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STUDY OF SOIL MOISTURE MOVEMENT AND RECHARGE TO GROUNDWATER DUE TO MONSOON RAINS AND IRRIGATION USING TRITIUM TAGGING TECHNIQUE IN HARDWAR DISTRICT

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PREFACE

Recharge estimation to groundwater is crucial to better water resources management particularly in arid and semi-arid regions. Conventionally the recharge to groundwater is estimated from the specific yield and the water table fluctuation. But this data is not generally available for the entire basin. Further as the water table elevation is effected by more than one process, conventional method may not be universally applicable. Therefore, nuclear methods specially tritium tagging technique is more useful and increasingly find wider application in the developing world.

The National Institute of Hydrology has taken up various hydrological studies in district Hardwar. As a part of these studies the Nuclear Hydrology Division has applied the tritium tagging technique to estimate the recharge to groundwater in Hardwar district. This report presents the details of the methodology adopted and discusses the results. This report will be highly useful to the engineers of water resources organisations of Uttranchal and other states.

The present study has been carried out by Sh. S.K. Verma, Scientist B and Dr. Bhishm Kumar, Scientist E1 and Head Nuclear hydrology division, and supported by Sh. Rajeev Gupta, RA, Sh. Suresh Kumar, Tech. Grade I, and Sh. V.K. Agarwal, RA, Sh. S.L.Srivastava, R.A. and Sh. Alok Kumar Sharma, Attendant.

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ABSTRACT

District Hardwar falls under the vast alluvial tract of Quaternary deposits of Indo-Gangetic plains in Uttranchal. It is bordered by river Ganga in the east, foot-hills of Himalayas in the north and districts Saharanpur and Bijnor in the west and south respectively. The area is well drained by a number of rivers and nallahs like Ratmau Rao, Solani, Ason and Song rivers and Sitla Nallah etc. The Solani river is the main source of natural drainage in the area. The upper Ganga canal flows across the study area and is the main source of recharge to shallow aquifers in the adjoining areas. Total geographical area of the district is 201466 hect. It comprises of 120898 hect cultivated, 37519 hect forested, 31132 hect built-up, 2115 hect barren land and 9802 hect uncultivated land. The yearly rainfall in normal year is 1077 mm while the normal monsoon rainfall is 892 mm. Sugarcane, wheat and rice are the main crops grown in the area. The soil in district Hardwar varies from sandy to silty loam.

The geo-hydrological data indicate three aquifers system in this region, e.g. shallow with in 60 feet depth below ground level (b.g.l), intermediate within 70-150 feet b.g.l. and deeper aquifer with in 300-500 feet depth b.g.l. The groundwater table varies place to place in the study area from 1.75 m to 30.27 m in pre-monsoon season while from 0.82 m to 29.39 m in post-monsoon season.

The present study aims to estimate the recharge to groundwater due to monsoon rain through the unsaturated porous media in case of cultivated and uncultivated fields. Artificial radioisotope was injected at two uncultivated and six cultivated sites before the onset of monsoon and soil samples were collected from the injection points after the rainy season. The results of recharge to groundwater in uncultivated land vary from 3% to 5% while 8% to 17% in cultivated land. The values of recharge to groundwater seem justified keeping in view the type of soil and other geo-hydrological conditions prevailing in the study area. Further studies using Neutron Moisture Probe and environmental isotope will throw more light on the interconnections of different aquifer systems, locations of recharge zones to deeper aquifers and major recharge sources.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The process of infiltration governs the recharge to groundwater from surface to the subsequent layers of soil, which is one of the most important parameters to study the movement of water through unsaturated soil. The infiltration may be defined as the process of the water penetrating from ground surface into soil mass.

Estimation of recharge to groundwater is essential for evaluation of groundwater resources. In most of the cases, major source of recharge to groundwater is due to precipitation. However, in the irrigated areas the return seepage also contributes to groundwater recharge significantly.

In addition to the precipitation and irrigation inputs, which contribute to the direct or vertical recharge to groundwater (unconfined aquifers), there is a lateral component of recharge through the sub-surface horizontal flow due to natural hydraulic gradient. The isotope techniques can be employed to estimate the vertical component of recharge.

The vertical component of recharge to groundwater can be estimated using naturally injected environmental isotopes like oxygen-18, deuterium and tritium including artificial tritium, which is required to be injected at the selected sites. In the present study, the artificial tritium has been used to estimate the vertical component of recharge to groundwater.

Tritium is a beta ray emitter having half life of 12.43 years. It emits beta radiations of 18.6 keV energy. In India, tritium can be obtained from Board of Radiation and Isotope Technology (BRIT), Bhabha Atomic Research Centre (BARC), Trombay, Mumbai.

In the present report, the percentage of recharge to groundwater due to rain and irrigation for the period from July' 1998 to October' 1998 in Hardwar district is determined using Tritium Tagging Technique.

2.0 DESCRIPTION OF STUDY AREA

The study area comprises of district Hardwar having a total area of about 201466 hect. It comprises of 120898 hect cultivated, 37519 hect forested, 31132 hect built-up, 2115 hect barren land and 9802 hect uncultivated land. District Hardwar is located between latitude 29° 35' to 30° 03' and longitude 77° 35' to 78° 15' (Fig.2.1). District Hardwar is a very famous city of Northern India where a large number of pilgrims use to come and have bath in holy Ganges through out the year. Besides, the district Hardwar is situated just beneath the Shiwalik mountain ranges. The details of the district in terms of its boundary, rivers, canals and test sites are shown in Fig. 2.1.

2.1 Location of Test Sites

The first site i.e. Bahadrabad was selected in tehsil and district Hardwar. Tritium injections were made in an uncultivated land lying near the campus of Block Development Office situated on the left side of Roorkee-Hardwar road at about 17 km from Roorkee. The second site i.e. Dhanauri was selected in tehsil Roorkee and district Hardwar and tritium injections were made in an cultivated land which falls near the Inspection Bunglow (canal) of U.P. Irrigation Department situated on the left side of old Hardwar road at about 14 km from Roorkee. The third site, i.e. NIH colony situated in tehsil Roorkee and district Hardwar road at about 5 km. from Roorkee. Tritium injection were made in a cultivated land in the campus of NIH colony. The fourth site, i.e. Bhagwanpur selected in tehsil, Roorkee and distt. Hardwar. Tritium injections were made in a cultivated land lying near Lehar restaurant situated on the right side of Roorkee-Saharanpur road at about 15 km from Roorkee. The fifth site, i.e. Jhabrera was selected in tehsil Roorkee and district Hardwar situated on the right side of Jhabrera-Iqbalpur road at about 17 km from Roorkee. The sixth site, i.e. Manglore in tehsil Roorkee and district Hardwar was selected and tritium injections were made in an cultivated land near Ruchika cold store lying on the left side of Roorkee-Delhi road at about 8.5 km away from Roorkee. The seventh site, i.e. Sultanpur was selected in tehsil Laksar and distt. Hardwar. Tritium injections were made in a cultivated land near Ma Bhagwati farm-house situated on the right side of Laksar-Hardwar road at about 12 km from Laksar. The eighth site, Gurukul Narsan was selected in tehsil Roorkee and distt. Hardwar and tritium injections were made in a cultivated land near the campus of Agriculture Degree College, which falls on right side of Roorkee-Delhi road at about 22 km from Roorkee.

Location of various test sites is shown in Fig. 2.1 and these sites are listed in Table 2.1 with other details.

2.2 Topography

The area of Hardwar is almost plain except the presence of Shiwalik mountain range in north. The district is bound by Shiwalik ranges in the north, river Ganga in the east, district Saharanpur and Bijnor in the west and south respectively. Most of the rivers of Hardwar district are flowing from west to east. The area is well drained by a number of rivers and nallahs like Ganga, Ratmau Rao, Solani, Ason and Song rivers and Sitla Nallah etc. The Solani river is the main source of natural drainage in the area. Besides these rivers, the Upper Ganga canal flows across the study area and is the main source of recharge to shallow aquifers in the adjoining areas. The Ganga canal receives its water from river Ganga itself at Hardwar.

2.3 Soil

The district Hardwar is a part of west Indo-Gangetic plain, which is mainly composed of alluvium material brought down by the rivers from the Himalayan region. The alluvium is made of sand, clay, silt, and gravel. The deposits of sand beds are the main source of groundwater in the district.

2.4 Climate and Rainfall

The study area experiences moderate type of sub-tropical monsoon climate. The rainy season in area extends from June to September under the influence of South-West monsoon. The area also receives some rainfall during January and February from North-East monsoon. July and August are the heaviest rainy-months. Normally, the rainfall ceases by the end of September. There is considerable variation in rainfall from year to year as well as from month to month in a year. The average annual rainfall of the area is 1077 mm of which about 85% rainfall is received during monsoon season.

The temperature begins to rise rapidly from about March till May, which is generally

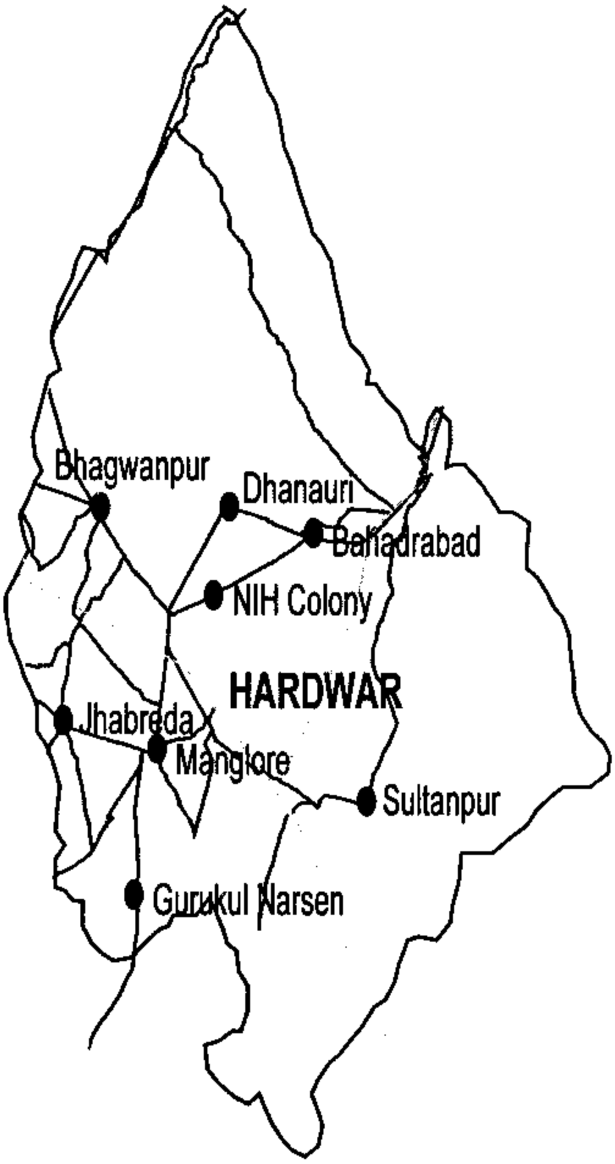


FIG. 2.1: INDEX MAP OF STUDY AREA WITH LOCATION OF TEST SITES

TABLE 2.1: LIST OF EXPERIMENTAL SITES ALONG WITH OTHER DETAILS

Sr. No.	Name of site	Whether cultivated/ uncultivated land	Date of tritium injection	Date of tritium sampling
1.	Bahadrabad	uncultivated	05-07-98	09-11-98
2.	Dhanauri	uncultivated	04-07-98	12-11-98
3.	NIH Colony	cultivated	05-07-98	09-11-98
4.	Bhagwanpur	cultivated	02-07-98	12-11-98
5.	Jhabrera	cultivated	03-07-98	11-11-98
6.	Manglore	cultivated	11-07-98	11-11-98
7.	Sultanpur	cultivated	11-07-98	10-11-98
8.	Gurukul Narsen	cultivated	03-07-98	11-11-98

hottest month of the year. With the on-set of the monsoon in the fourth week of June, there is an appreciable drop in day temperature. From mid November onwards, both day and night temperature decreases rapidly. December and January are the coldest months of the year. In winter, cold waves affect the area in the wake of Western disturbances passing across North India. Normally, the temperature varies from 5^0 C to 45^0 C throughout the year. On the whole, the days are warm and nights are cooler. The rainfall data required for the study have been collected for the period from June 1998 to November 1998 from the office of the collector, collection section, Hardwar which are incorporated in Table 4.10.

2.5 Water-table Condition

The geo-hydrological data indicate three aquifers system in the study area, e.g. shallow with in 60 feet depth below ground level, intermediate within 70-150 feet below ground level and deeper aquifer within 300-500 feet depth below ground level. The groundwater level varies from place to place in the study area from 1.75 to 30.27 m in pre-monsoon season while from 0.82 m to 29.39 m in post-monsoon season.

The pre-monsoon and post-monsoon groundwater levels in the wells located in the study area for the year 1998 are given in Table 2.2. The groundwater department of U.P. in the year 1998 measured these levels.

2.6 Irrigation Practices and Crops

As the general topography of the area under study is plain, surface/sub-surface methods of irrigation are most commonly used. The ploughing is done either by oxen or tractors. Somewhere land is irrigated by tube wells/bore wells while somewhere it is irrigated by canal or river water. The important crops of the area are sugarcane, rice, wheat, gram, barley, mustard etc. These crops are grown generally in rabi and kharif seasons.

TABLE 2.2: WATER LEVELS IN THE WELLS (BGL) AT EXPERIMENTAL SITES

(Source: U.P. Groundwater Department, Roorkee)

Sr. No.	Name of site	Pre-monsoon (m)	Post-monsoon (m)
1.	Bahadrabad	6.17	3.32
2.	Dhanauri	7.05	6.55
3.	NIH Colony	6.15	3.40
4.	Bhagwanpur	3.90	1.54
5.	Jhabrera	6.32	4.12
6.	Manglore	7.83	5.65
7.	Sultanpur	3.86	2.24
8.	Gurukul Narsen	2.78	0.83

3.0 REVIEW OF STUDIES CARRIED OUT IN INDIA

This method was first applied by Zimmerman et al (1967 a, b) in West Germany. Munnich (1968 a, b) also studied the moisture movement in the unsaturated zone by Tritium tagging method. The concept of water movement through soils, termed the piston flow model was developed.

Datta (1975) carried out pioneering work in India using tritium tagging method. Datta et al.(1973,1977) have first taken up this study in Western UP, Haryana and Punjab. The average recharge values reported by them in Western U.P., Punjab and Haryana are 25%, 18% and 15% of the average rainfall, 98.9 cm, 46 cm and 47 cm respectively. Datta et al.(1977) also measured the rate of downward movement of soil water alongwith groundwater recharge in Sabarmati basin in Gujarat covering an area of 22000 sq. km . The downward movement rate varied from 5 cm/yr. to 280 cm/yr., while recharge value was found to be 10% of the average rainfall, 80cm. Datta et al. have also developed a conceptual model for the study of transport of soil water or recharge through unsaturated soil zone.

Athavale (1977) has estimated recharge to the phreatic aquifer of lower Maner basin, covering 1600 sq. km area and having seven different geological formations using tritium tagging technique and found the recharge values ranging from 4.7 cm to 24 cm with an average for the entire basin, 9.5 cm for annual average rainfall 125cm. Athavale et al.(1978,1980) have also carried out the recharge measurements in few basins namely, Godavari-Purna basin, the Kukadi basin in Deccan traps and Banganga basin between Jaipur and Agra.

Datta et al.(1980) and Gupta and Sharma(1984) have also carried out study of recharge to groundwater in Sabarmati basin and Mahi right bank canal command area respectively. About forty representative stations were established in different parts of the Sabarmati basin and soil moisture movement was monitored for a period of three years (1976-79). The results obtained for the percentage of recharge indicated a moderate to low values i.e. 18%, 14% and 6%. About 14% of the total average rainfall was estimated to be stored in the Sabarmati basin. In Mahi right bank canal command area, the percentage of recharge to groundwater was estimated little higher

(23%) indicating a high return flow from irrigation. A comparison drawn from the results of recharge obtained in Sabarmati basin with those for the Ganga, the Ramganga and the Yamuna basins in Northern India indicated a relatively higher ground water recharge (18%).

Empirical formulae based on the experimental results have also been established by Datta et al.(1979). Studies of soil moisture movement and groundwater recharge carried out by PRL scientists in Thar desert using tritium tagging method indicated the factors which control groundwater recharge. The groundwater recharge was found to vary between 5-14% of the annual rainfall.

Sharma and Gupta (1985) and Bhandari et al.(1986) have completed two major projects i.e. Sabarmati hydrology project and isotopic study of soil moisture movement in Thar desert. The scientists of PRL used various radioisotopes like tritium, radiocarbon, Si-32 and Uranium isotopes along with dissolved chemical constituents to find out the values of ground water recharge from infiltration of rain water in Sabarmati basin, Mahi Right Bank Canal command area and coastal Saurashtra.

Mukherjee (1986) and Muhkerjee et al. (1987) have also carried out study of recharge to groundwater in rain fed alluvial area and in IARI farm using tritium tagging technique. This group has also carried out a few experiments to study the recharge at different places having similar soil conditions but different crops and irrigation practices. These studies showed that more recharge takes place in fields with irrigation watering and less fractional recharge through fields with vegetation.

Rao and Jain (1985) have used potassium-cobalt-cyanide as a tracer instead of tritium for recharge measurements and reported its advantage over the tritium for recharge measurements. Its movement can be monitored in-situ by radiation logging of the ^{60}Co through an adjacent bore hole. This group has also carried out study of recharge to groundwater using tritium tracer in Tap alluvial region in Maharashtra and in some parts of Rajasthan. Some studies are also carried out in Karnataka.

Singh and Satish Chandra (1978) have studied the recharge to groundwater due to rains using tritium tagging technique in Sharda Command area of Uttar Pradesh.

Raja et al.(1983) also carried out extensive studies of recharge to groundwater due to rain using tritium tagging technique in various areas of Uttar Pradesh like Gandak Command area, Ganga-Sarda area, Agra-Mathura area, Roorkee area, Deoband Branch Command area, Eastern Yamuna Canal Command area, Sarda Sahayak Command area, Saryu Canal command area and percentage recharge due to rain for these areas were found to be 21.38, 24.1, 22.54, 18.5, 18.2, 21.0, 20.85, and 21.25 respectively.

The U.P. Ground Water Department, Lucknow has also covered the Bundelkhand districts of U.P. by carrying out yearly study of recharge to groundwater due to rain and irrigation using tritium tagging technique in Bundelkhand and Vindhyan regions. The results of the recharge to groundwater due to rains in rainy season varied from 9% to 29% in Bundelkhand region. These studies are continued by U.P. Ground Water Department, Lucknow in Uttar Pradesh to cover other districts.

4.0 METHODOLOGY

4.1 Tritium Tagging Method

As it is clear from its name, tritium, a radioactive isotope is used as a tracer to trace the movement of water as it fulfils the requirement of an ideal tracer. An ideal tracer should have the following characteristics:

a) The tracer should behave same as normal water and should not be lost or reiterated due to adsorption or ion exchange. Generally anions and neutral molecules are better in this regard to cations.
b) The tracer should have a high detection sensitivity.
c) The health and handling hazards should be minimum.
d) The duration of the study is generally about 1 to 2 years and hence the radio-tracer should have considerable half life (about 1 year) from the study point of view but less half-life from health hazard point of view. Therefore, radio-isotopes are selected keeping in view the both aspects.

Tritium as Tracer

a) It behaves similar to normal water as it is a molecule of water.
b) It is a pure beta emitter of low energy (18.6 keV) and belongs to the lowest radio-toxicity class.
c) It can be measured with a high detection sensitivity.
d) It has comparatively long half life (12.23 years) and hence useful for soil moisture movement studies. The long half life makes it possible to store the tracer in the laboratory and no particular shielding is required.

Principle of the Technique

The principle of the tritium tagging technique is mainly based on the following assumptions [Zimmermann et al. (1967) and Munnich, K.D. (1968)].

The vertically downward movement of soil moisture is very slow due to which the lateral mixing between soil moisture portions of different flow velocities even with the stationary also takes place and the moisture flows in a discrete layers in such a way that if any fresh water will be added to the top surface of the soil, the infiltrated layer of the water pushes the older layer downward in the soil system and so on till the last layer of moisture reaches the saturated zone. This concept of water flow in unsaturated zone has been treated as the concept of piston type flow.

On the basis of these assumptions, if a radio-isotope (tritium) is tagged below the active root zone and also not affected by sun heating (say below 75cm to 1m), the tagged radio-isotope will be mixed with the soil moisture available at the depth and act as an impermeable sheet. Therefore, if any water will be added to the top of the soil surface, it will be infiltrated into the ground by pushing down the older water, thus the shift in the tritium peak can be observed after some time (say after laps of one season). But, the tritium peak will be broadened due to molecular diffusion, stream line dispersion, asymmetrical flow and other hetrogeneties of the soil media.

The soil samples from the injection point are collected at the interval of 10 or 15 cm depth after pinpointing it very accurately. The soil core so removed are collected and kept in a air tight plastic container or polythene packs. The soil moisture is obtained from soil samples by vacuum distillation and also the dry density and moisture content determined by gravimetric method using either oven or infra-red moisture balance, the later is preferred due to superiority over the normal gravimetric method. The tritium contents are determined in the soil moisture, obtained by the distillation of the soil samples, with the help of Liquid Scintillation Spectrometer using suitable liquid scintillator. The counting rates so obtained, say counts per minute or per 100 seconds or per 2 minutes depending upon the number of counts obtained per second in order to increase the total number of counts to reduce the statistical error, are plotted with respect to depth and the center of gravity of the tritium peak so obtained is calculated. By subtracting the depth of injection from the C.G. of the tritium peak, the shift of the tritium peak can be obtained. Now as per the principle laid down by the founder investigators (1967), the multiplication of the tritium peak shift and effective average volumetric moisture content in the tritium peak shift region will provide the information of recharge to ground water during the time interval of tritium injection and sampling. The value of effective average volumetric moisture content can be obtained by subtracting the field capacity of the peak shift region from the average volumetric soil moisture content in the peak shift region at the time of sampling. Mathematically the equation for the estimation of percentage of recharge to groundwater can be written as:

$$R = \theta_v \, d \, (100/p)$$

where,

R is the percentage of recharge to ground water

θ_v is the effective average volumetric moisture content in the tritium peak shift region

d is the shift of tritium peak in cm

p is precipitation and/or irrigation in cm

Source of Errors and Precautions

The use of tritium tagging technique may lead to the various source of errors due to different practical problems involved. The main source of errors can broadly be categorised in three steps, used to perform this study.

1) Conducting field experiment.
2) Estimation of tritium and volumetric moisture contents.
3) Estimation of recharge to ground water using experimental data.

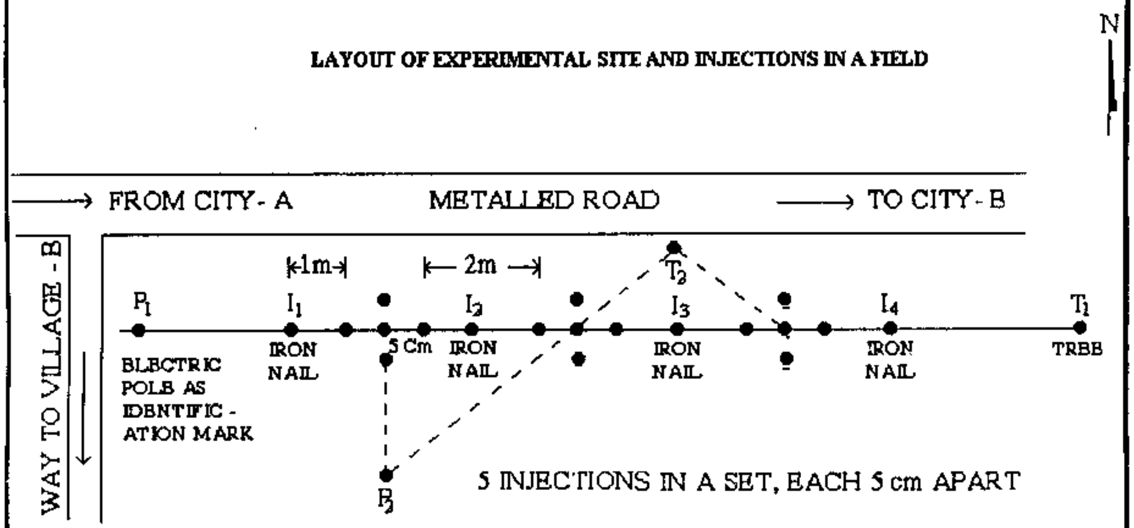
Conducting Field Experiment

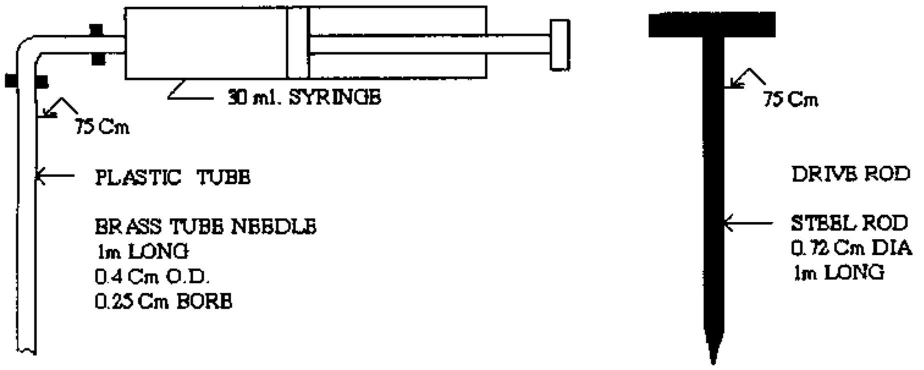
In order to conduct the field experiment, the following steps are involved which should be dealt very carefully to minimise the possible errors.

1) Selection of representative field (site).
2) Marking of site for relocation.
3) Quantity of activity and injection of tritium at certain depth.
4) Relocation of site, collection and storing of soil samples.

The procedure to be followed in the steps mentioned above, although purely depends on the practice and common sense of the user of this technique but the following criteria can be adopted in order to minimise the possible errors and variations that may occur in case of different users.

1) Selected site should represent the area i.e., it should have the topographical and geomorphological features similar to the nearby area.
2) Site should be plain for all practical purposes as this technique is not practically valid for hilly and very high sloppy areas.
3) The site should be at a place where the marking points like tree, electric poles or other similar types of natural or man made identification marks exist in maximum possible directions at some distance (not very close to site). Otherwise, the identification marks will have to be fixed by the user.
4) Besides the identification marks already existing at some distance from the tritium injection points, few additional marks, like iron nails should be fixed at very close distance, say 1 or 2 m around the injected point in order to reduce the inaccuracy that may occur in the measurement of long distances of natural or man made identification marks.
5) The availability of rainfall and/or irrigation data should be ensured before the selection of a particular site.
6) For correct estimation of the recharge to the ground water, the site should be selected in both type of fields i.e., cultivated and uncultivated fields.
7) Tritium should be injected directly at the specified depth using a syringe, plastic pipe and metallic pipe.
8) 2ml of tritium having specific activity at least 25 to 40 μCi/cc should be injected at a depth well below the root zone and sun heating zone, say 70 cm for temperate region to 100 cm for arid region, in all the five holes, each 10 cm apart after making a set of injection points, as shown in Fig. 4.1. The holes should be completely filled with soil after injecting tritium in order to reduce the direct loss of injected tracer due to evaporation and also to avoid the direct entry of water.
9) Layout of the experimental site should be prepared very carefully for the relocation of the site.
10) The site should be relocated very precisely and soil sample should be collected at the


LAYOUT OF EXPERIMENTAL SITE AND INJECTIONS IN A FIELD



SYRINGE AND DRIVE ROD

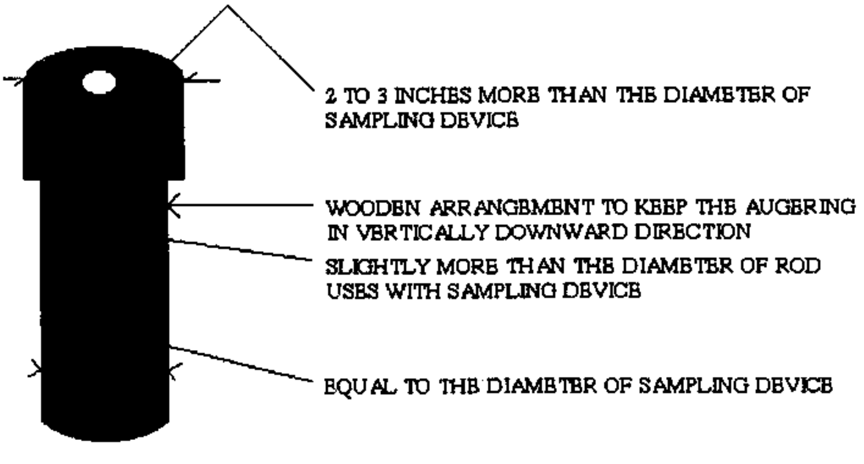


FIG. 4.1: SYSTEMATIC DIAGRAM OF INJECTION LAYOUT AND IMPLEMENTS FOR ARTIFICIAL TRITIUM INJECTION AT TEST SITE

interval of 10cm or 15cm either using a hand auger or any other coring device having sampling tubes.

11) All precautions should be taken to collect the soil sample in vertically downward direction.

12) In order to minimise the contamination of soil samples at lower depths, all precautions should be taken at the time of lowering the sample collection device so that it could not touch to the side walls of the bore hole.

13) In order to minimise the loss of trotted water content due to evaporation, the soil samples should be kept in an air tight plastic box or plastic bags to bring them to laboratory for various analyses.

Estimation of Tritium and Volumetric Moisture Contents

In order to estimate the tritium and volumetric moisture content, the following steps are involved, which should be taken very carefully:

1) Measurement of volume and weight of the soil samples.
2) Gravimetric analysis of the soil samples.
3) Vacuum distillation of the soil samples.
4) Selection of the proper liquid scintillator and counting system.
5) Volumetric measurement of scintillator and tritiated water sample.
6) Measurement of tritium activity and counting time.

The points mentioned above are quite familiar and precautions, which should be taken during the steps mentioned at sl.no.1 to 3, are very common. But, the selection of proper liquid scintillator and counting system needs some special attention in order to minimise the statistical error. Although, more tritium counts can be obtained either by increasing the counting time or by injecting more tritium into the ground to minimise the statistical error but, the first option is better as the injection of high activity should be avoided for all practical purposes. In addition, the selection of suitable liquid scintillator and counting system is also an important aspect to get the higher accuracy in the measurement of tracer activity.

The repeatability in the measurement of volumes of the liquid scintillator and tritiated water in case of each sample is very important in order to locate the tritium peak at its real position. The counting time should be increased to get the more tritium counts if all other precautions have already been taken into account and still tritium counts are appearing less per sec or per minute.

Estimation of Recharge to Ground Water

In order to estimate the correct recharge to ground water the following points should be considered carefully:

1) Centre of gravity of tritium peak.
2) Average volumetric moisture content in the peak shift region at the time of sampling.
3) Rainfall and/or irrigation data.
4) Type of soil and topography of the field.
5) Position of the ground water level.
6) Time period of the study.
7) Percentage of the cultivated and uncultivated fields in the study area.

Although the points mentioned above are self explanatory, but even if the required data like rainfall and/or irrigation, type of soil, water level fluctuations, groundwater withdrawal, tritium peak shift, and moisture content etc. are available for the test sites, the common sense is required to arrive at any conclusion on the basis of the experimental data e.g., the recharge to ground water can not be more than the precipitation and/or irrigation while in certain conditions, the field may be completely submerged of water due to short duration flood or the site may be located at a place where the water from the nearby fields stores during the rainfall, the obtained value will show more ground water recharge at that site than the amount of water supplied, but in such a case the recharge value can not represent the nearby area. Similarly, if any area is having more %age of uncultivated land, the values obtained only for the cultivated fields can not be applied to calculate the total recharge to ground water due to precipitation and or irrigation to the aquifer existing in that area.

4.2 Field Experiments

Field experiments consisted of tritium injections at various sites located in the study area before on-set of monsoon season and carrying out sampling immediately after monsoon.

4.2.1 Tritium Injection

The selection of any particular site for the study was done, considering only the type of surface soil and accessibility of the area. Tritium injections were carried out at 8 sites, which are shown in Fig. 2.1.

Two sets of tritium injection were made at 8 sites during July 1998. These sets were located on a line fixed by choosing appropriate bench marks (usually electric or telephone poles). Each set of injection consisted of one central injection on the line and four injections in a circle of radius 10 cm around it. This is done in order to make sure that the tracer is not lost due to a possible slight misalignment in pin-pointing the injection point while sampling the site. The drive rods (10 mm dia) were first hammered into the soil, for making 70 cm deep holes. The drive rods were then pulled out and stainless steel pipe (injection pipe) was inserted into each hole. The tritium of specific activity of 200 mCi/cc bought from BARC, Mumbai was diluted to the specific activity of 40 μCi/cc. About 2 ml of tritium of specific activity of 40 μCi/cc was injected in each hole with the help of plastic syringe through the injection pipe care being taken that there was minimum disturbance to the natural condition of the soil due to the injection. Each hole was completely filled up with the soil after carrying out tritium injection in the same. At each site few iron nails were hammered on the line of sets of injection and left in the ground, which acted as markers for subsequent location of the sites. The farmers for application of irrigation and/or precipitation left the field for its normal use.

4.2.2 Sampling

The soil sampling was carried out at the time of injection and immediately after the monsoon i.e. during the month of November 1998. Soil samples were collected layer by layer (10 cm sections) with the help of a hand auger of 2" diameter starting from ground surface to about 250 cm. The soil samples were carefully collected and packed in properly sealed polyethylene bags so that there was no exchange of the moisture with the atmosphere and brought to the laboratory for the analysis.

4.3 Laboratory Experiments

The laboratory experiments consisted of estimation of soil moisture content, particle size analysis and measurement of tritium counts in the soil samples.

4.3.1 Soil moisture content

The moisture content of the soil samples on wet weight basis was estimated by gravimetric method using infrared moisture balance.

Wet weight of each soil sample was determined by weighing the sampling using electronic balance. After that small amount of soil sample (approximately 10 gm) was kept on the infrared moisture balance in order to dry the sample due to the radiations of the equipment which gave direct value of soil moisture content (percentage by wet weight basis of the sample). Bulk density for each sample was determined by dividing the wet weight of the sample by the volume of the each sample, which was equivalent to the volume of hand auger of known diameter for a particular depth of soil column. Volumetric moisture content for each soil sample was estimated by multiplying the moisture content obtained by infrared moisture balance on wet weight basis and bulk density of the soil. The values of volumetric moisture contents are tabulated in Table 4.1 to 4.8.

4.3.2 Particle size analysis

The samples collected from the field were tested in the Soil and Groundwater laboratory, National Institute of Hydrology, for carrying out particle size distribution. Particle size distribution of the soil samples was carried out by sieve analysis and master sizer analysis. Soil samples were washed with distilled water to remove the soluble salts. The washed samples were separated into two fractions i.e. +75 micron and -75 micron through wet sieving. Sieve analysis was performed for the fraction of soil retained on 75 micron sieve (+75 micron). The portion passed through the 75 micron sieve (-75 micron) was analysed by master sizer. The test results

TABLE 4.1: VOLUMETRIC MOISTURE CONTENT, NET TRITIUM COUNT RATE AND RECHARGE TO GROUNDWATER AT BAHADRABAD SITE

Depth (cm)	Volumetric Moisture Content	Net Tritium Count/min/ml	Determination of Recharge to groundwater for the period from 05.07.98 to 9.11.98
0-10	0.128	8	Depth of tritium injection = 70 cm Tritium peak shift (d) = 104.99 cm Average vol. moisture content in peak shift region = 0.110 Field capacity in peak shift region = 0.05 Effective average vol. moisture content in peak shift region (θ_v) = 0.06 Recharge to groundwater (R) = θ_v * d = 6.30 cm
10-20	0.133	24	
20-30	0.156	40	
30-40	0.155	463	
40-50	0.135	64	
50-60	0.116	26	
60-70	0.110	11	
70-80	0.116	31	
80-90	0.115	44	
90-100	0.108	56	
100-110	0.129	430	
110-120	0.137	860	
120-130	0.143	1234	
130-140	0.112	148	
140-150	0.100	223	
150-160	0.075	305	
160-170	0.072	871	
170-180	0.069	585	
180-190	0.103	651	
200-210	0.130	42	
210-220	0.209	54	
220-230	0.200	58	
240-250	0.240	35	

TABLE 4.2: VOLUMETRIC MOISTURE CONTENT, NET TRITIUM COUNT RATE AND RECHARGE TO GROUNDWATER AT DHANAURI SITE

Depth (cm)	Volumetric Moisture Content	Net Tritium Count/min/ml	Determination of Recharge to groundwater for the period from 04.07.98 to 12.11.98
0-10	0.108	25	Depth of tritium injection = 70 cm Tritium peak shift (d) = 89.79 cm Average vol. Moisture content in peak shift region = 0.08 Field capacity in peak shift region = 0.04 Effective average vol. moisture content in peak shift region (θ_v) = 0.04 Recharge to groundwater (R) = θ_v * d = 3.59 cm
10-20	0.092	54	
20-30	0.157	1	
30-40	0.170	34	
40-50	0.084	9	
50-60	0.116	19	
60-70	0.082	18	
70-80	0.068	18	
80-90	0.050	15	
90-100	0.044	8	
100-110	0.046	1	
110-120	0.059	2	
120-130	0.057	233	
130-140	0.088	6	
140-150	0.106	5	
150-160	0.231	3	
160-170	0.117	759	
170-180	0.199	1	
180-190	0.267	5	
190-200	0.190	8	
200-210	0.164	8	
210-220	0.120	11	
220-230	0.155	23	
230-240	0.097	47	
240-250	0.111	15	

TABLE 4.3: VOLUMETRIC MOISTURE CONTENT, NET TRITIUM COUNT RATE AND RECHARGE TO GROUNDWATER AT NIH COLONY SITE

Depth (cm)	**Volumetric Moisture Content**	**Net Tritium Count/min/ml**	**Determination of recharge to groundwater for the period from 05.07.98 to 9.11.98**
0-10	0.189	0	Depth of tritium injection = 70 cm Tritium peak shift (d) = 98.53 cm Average vol. moisture content in peak shift region = 0.376 Field capacity in peak shift region = 0.19 Effective average vol. moisture content in peak shift region (θ_v) = 0.186 Recharge to Groundwater (R) = $\theta_v * d$ = 18.33 cm
10-20	0.166	0	
20-30	0.226	0	
30-40	0.366	59	
40-50	0.247	56	
50-60	0.273	38	
60-70	0.344	22	
70-80	0.320	69	
80-90	0.251	304	
90-100	0.285	539	
100-110	0.377	279	
110-120	0.535	19	
120-130	0.443	220	
130-140	0.493	70	
140-150	0.445	14	
150-160	0.457	46	
160-170	0.153	102	
170-180	0.187	151	
180-190	0.293	105	
190-200	0.528	59	

TABLE 4.4: VOLUMETRIC MOISTURE CONTENT, NET TRITIUM COUNT RATE AND RECHARGE TO GROUNDWATER AT BHAGWANPUR SITE

Depth (cm)	**Volumetric Moisture Content**	**Net Tritium Count/min/ml**	**Determination of Recharge to groundwater for the period from 02.07.98 to 12.11.98**
0-10	0.113	0	Depth of tritium injection = 70 cm Tritium peak shift (d) = 134.37 cm Average vol. moisture content in peak shift region = 0.274 Field capacity in peak shift region = 0.15 Effective average vol. moisture content in peak shift region (θ_v) = 0.124 Recharge to Groundwater (R) = θ_v * d = 16.66 cm
10-20	0.138	0	
20-30	0.151	81	
30-40	0.200	188	
40-50	0.250	123	
50-60	0.266	58	
60-70	0.305	15	
70-80	0.247	41	
80-90	0.260	36	
90-100	0.304	32	
100-110	0.284	38	
110-120	0.260	45	
120-130	0.289	79	
130-140	0.309	47	
140-150	0.313	61	
150-160	0.202	14	
160-170	0.259	139	
170-180	0.279	265	
180-190	0.270	543	
190-200	0.291	242	
200-210	0.321	568	
210-220	0.405	409	
220-230	0.398	251	
230-240	0.358	392	
240-250	0.412	318	

TABLE 4.5: VOLUMETRIC MOISTURE CONTENT, NET TRITIUM COUNT RATE AND RECHARGE TO GROUNDWATER AT JHABRERA SITE

Depth (cm)	Volumetric Moisture Content	Net Tritium Count/min/ml	Determination of Recharge to groundwater for the period from 03.07.98 to 11.11.98
0-10	0.037	0	Depth of tritium injection = 70 cm Tritium peak shift (d) = 146.18 cm Average vol. moisture content in peak shift region = 0.28 Field capacity in peak shift region = 0.16 Effective average vol. moisture content in peak shift region (θ_v) = 0.12 Recharge to Groundwater (R) = θ_v * d = 17.54 cm
10-20	0.077	0	
20-30	0.129	0	
30-40	0.167	0	
40-50	0.213	58	
50-60	0.226	11	
60-70	0.189	20	
70-80	0.226	30	
80-90	0.213	68	
90-100	0.233	43	
100-110	0.260	31	
110-120	0.301	33	
120-130	0.260	53	
130-140	0.305	27	
140-150	0.289	36	
150-160	0.246	15	
160-170	0.260	10	
170-180	0.294	11	
180-190	0.308	18	
190-200	0.330	25	
200-210	0.040	57	
210-220	0.332	23	
220-230	0.309	16	
230-240	0.253	56	

TABLE 4.6: VOLUMETRIC MOISTURE CONTENT, NET TRITIUM COUNT RATE AND RECHARGE TO GROUNDWATER AT MANGLORE SITE

Depth (cm)	**Volumetric Moisture Content**	**Net Tritium Count/min/ml**	**Determination of Recharge to groundwater for the period from 11.07.98 to 11.11.98**
0-10	0.176	102	Depth of tritium injection = 70 cm Tritium peak shift (d) = 112.35 cm Average vol. moisture content in peak shift region = 0.328 Field capacity in peak shift region = 0.17 Effective average vol. moisture content in peak shift region (θ_v) = 0.158 Recharge to Groundwater (R) = θ_v * d = 17.75 cm
10-20	0.000	80	
20-30	0.207	58	
30-40	0.219	36	
40-50	0.222	56	
50-60	0.287	80	
60-70	0.287	11	
70-80	0.251	55	
80-90	0.277	99	
90-100	0.272	139	
100-110	0.270	104	
110-120	0.324	134	
120-130	0.381	68	
130-140	0.407	347	
140-150	0.362	312	
150-160	0.341	573	
160-170	0.329	610	
170-180	0.401	647	
180-190	0.341	683	
190-200	0.425	1314	
200-210	0.347	717	
210-220	0.423	386	
220-230	0.473	56	

TABLE 4.7: VOLUMETRIC MOISTURE CONTENT, NET TRITIUM COUNT RATE AND RECHARGE TO GROUNDWATER AT SULTANPUR SITE

Depth (cm)	Volumetric Moisture Content	Net Tritium Count/min/ml	Determination of Recharge to groundwater for the period from 11.07.98 to 10.11.98
0-10	0.219	0	Depth of tritium injection = 70 cm Tritium peak shift (d) = 135.90 cm Average vol. moisture content in peak shift region = 0.330 Field capacity in peak shift region = 0.16 Effective average vol. moisture content in peak shift region (θ_v) = 0.17 Recharge to Groundwater (R) = $\theta_v * d = 23.1$ cm
10-20	0.157	0	
20-30	0.257	0	
30-40	0.285	0	
40-50	0.283	0	
50-60	0.386	777	
60-70	0.319	762	
70-80	0.228	746	
80-90	0.284	1180	
90-100	0.272	1145	
100-110	0.282	971	
110-120	0.361	798	
120-130	0.321	685	
130-140	0.396	619	
140-150	0.342	491	
150-160	0.326	362	
160-170	0.312	235	
170-180	0.325	141	
180-190	0.337	469	
190-200	0.429	798	
200-210	0.455	1515	
210-220	0.464	1109	

TABLE 4.8: VOLUMETRIC MOISTURE CONTENT, NET TRITIUM COUNT RATE AND RECHARGE TO GROUNDWATER AT GURUKUL NARSEN SITE

Depth (cm)	Volumetric Moisture Content	Net Tritium Count/min/ml	Determination of Recharge to groundwater for the period from 03.07.98 to 11.11.98
0-10	0.106	9	Depth of tritium injection = 70 cm Tritium peak shift (d) = 121.26 cm Average vol. moisture content in peak shift region = 0.164 Field capacity in peak shift region = 0.13 Effective average vol. moisture content in peak shift region (θ_v) = 0.07 4 Recharge to Groundwater (R) = $\theta_v * d$ = 8.97 cm
10-20	0.118	2	
20-30	0.145	9	
30-40	0.151	17	
40-50	0.149	24	
50-60	0.162	17	
60-70	0.112	10	
70-80	0.151	34	
80-90	0.149	23	
90-100	0.149	31	
100-110	0,148	12	
110-120	0.161	9	
120-130	0.143	5	
130-140	0.159	27	
140-150	0.177	1	
150-160	0.169	18	
160-170	0.173	26	
170-180	0.187	17	
180-190	0.209	12	
190-200	0.190	19	
200-210	0.267	24	
210-220	0.218	30	
220-230	0.222	17	
230-240	0.262	22	
240-250	0.290	28	

of the analysis for various sites are given in Table 4.9(a) to 4.9(h).

4.3.3 Water extraction from soil samples

After determination of soil moisture content for the soil samples collected from each 10 cm depth using infrared moisture balance, each sample was subjected to distillation under low pressure to avoid volatile impurities being collected along with the water. Water from the each soil sample was extracted and stored in the plastic/glass vials.

4.3.4 Tritium activity measurement with LSC

Radioactivity is the result of an unstable combination of protons and neutrons in the nucleus, and the attempt to arrive at a more stable combination. This stable combination is frequently attained by the emission of an alpha or beta particle associated with or without gamma radiations.

Beta Particles are energetic electrons emitted from the nucleus (neutron-->electron + proton + v) of many radioisotopes. The energy released by this emission is dependent on the radioisotope and is shared between the beta particle and the anti-neutrino (v). Because of this energy sharing and the fact that the anti-neutrinos are not detectable, beta spectra are very broad. Normally they start at 0 keV (all energy is given to the anti-neutrino) and end at some E_{max} keV depending on the radioisotope.

Usually beta particles do not travel far after emission; they rarely penetrate through the vial in which they are contained. Therefore for beta particles it is necessary to put the "detector" as close to the decay particles as possible, that is, inside the vial. This detector is the liquid scintillation cocktail. A scintillation sample vial consists of the following:

1. radioactive sample and
2. a liquid scintillation cocktail

normally consisting of the following components:

Solvent: Typically toluene, xylene, pseudocumene or an alkyl benzene (biodegradable) type solvent.

TABLE 4.9(a): PARTICLE SIZE DISTRIBUTION FOR BAHADRABAD SITE

Sr. No.	Depth (cm)	Gravel (%) (>2.0 mm)	Sand (%) (2 mm-0.075 mm)	Silt (%) (0.075 mm-0.002 mm)	Clay (%) (<0.002 mm)	Silt+ Clay (%)
1.	0-30	0.03	49.67	48.16	2.14	50.32
2.	30-60	0.04	53.85	44.10	2.01	46.11
3.	60-90	0.00	55.70	42.11	2.18	44.29
4.	90-120	0.00	56.34	42.46	1.20	43.66
5.	120-150	0.00	52.86	45.58	1.56	47.14
6.	150-180	0.00	72.78	26.27	0.95	27.22
7.	180-210	0.00	64.26	34.48	1.26	35.74
8.	210-240	0.00	52.22	46.11	1.67	47.78
Average		0.008	57.21	41.16	1.62	42.78

TABLE 4.9(b): PARTICLE SIZE DISTRIBUTION FOR DHANAURI SITE

Sr. No.	Depth (cm)	Gravel (%) (>2.0 mm)	Sand (%) (2 mm-0.075mm)	Silt+ Clay (%) (<0.075 mm)
1.	0-30	0.00	56.86	43.14
2.	30-60	0.31	78.45	21.25
3.	60-90	0.05	80.85	19.1
4.	90-120	0.00	80.48	19.52
5.	120-150	0.00	78.11	21.89
6.	150-180	1.88	49.19	48.93
7.	180-210	0.63	42.08	57.29
8.	210-240	2.30	55.77	41.98
Average		0.65	65.22	34.14

TABLE 4.9(c): PARTICLE SIZE DISTRIBUTION FOR NIH COLONY SITE

Sr. No.	Depth (cm)	Gravel (%) (>2.0 mm)	Sand (%) (2 mm-0.075 mm)	Silt (%) (0.075 mm-0.002 mm)	Clay (%) (<0.002 mm)	Silt+ Clay (%)
1.	0-30	0.0	40.68	57.72	1.60	59.32
2.	30-60	0.0	17.31	80.32	2.37	82.69
3.	60-90	0.0	39.71	58.69	1.60	60.29
4.	90-120	0.0	27.85	69.96	2.19	72.15
5.	120-150	0.0	8.88	87.69	3.43	91.12
6.	150-180	0.0	25.19	72.66	2.15	74.81
7.	180-210	0.0	58.50	40.42	1.08	41.50
8.	210-240	0.0	45.38	53.07	1.55	54.62
Average		0.0	32.94	65.07	1.99	67.06

TABLE 4.9(d): PARTICLE SIZE DISTRIBUTION FOR BHAGWANPUR SITE

Sr. No.	Depth (cm)	Gravel (%) (>2.0 mm)	Sand (%) (2 mm-0.075 mm)	Silt (%) (0.075 mm-0.002 mm)	Clay (%) (<0.002 mm)	Silt+ Clay (%)
1.	0-30	0.14	39.91	57.01	2.94	59.95
2.	30-60	0.10	21.53	73.67	4.71	78.38
3.	60-90	0.11	11.84	83.05	4.99	88.04
4.	90-120	0.83	7.76	86.11	5.30	91.41
5.	120-150	1.04	8.11	86.50	4.35	90.85
6.	150-180	0.00	30.44	66.27	3.29	69.56
7.	180-210	0.00	30.87	67.07	2.06	69.13
8.	210-240	0.00	52.02	46.24	1.74	47.98
Average		0.28	25.31	70.74	3.67	74.41

TABLE 4.9(e): PARTICLE SIZE DISTRIBUTION FOR JHABRERA SITE

Sr. No.	Depth (cm)	Gravel (%) (>2.0 mm)	Sand (%) (2 mm-0.075 mm)	Silt (%) (0.075 mm-0.002 mm)	Clay (%) (<0.002 mm)	Silt+ Clay (%)
1.	0-30	0.16	35.22	61.78	2.84	64.62
2.	30-60	0.06	27.63	68.06	4.25	72.31
3.	60-90	0.06	27.67	68.63	3.64	72.27
4.	90-120	0.06	28.02	69.02	2.90	71.92
5.	120-150	0.12	32.23	65.16	2.50	67.66
6.	150-180	0.05	14.81	80.80	4.34	85.14
7.	180-210	0.07	19.96	77.25	2.72	79.97
8.	210-240	0.16	4.97	88.73	6.15	94.88
Average		0.09	23.81	72.43	3.67	76.10

TABLE 4.9(f): PARTICLE SIZE DISTRIBUTION FOR MANGLORE SITE

Sr. No.	Depth (cm)	Gravel (%) (>2.0 mm)	Sand (%) (2 mm-0.075 mm)	Silt (%) (0.075 mm-0.002 mm)	Clay (%) (<0.002 mm)	Silt+ Clay (%)
1.	0-30	0.54	20.78	75.97	2.71	78.68
2.	30-60	0.36	13.62	81.62	4.40	86.02
3.	60-90	0.32	8.92	86.24	4.53	90.77
4.	90-120	0.07	5.95	89.35	4.63	93.98
5.	120-150	0.07	5.53	90.16	4.24	94.40
6.	150-180	0.00	4.50	91.91	3.59	95.50
7.	180-210	0.00	5.51	91.74	2.76	94.50
Average		0.19	9.26	86.71	3.84	90.55

TABLE 4.9(g): PARTICLE SIZE DISTRIBUTION FOR SULTANPUR SITE

Sr. No.	Depth (cm)	Gravel (%) (>2.0 mm)	Sand (%) (2 mm-0.075 mm)	Silt (%) (0.075 mm-0.002 mm)	Clay (%) (<0.002 mm)	Silt+ Clay (%)
1.	0-30	1.23	26.67	69.93	2.16	72.09
2.	30-60	1.14	28.32	67.89	2.64	70.53
3.	60-90	1.36	28.04	67.78	2.82	70.60
4.	90-120	4.44	14.08	78.79	2.70	81.49
5.	120-150	1.92	7.75	87.29	3.03	90.32
6.	150-180	4.09	9.92	82.51	3.48	85.99
7.	180-210	1.41	8.15	87.66	2.78	90.44
8.	210-240	1.48	7.93	87.55	3.04	90.59
Average		2.13	16.36	78.67	2.83	81.51

TABLE 4.9(h) : PARTICLE SIZE DISTRIBUTION FOR GURUKUL NARSEN SITE

Sr. No.	Depth (cm)	Gravel (%) (>2.0 mm)	Sand (%) (2 mm-0.075 mm)	Silt (%) (0.075 mm-0.002 mm)	Clay (%) (<0.002 mm)	Silt+ Clay (%)
1.	0-30	0.00	48.49	48.76	2.75	51.51
2.	30-60	0.00	46.10	51.14	2.77	53.91
3.	60-90	0.00	42.55	54.11	3.34	57.45
4.	90-120	0.00	42.46	54.27	3.26	57.53
5.	120-150	0.00	41.98	54.52	3.50	58.02
6.	150-180	0.00	42.29	54.82	2.89	57.71
7.	180-210	0.00	44.16	53.89	1.95	55.84
8.	210-240	0.00	62.39	36.39	1.22	37.61
Average		0.00	46.30	50.98	2.71	53.70

Emulsifier: A detergent type molecule (like Triton X-100) that ensures proper mixing of aqueous samples in organic solvents.

Fluor: A fluorescent solute (like PPO).

The function of the scintillation cocktail is to convert the energy of the radioactive decay particles into visible light, which can be detected by the scintillation counter.

The amount of light being emitted from the vial is proportional to the energy of the particle. That is, the higher the energy of a particle, the more solvent molecules it is able to excite and, therefore, more light is generated.

This light is emitted from the LS sample vial in all directions and is "directed" in to two photomultiplier tubes (PMT's) which convert the light into a measurable electrical pulse.

The liquid scintillation system which is at present being used at Nuclear Hydrology Laboratory of National Institute of Hydrology, Roorkee is Model 'System 1409' (Wallac Oy, Finland) whose efficiency is around 60%. The system provides an elegant way of counting the activity of tritium using 'Easy Count' approach.

Ten ml of scintillation cocktail 'W' (SRL, Mumbai) was poured in to each scintillation vial depending upon the number of samples to be analysed. Cocktail 'W' is commercially available and is composed of the following:

1,4 - Dioxane	1 litre
2,5 - Diphenyl oxazole (PPO)	10gm
[1,4-Di-2,(5-Phenyloxazolyl)-Benzene] (POPOP)	0.25 gm
Naphthalene	100 gm

The scintillation vials containing 10 ml of cocktail 'W' were placed in the counting chamber of the liquid scintillation counter for 300 seconds and back ground counts (in counts per minute) for cocktail 'W' were obtained by the system. One ml of tritiated water extracted from each soil sample was mixed with 10 ml of cocktail 'W' (whose background counts has already been measured with LSC) in the scintillation vials.

The vials containing 1 ml of soil water and 10 ml of cocktail 'W' were placed in the counting chamber of the liquid scintillator counter 'System 1409' in order and each sample was counted for 300 seconds and count rate (in counts per minute) for each sample was obtained by this system. These count rates were corrected for background counts in order to get net tritium counts per minute. The net tritium count rates for various sites are tabulated in Table 4.1 to 4.8.

4.4 Determination of Recharge to Groundwater

The net tritium count rate (counts per minute or CPM) for various sites were plotted as a histogram against the individual depth intervals which shows position of the original and shifted peaks of injected tritium. The movement of injected tritium and soil moisture at various test sites is shown in Fig. 4.2 to 4.9. After getting the shifted tritium peak, the centre of gravity of the peak was determined and the shift of the peak from original depth of injection of 70 cm was calculated.

The values of recharge to groundwater for various sites were determined by multiplying the peak shift of tritium as calculated above and effective average volumetric moisture content in the peak shift region and are given in Table 4.1 to 4.8.

The percentage of recharge to groundwater at various experimental sites due to monsoon rain for the year 1998 and irrigation are given in Table 4.10.

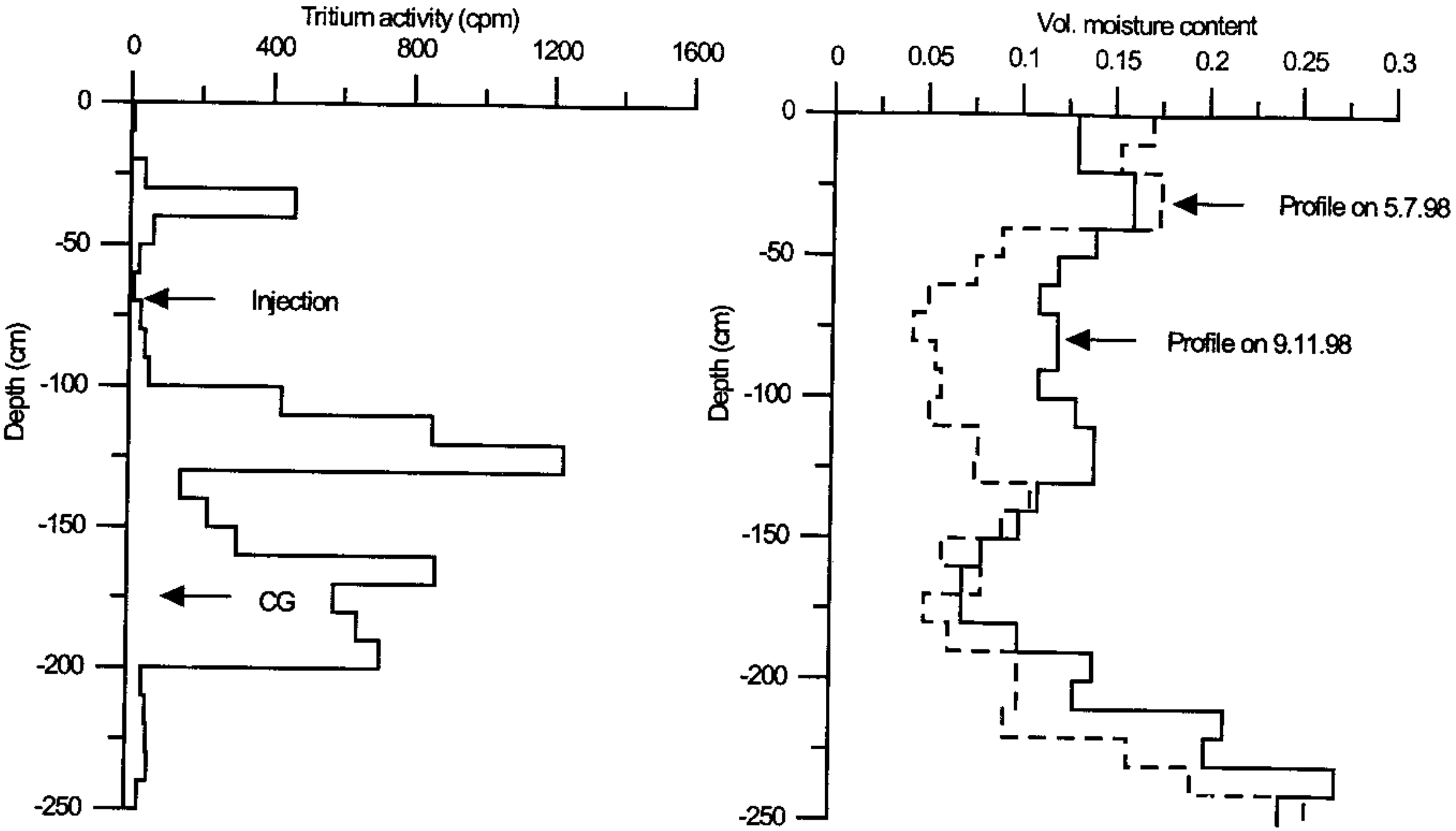


FIG. 4.2: MOVEMENT OF TRITIUM AND SOIL MOISTURE AT BAHADRABAD SITE

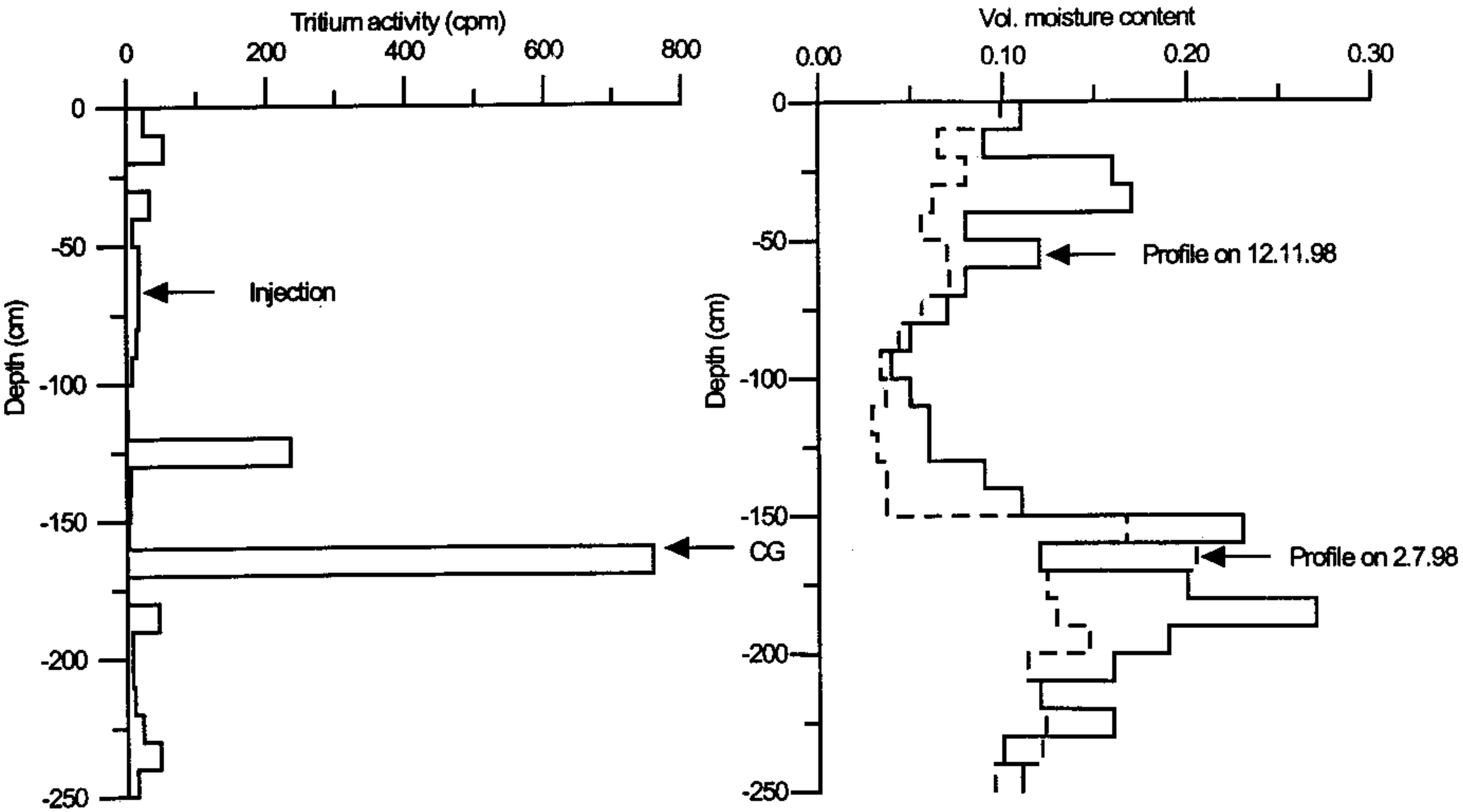


FIG. 4.3: MOVEMENT OF TRITIUM AND SOIL MOISTURE AT DHANAURI SITE

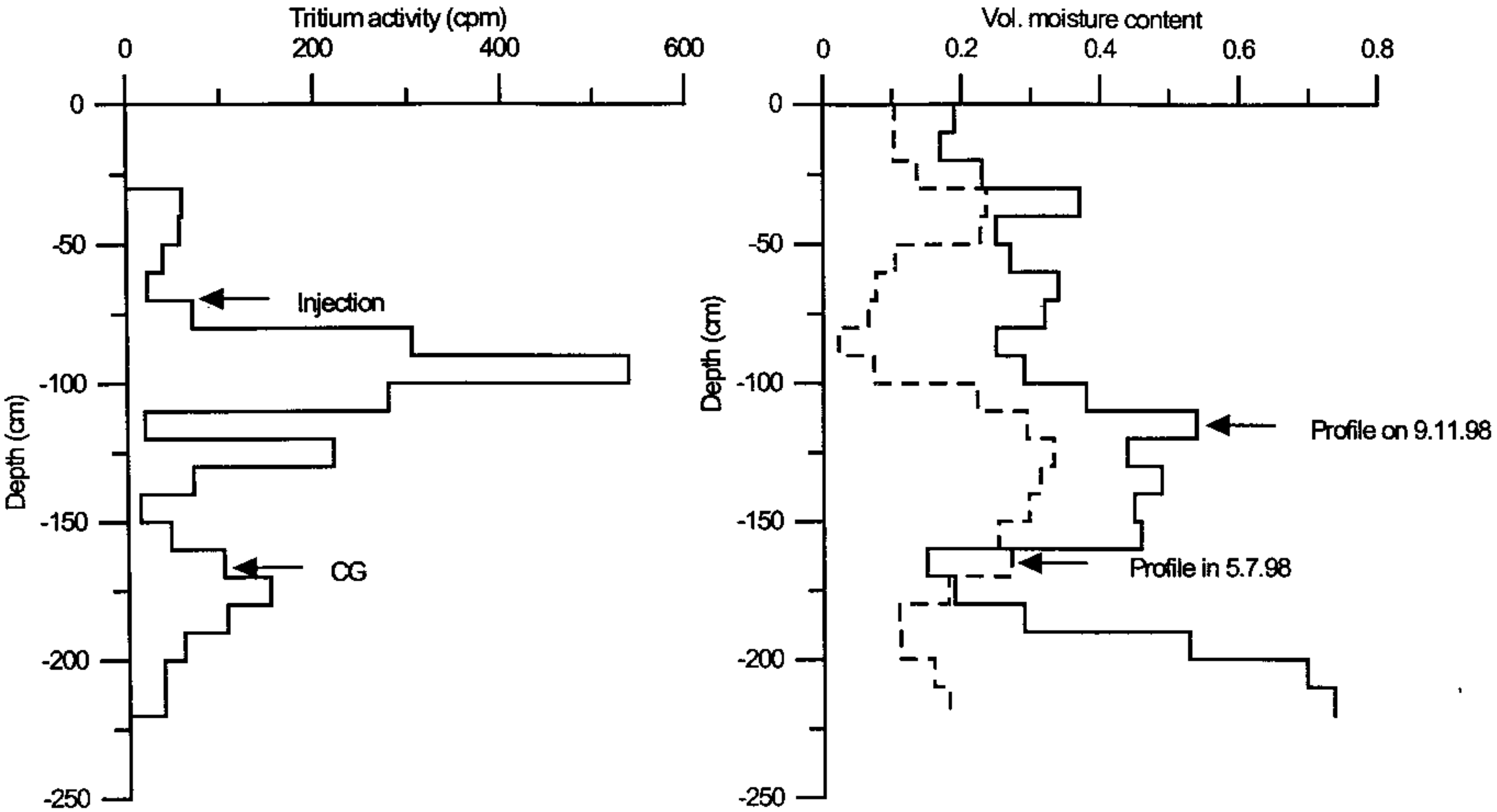


FIG. 4.4: MOVEMENT OF TRITIUM AND SOIL MOISTURE AT NIH COLONY SITE

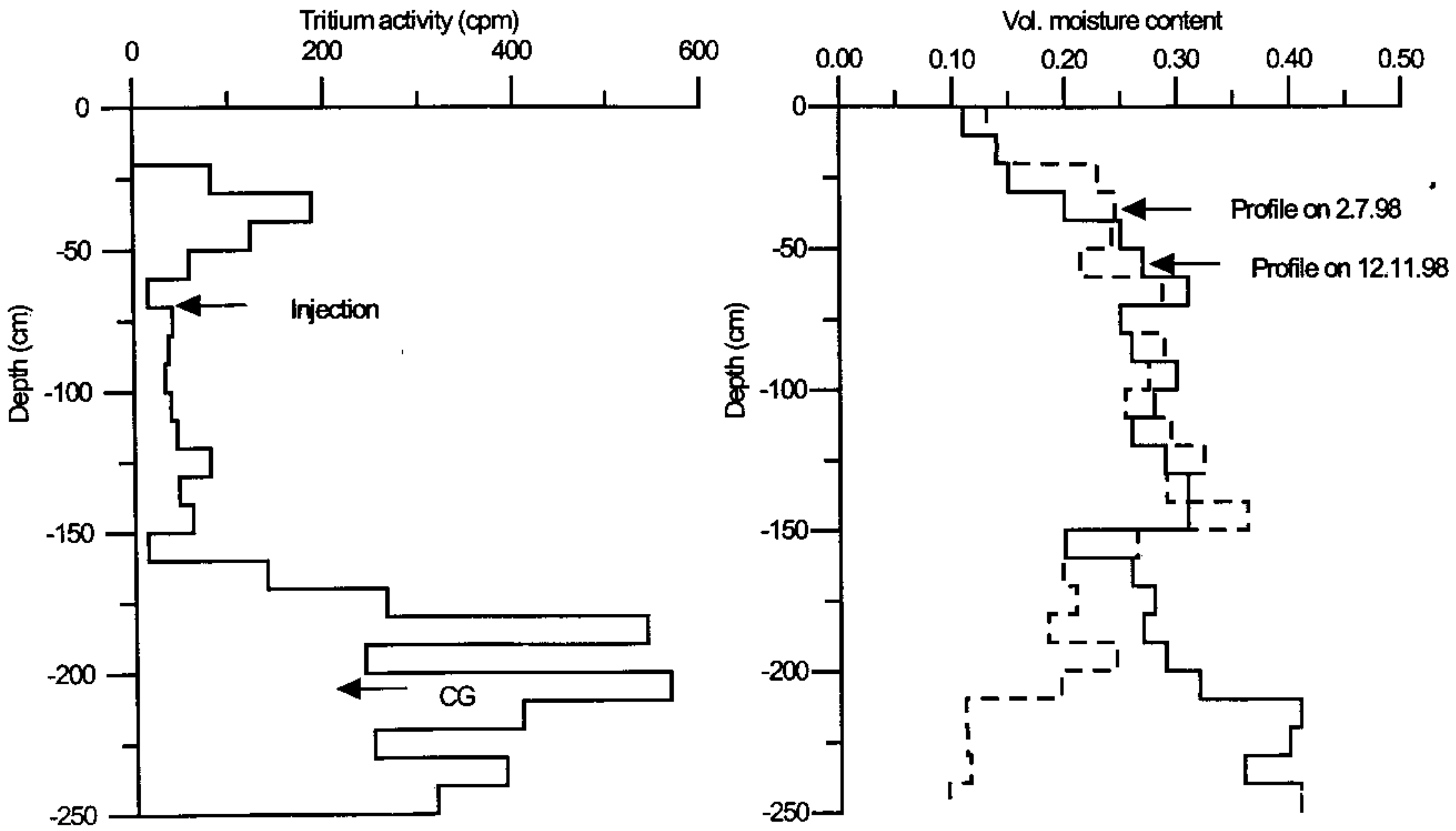


FIG. 4.5: MOVEMENT OF TRITIUM AND SOIL MOISTURE AT BHAGWANPUR SITE

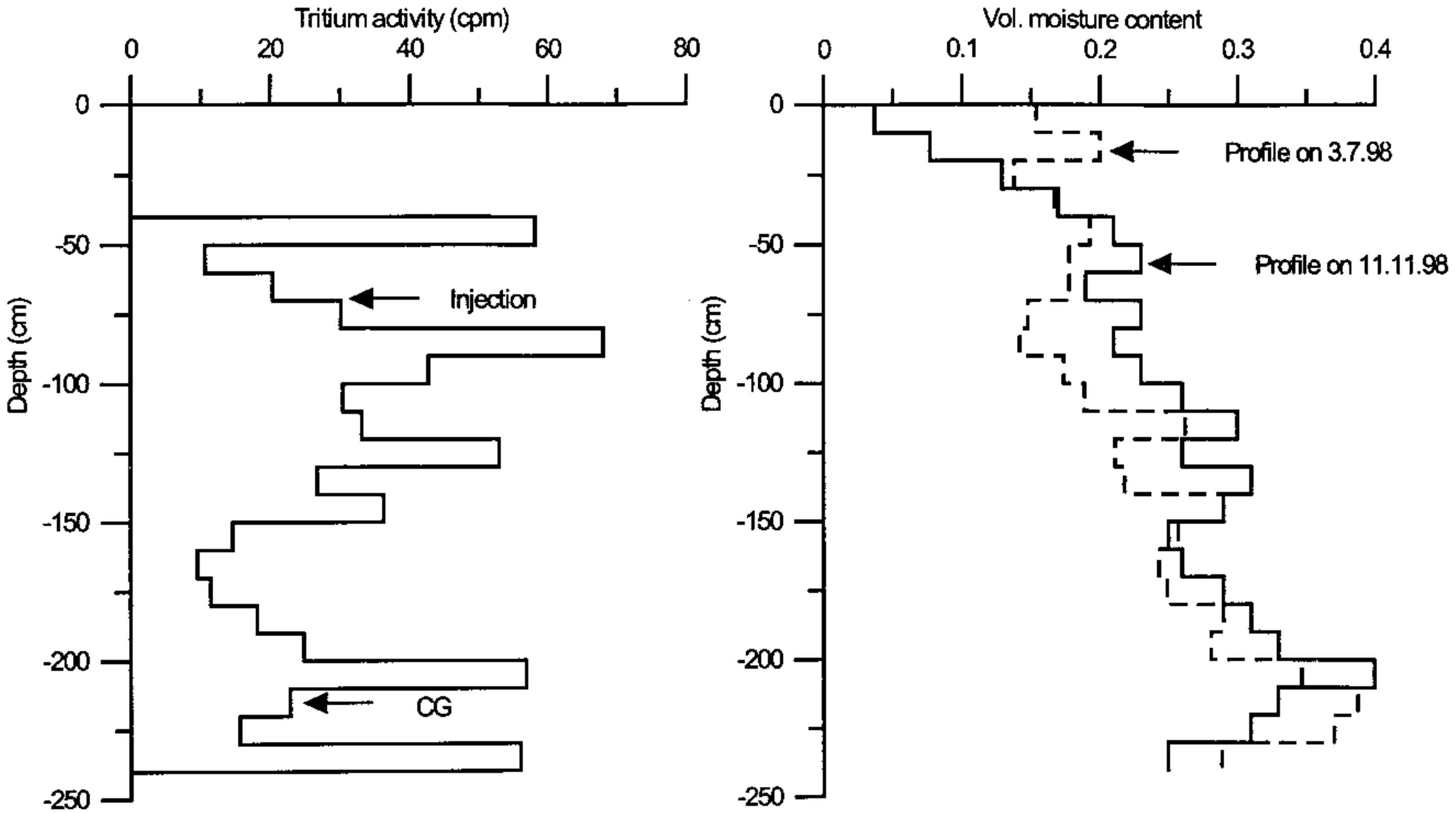


FIG. 4.6: MOVEMENT OF TRITIUM AND SOIL MOISTURE AT JHABRERA SITE

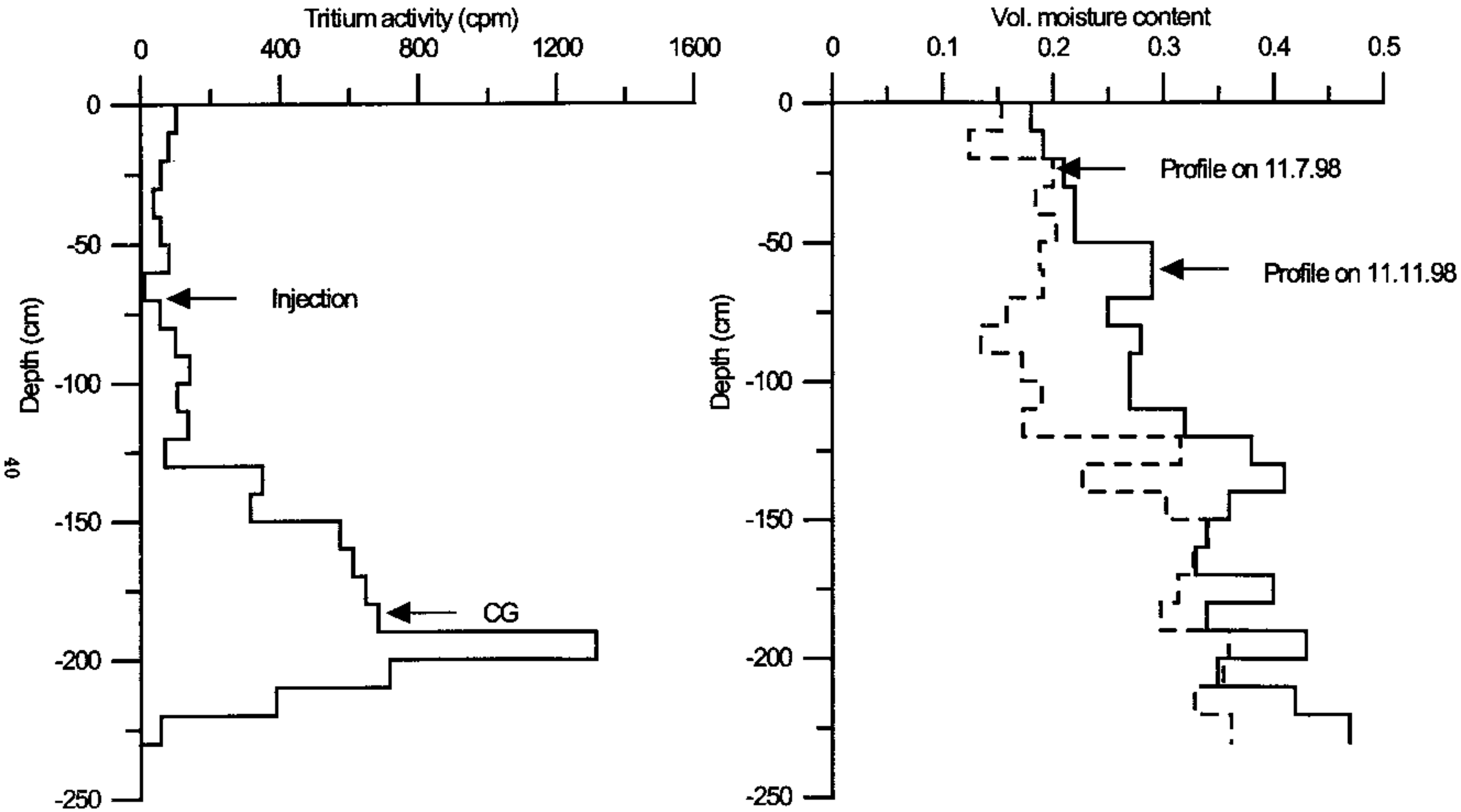


FIG. 4.7: MOVEMENT OF TRITIUM AND SOIL MOISTURE AT MANGLORE SITE

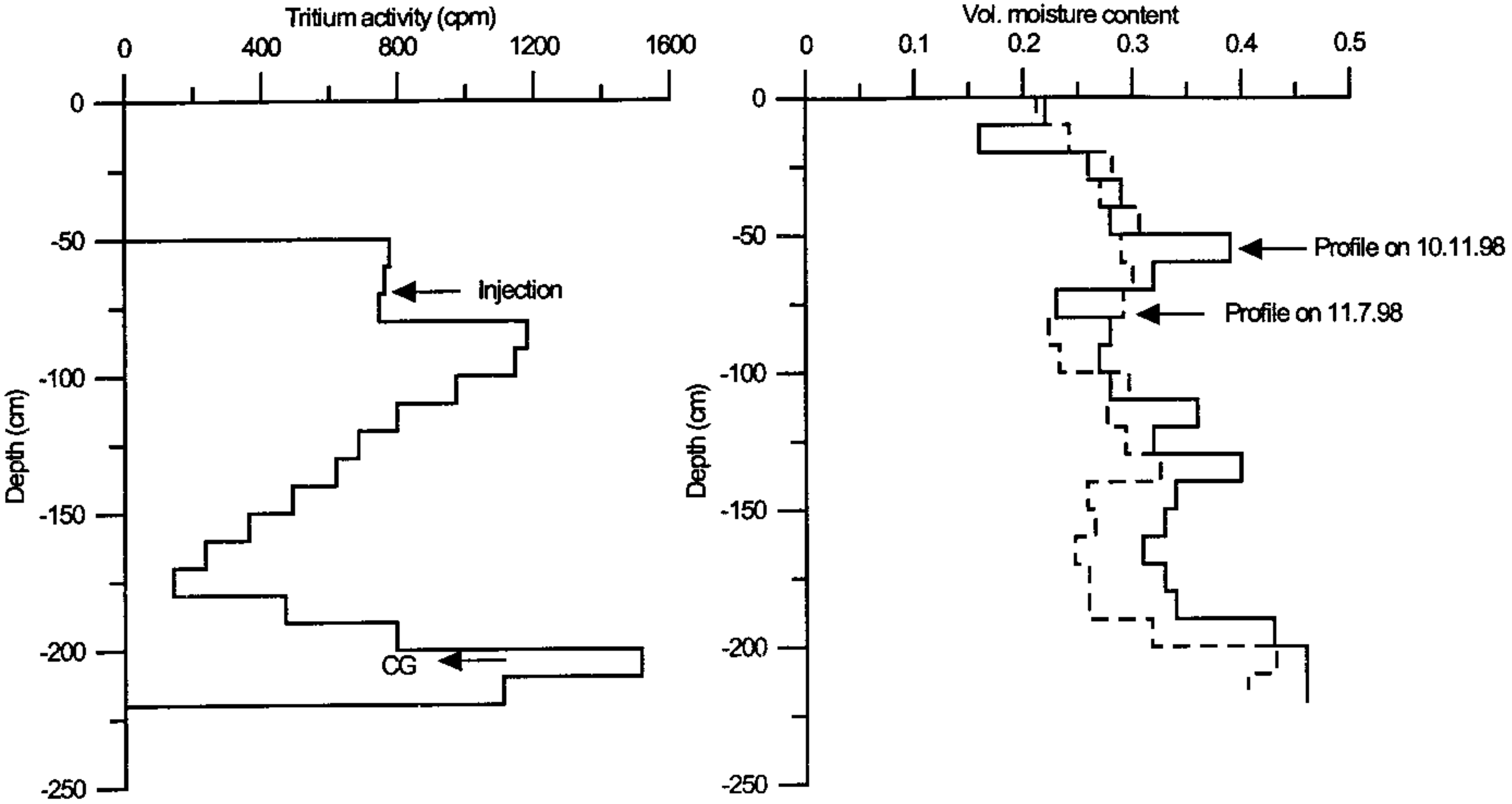


FIG. 4.8: MOVEMENT OF TRITIUM AND SOIL MOISTURE AT SULTANPUR SITE

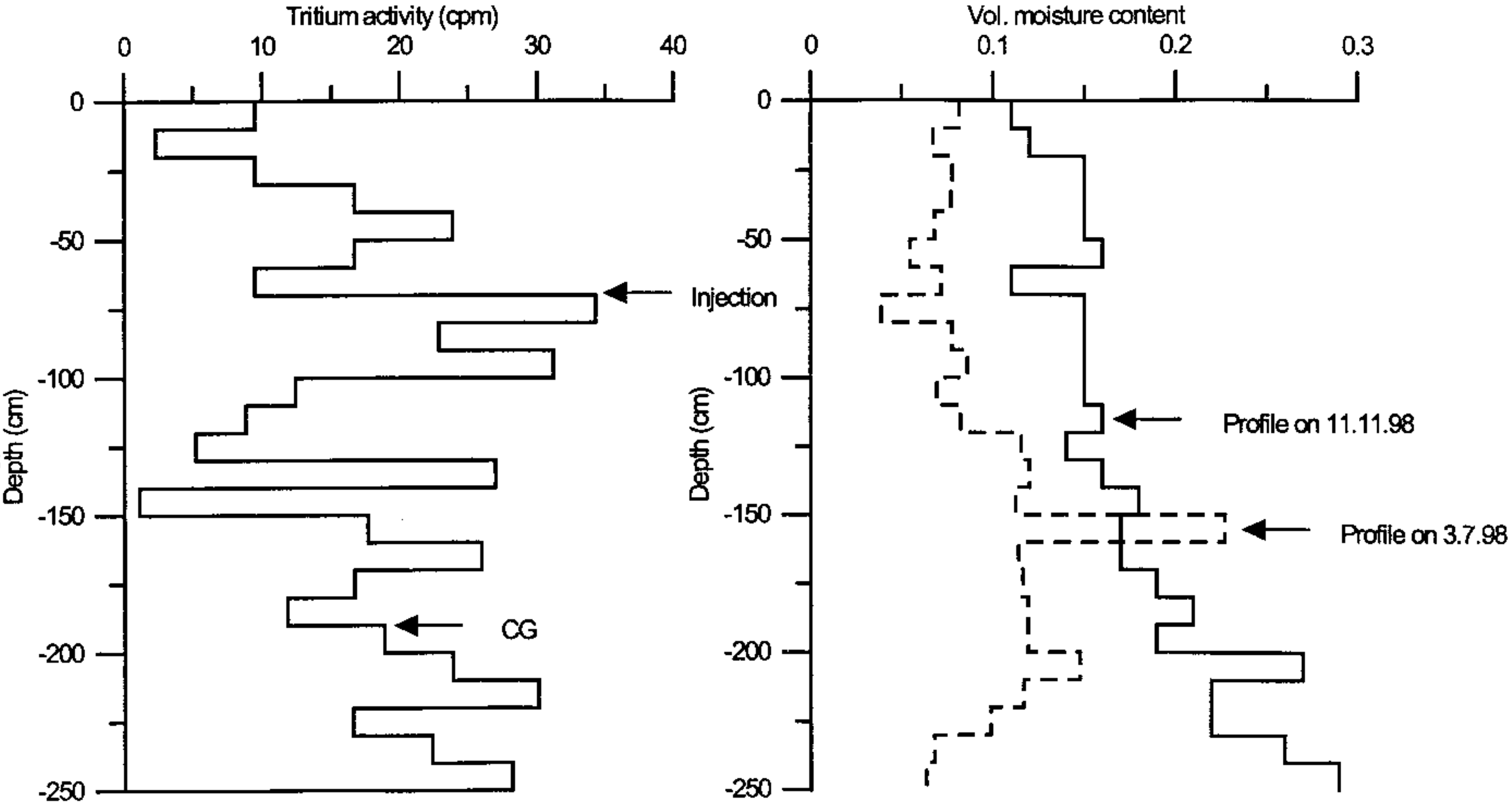


FIG. 4.9: MOVEMENT OF TRITIUM AND SOIL MOISTURE AT GURUKUL NARSEN SITE

TABLE 4.10: PEAK SHIFT, AV. VOLUMETRIC MOISTURE CONTENT, RECHARGE, RAINFALL, IRRIGATION AND % RECHARGE FOR VARIOUS EXPERIMENTAL SITES IN DISTRICT HARDWAR

Sr. No.	Name of Site	Peak shift (cm)	Av. Vol. Moist. Content	Field Capacity	Eff. Av. Vol. Moist. Content	Recharge (cm)	Rainfall (cm)	Irrigation (cm)	Recharge (%)
1.	Bahadrabad	104.99	0.110	0.05	0.06	6.30	120.5	0.00	5.23
2.	Dhanauri	89.79	0.08	0.04	0.04	3.59	116.95	0.00	3.07
3.	NIH Colony	98.53	0.376	0.19	0.186	18.33	108.80	0.00	16.84
4.	Bhagwanpur	134.37	0.274	0.15	0.214	16.66	113.30	0.00	14.70
5.	Jhabrera	146.18	0.280	0.16	0.120	17.54	113.30	0.00	15.48
6.	Mangalore	112.35	0.328	0.17	0.158	17.75	113.30	0.00	15.67
7.	Sultanpur	135.90	0.330	0.16	0.170	23.10	105.77	30.00	17.01
8.	Gurukul Narsen	121.26	0.164	0.13	0.074	8.97	108.6	0.00	8.26

5. RESULTS AND DISCUSSION

The result of recharge to groundwater due to rainfall during monsoon season for the year 1998 and irrigation using tritium tagging technique (radio-tracer method) at each experimental site namely, Bahadrabad (uncultivated-UC), Dhanauri (UC), NIH Colony (cultivated-C), Bhagwanpur (C), Jhabrera (C), Manglore (C), Sultanpur (C) and Gurukul Narsen (C) is given in Table 4.10 along with other details. The details of particle size analysis of soil samples collected from different sites are given in Tables 4.9(a) to 4.9(h).

The value of recharge in uncultivated land varies from 3 to 5% where the sand composition is high (57 to 66%). Therefore, the recharge through uncultivated land having high contents of silt and clay may be as minimum as possible (1 to 2% only). On the other hand, the recharge to groundwater through cultivated land varies from 8 to 17%. It is clearly seen from the data that recharge to groundwater takes place at the rate of around 15% of the rainfall at most of the places except in few cases, like Gurukul Narsen where recharge value is considerably low and Bahadrabad and Dhanauri where recharge value should be high (up to 35% owing to the high percentage of sand composition).

The studies carried out by Roorkee Division of U.P. Ground Water Department (UPGWD) indicate critical stage of development in block Gurukul Narsen, semi critical in Laksar and normal in other blocks (Bahadrabad, Roorkee, Bhagwanpur, Khanpur etc.). The low value of recharge to groundwater obtained at site Gurukul Narsen inspite of comparatively higher composition of sand (>46%) clearly indicate higher values of surface runoff. However, the overall recharge to groundwater (approx. 15%) in district Hardwar is comparatively less than the value generally considered (up to 25%) as per the norms decided by the Ground Water Estimation Committee. This may be due to higher slope and various other geo-morphological features and hydro-geological conditions.

Based on the last 10 years groundwater table data, Roorkee Division, UPGWD has also indicated decline trend in groundwater table in blocks Bahadrabad, Gurukul Narsen, Khanpur, Laksar and Roorkee while rising trend in block Bhagwanpur. The low recharge values obtained at different sites, although indicate that there should be decline trend in groundwater table at most of the places in the study area but, keeping in view the possibility of considerable recharge due to seepage from Upper Ganga canal, it seems that natural drainage is very effective in the study area that keeps the groundwater table either stable or decreasing at a marginal rate.

The type of soil supports the recharge value obtained at different sites in the study area. However, more light may be thrown on the recharge characteristics of the study area on the basis of studies carried out using neutron moisture probe and environmental isotopes to understand the location of recharge zones and major recharge sources to deeper aquifers. Further analysis of rainfall data, type of soil with estimated value of recharge to groundwater will be carried out for the study area between Hardwar and Saharanpur (separate report has been prepared for district Saharanpur) and a publication will be brought out to make the study more meaningful on the pattern of research paper published by B.Kumar and Rm.P. Nachiappan (1995).

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