and Discussions

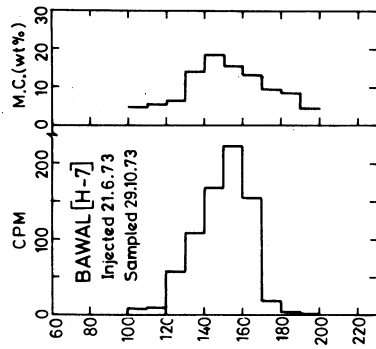
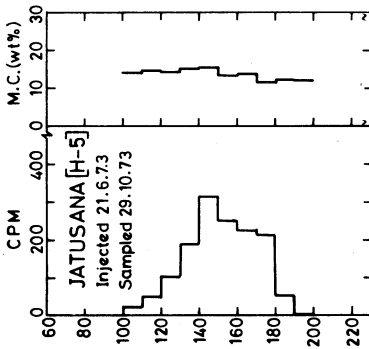
First Sampling

For the sites that were sampled in November 1973, viz., after the 1973 monsoon, the data are given in Table 2. Some typical tritium and moisture profiles are shown in Figs. 3, 4, and 5. Results of bulk density measurements showed that it gets lowered in surface samples due to loss of moisture from the topsoil. For our work only the average interior densities are needed and are given in Table 2. Entries have also been made on rainfall data (from Board of Revenue records) and the amount of supplemental irrigation. The latter has been calculated from a knowledge of the frequency of watering and assuming that each watering, on an average, amounts to 7.6 cm of water. Both moisture contents (percentage by weight of dry soil) and clay contents are for the averages between the injection depth and the position of the displaced tracer peak.

For the 13 sites in Table 2, the average recharge due to 1973 monsoon (and supplemental irrigation) comes out to be 8.5 cm of water. This is about 18 per cent of the average rainfall (47 cm) in that area. The draft is certainly greater than 8.5 cm of water. Seepage from canals and subsurface flow from the bordering areas must be contributing to a significant extent to the groundwater recharge in Haryana state. Moreover, in most areas the groundwater is being 'mined' because the water table is getting progressively lowered.

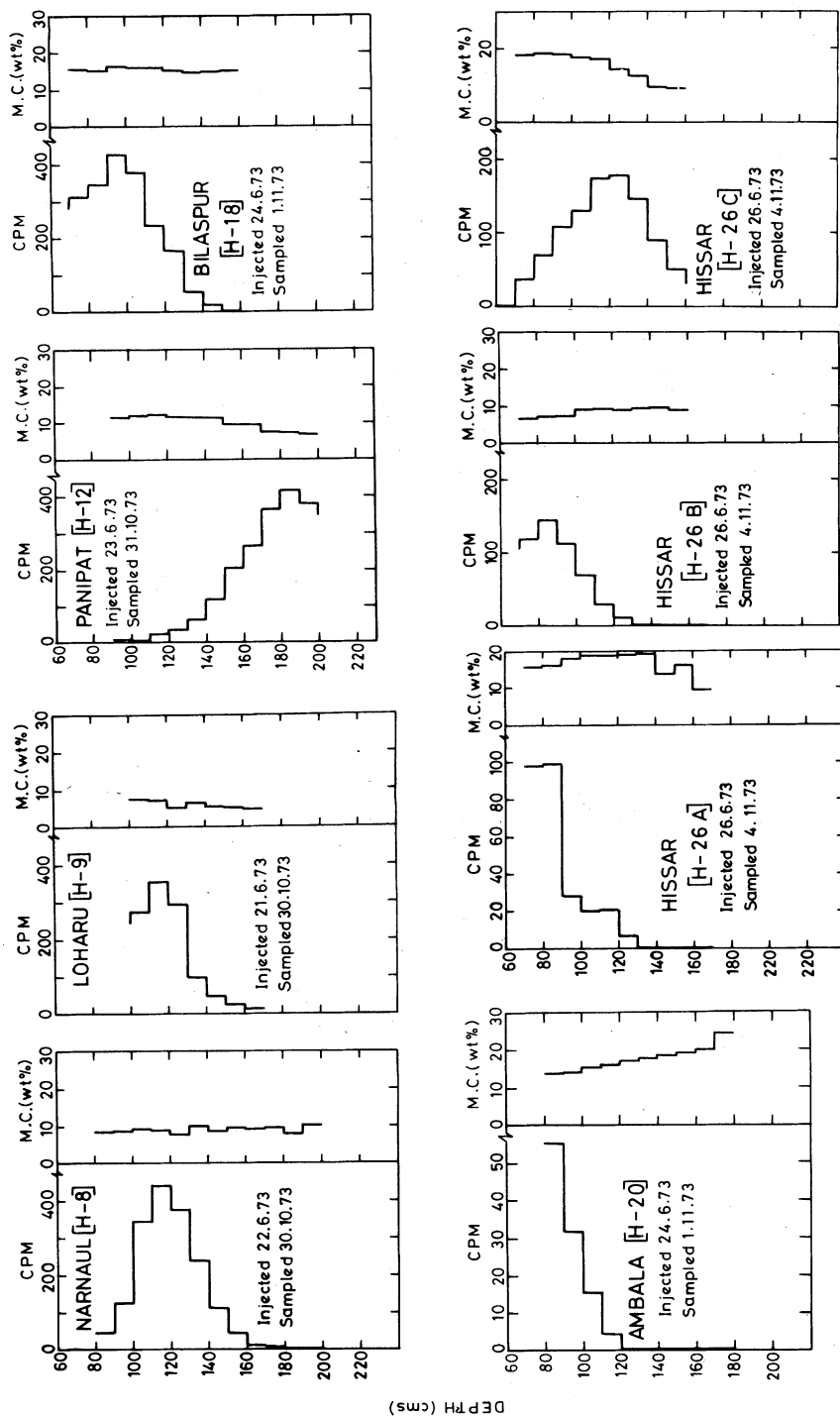
Table 2 - Data on recharge from July 1973 to November 1973

Site	Bulk density ($g\ cm^{-3}$)	Moisture (Wt.per cent)	Clay (wt. per cent)	Dis- placement of tracer peak (cm)	Re- charge (cm)	Watering (cm)	$\frac{Re}{R+I}$	Rain- Irriga- tion	
								R	I
H- 2 Palwal	1.8	18	15.3	34	6.6	51	Nil	51	0.13
H- 4 Pataudi	1.7	6.4	7.0	103	10.5	32	Nil	32	0.33
H- 5 Jatusana	2.0	13	9.1	80	18	51	Nil	51	0.36
H- 7 Bawal	1.9	12	5.7	85	13	42	Nil	42	0.31
H- 8 Narnaul	1.8	10	15.1	50	8.2	44	Nil	44	0.19
H- 9 Loharu	1.8	8.0	8.2	50	6.7	37	Nil	37	0.18
H-12 Panipat	1.5	13	9.4	120	21	74	8	74	0.26
H-14A Karnal	1.8	16	25.7	12	3.0	53	46	53	0.030
H-14C Karnal	1.9	20	20	18	5.7	53	46	53	0.057
H-15 Karnal	1.7	8.6	17	22	3.0	53	15	53	0.046
H-18 Bilaspur	1.8	15	12	34	8.0	51	Nil	51	0.16
H-20 Ambala	1.5	16	21.5	20	4.1	55	Nil	55	0.075
H-22 Jhansa	1.8	17	31.0	20	5.2	49	Nil	49	0.10
H-23 Mundri	1.8	17	20.8	0	0	57	Nil	57	0
H-26A Hissar	2.0	16	23	20	5.5	14	23	14	0.15
H-26B Hissar	1.8	8	21.6	20	2.7	14	23	14	0.072
H-26C Hissar	1.7	8	14.6	60	7.6	14	15	14	0.20



DEPTH (cm)

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Figs. 3-5. Activity and moisture profiles at some sites sampled after one monsoon.

Second Sampling

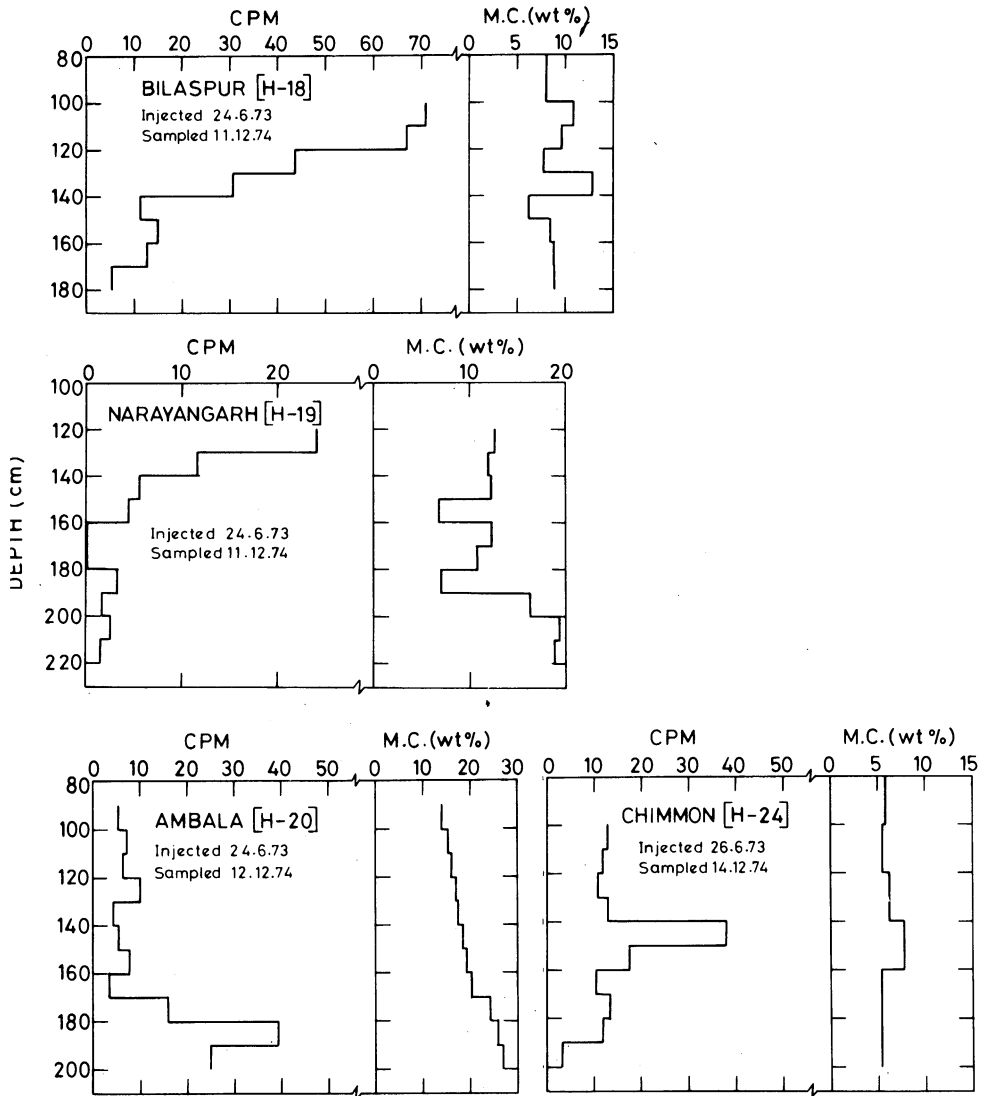
Second sampling was done at all the sites in December 1974. These data are given in Table 3. Some tritium and moisture profiles are plotted in Figs. 6, 7, and 8. Soil sample analyses were also carried out. Average clay contents between the surface to the peak position are given in Table 3. At a few sites significant differences in soil properties are noticed. Otherwise the soil analysis results are similar to those from the same sites sampled previously. Bulk density measurements were not made. Previously measured values have been used where available. For the other sites a mean value of 1.8 g cm^{-3} has been assumed.

At the Sonapat (H-11) site, both injection sets were sampled during this round to check the reproducibility of the data. The profiles are compared in Fig. 9. These show very good agreement. The recharge values are nearly identical, as expected. The value of average recharge for 17 sites for a two years period is 20 cm of water. Generally the recharge for the second year (December 1973 to December 1974) is seen to be higher

Table 3 - Experimental data for the sites sampled after two years' rains
 Injected - 20.6.1973 to 26.6.1973; sampled - 7.12.1974 to 14.12.1974

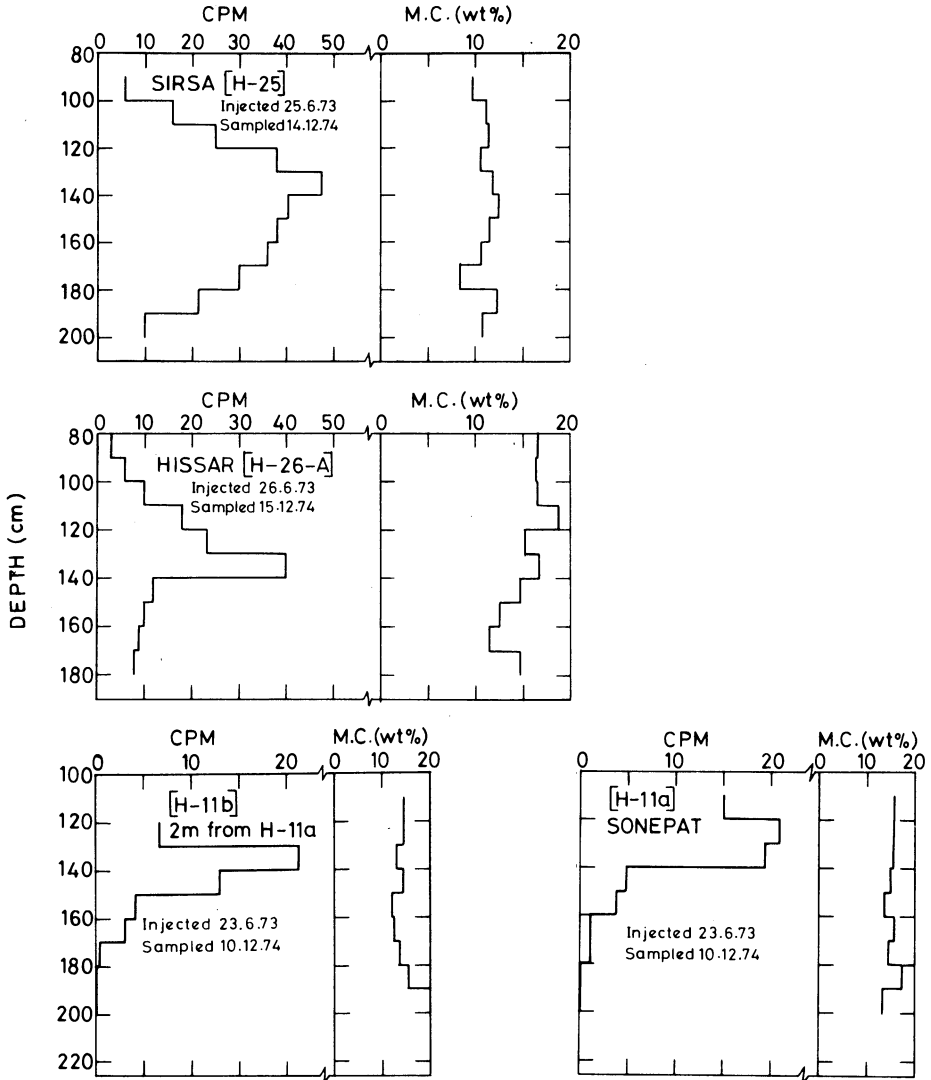
Site	Average water content (wt.%)	Average clay content (wt.%)	Displacement of tracer (cm)	Recharge Re (cm)	Watering (cm)		$\frac{Re}{R+I}$
					I	(R+I)	
H- 1 Ballabgarh	16	18.7	>80	>20	148	-	-
H- 2 Hassanpur	22	29.4	60	20	66	123	0.16
H- 4 Pataudi	17	7.7	160	37	58	159	0.23
H- 5 Jatusana	20	9.5	140	49	Nil	86	0.57
H- 7 Bawal	12	6.6	180	33	22	132	0.25
H- 8 Narnaul	16	11.4	70	19	132	222	0.085
H- 9 Loharu	13	8.1	90	17	Nil	60	0.28
H-10 Rohtak	17	25.1	100	26	28	97	0.27
H-11A Sonapat	18	12.4	60	17	33	125	0.14
H-11B Sonapat	17	14.9	70	18	33	125	0.14
H-16 Radaur	12	12.7	90	17	71	205	0.083
H-17 Yamunanagar	15	19.6	60	14	46	87	0.16
H-18 Bilaspur	10	11.7	114	18	Nil	98	0.18
H-19 Narayangarh	12	19.4	60	12	21	180	0.07
H-20 Ambala	8	18.5	120	12	Nil	130	0.092
H-24 Chimmon	6	11.9	80	8	61	124	0.065
H-25 Sirsa	11	19.5	75	13	61	124	0.105
H-26A Hissar	17	20.2	60	20	Nil	83	0.24
H-26B Hissar	6	20.1	40	4	44	127	0.03
H-26C Hissar	7	12.4	85	9	44	119	0.075

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Figs. 6-7. Activity and moisture profiles at some sites sampled after two monsoons.

than that for the first year (June 1973 to December 1973). Reasons for this may be partly due to longer duration (and hence greater irrigation) and also due to better rains in the 1974 monsoon. The fractional recharge for the second sampling is in general lower as compared to the first sampling for the same site. Presumably, irrigation, which must be higher in the second sampling, contributes to a smaller fractional recharge.



Figs. 8-9. Activity and moisture profiles at some sites sampled after two monsoons.

Factors Affecting Recharge

Our studies (Datta 1975; Goel et al. 1975) in Western Uttar Pradesh (India) show that the recharge, R_e , from rainfall, R , and supplemental irrigation, I , in unconsolidated deposits depends in a significant way on the average clay contents of the soil and can be given by the following relation:

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$$Re = 0.40(R+I) \exp[-0.46(ACP)]$$

Here ACP is average clay content of the soil (weight percent). In Fig. 10 the curve giving this relation is plotted along with the present data from Haryana. The points fall reasonably well on the U.P. curve. It is plausible that for the semi-arid regions of Haryana, and where supplemental irrigation is often comparable to the rainfall, a different relation holds. However, the limited data available at present do not warrant such an attempt. Water-logged areas (with shallow water table) are consistently below the calculated curve. Such an observation has been made by us earlier in the Western U.P. studies also.

The limited sites that have been covered so far do not permit a more general discussion on the groundwater budget of the State of Haryana. However, it is obvious that the vertical recharge is insufficient to replenish the present draft in most of the areas that have been studied.

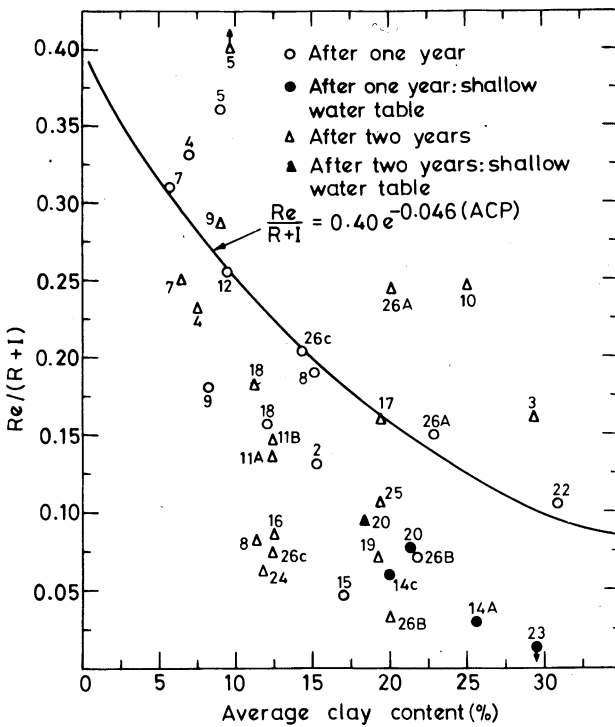


Fig. 10. Variation of the fractional vertical recharge with average clay contents of the soil.

Shapes of Tritium Profiles

Zimmermann et al. (1967) have shown that an initially sharp tracer peak spreads out to a Gaussian shape after sometime due to molecular diffusion. Thus, in the vertical, a dispersion is superimposed on the slow movement of the moisture layer. The tritium activity profiles for a homogeneous soil, and where the grains are not too large, should exhibit Gaussian shapes. The width of the Gaussian (σ) enables a calculation of the diffusion coefficient (D) of water in soil from the relation $\sigma^2 = 2 Dt$ where t is the time interval between injection and sampling. Gaussian curves of different σ and peak height were drawn and the observed tritium count profiles were matched to obtain the σ values. For a large number of cases the matching was satisfactory (S). In some cases the profiles were incomplete (I.P.) because all the soil sections were not counted. Even then many such cases showed Gaussian shapes. Few cases were clearly non-Gaussian and assymmetric. Inhomogeneous nature of the soil might be a cause for some such cases. Moreover in regions of shallow water table the lower portion of the tagged layer gets diluted on meeting the saturation zone and the profile is expected to become skew.

The diffusion coefficient for water in soils as calculated for various sites, is entered in Table 4. The values range from 1.0×10^{-5} to 1.8×10^{-5} cm^2/sec and are close to the published values of the molecular diffusion coefficient for water in soils (Smith et al. 1970). Unfortunately we did not undertake temperature measurements at various depths at any of the sites which limits a more detailed discussion.

Table 4 - Diffusion coefficient for water in soils

Site	Time (days)	σ (cm)	Diffusion coefficient (cm^2/sec)	Matching
H- 2 Palwal	128	15	1.0×10^{-5}	S(I.P.)
H- 5 Jatusana	128	18	1.4×10^{-5}	S
H- 7 Bawal	128	15	1.0×10^{-5}	S
H- 9 Loharu	128	20	1.8×10^{-5}	G
H-15 Karnal	130	15	1.0×10^{-5}	S(I.P.)
H-12 Panipat	128	20	1.8×10^{-5}	S(I.P.)
H-18 Bilaspur	128	17	1.3×10^{-5}	S(I.P.)
H-20 Ambala	128	20	1.8×10^{-5}	S(I.P.)
H-25B Hissar	128	20	1.8×10^{-5}	S(I.P.)
H-25C Hissar	128	20	1.8×10^{-5}	G

S = satisfactory, G = good and I.P. = incomplete profile

Conclusions

The present results obtained from a limited number of sites may not represent the true average vertical recharge for the entire state. However, some gross conclusions are apparent. In the semi-arid climate that prevails in this region, the fractional recharge of about 0.15 is, as expected, significantly smaller than the corresponding value of 0.20 found for Western Uttar Pradesh (Datta et al. 1973). The seriousness of the low value becomes more of concern when it is noted that the average vertical recharge for the two monsoons is less than 10 cm of water each year which is far below the present day exploitation. Some contribution from lateral seepages from canals and the sub-surface flows from the neighbouring areas might be adding some component to the groundwater budget of Haryana. However, this must be small because generally the water table is going down in most areas of the state. Moreover increasing demands on water resources arising out of the increasing agricultural and industrial needs would demand a still larger draft in near future. Means and ways to increase recharge must be developed with a very high priority.

Acknowledgments

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