HYDROGEOLOGICAL STUDIES OF ALLUVIAL AREAS IN PARTS OF SAHARANPUR DISTRICT (U. P.) INDIA

BY

K. V. RAGHAVA RAO, M. Sc.

THESIS SUBMITTED FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY OF
UNIVERSITY OF ROORKEE

DEPARTMENT OF GEOLOGY
UNIVERSITY OF ROORKEE
ROORKEE

1965

"HYDROGEOLOGICAL STUDIES OF ALLUVIAL AREAS IN PARTS OF SAHARANPUR DISTRICT (U.P.); INDIA."

By

K. V. RAGHAVA RAO, M.Sc.

Enrolement No.16.

THESIS SUBMITTED FOR THE DEGREE OF DOCTOR OF PHILOSOPHY OF UNIVERSITY OF ROORKEE:

DEPARTMENT OF GEOLOGY

University of Roorkee
Roorkee.

1965.

This is to certify that the thesis entitled "Hydrogeological Studies of Alluvial Areas in parts of Saharanpur District (U.P.), India" that is being submitted by Shri K.V.Raghava Rao, M.Sc., for the award of the Ph.D. degree of the University of Roorkee is a result of bonafide research work carried out by him under my supervision and guidance. The results embodied in this thesis have not been submitted for the award of any degree or dimploma of this University. The candidate has completed the specified 24 months of full time research.

R S Mithal 5/9/65

(R .S.MITHAL),
M.Sc., Ph.D , D.I.C.(Lond.)
Professor and
Head of Geology and
Geophysics
University of Roorkee,
Roorkee .

PREFACE

Amongst the five elements which are so basic to man's existence in the Universe, water is considered the 'Elan Vital'. This natural resource occurs both as surface and ground water bodies. Keeping in view the plentiful supplies of the surface water in our country, it looks cynical to over emphasise the importance of the investigations related to groundwater resources. But of late, many an experience has shown that a new lease on life and forward look to growth in agricultural and industrial economy could only be vouchsafed through plentiful groundwater supplies.

The area of the present studies is surrounded on three sides by surface water sources. Fascinating to note is that the water supply largely depends on the ground water resources tapped by deep tubewells. This very paradox prompted the writer to choose the subject matter of the thesis as something akin to an applied investigation of the ground water resources in and around Roorkee.

Though the Civil Engineering Department of the University of Roorkee and the Uttar Pradesh Irrigation Research Institute situated at Roorkee have carried out researches related basically to ground water, no attempt has been made to combine knowledge of geology with ground water hydrology. The chief aim of the writer is to present the data on these lines and the study dominates the applied aspects over the descriptive and fundamental features. To achieve the same, the present study is supported by projected field data and inventory over a period of four years from 1960 to 1964. This has proved useful towards the analysis of ground water regime studies in the area chosen for the purpose. This approach was found necessary as the objective was not only collection of data and apparent acedemic discussion but also utilisation of results purposefully.

While presenting the material, emphasis has also been placed on methods of analysis of ground water data related to special situations such as nature of ground water reservoirs as revealed by isopach maps, sedimentological aspects of the alluvial formations, mapping of the specific capacities of the alluvial deposits, hydrometereological studies, analysis of geohydrologic parameters of water bearing formations, statistical analysis of water level fluctuations, thermograph studies, ground water chemistry of the aquifers and quantitative assessment of ground water potential.

It may also be realised that the boundaries of the chosen topic by the writer are undefined, especially keeping in view of the progress made in the technically advanced countries in the science of hydrogeology. However, it has been endeavoured to include all that was considered significant and useful and could be performed within the limited space, available time and the facilities.

K.V. Raghava Rao
5/9/65.

(K.V. RAGHAVA RAO),

ACKNOWLEDGEMENT.

I take this opportunity to place on record my deep sense of gratitude to the authorities of the Ministry of Food and Agriculture, Department of Agriculture, Government of India for permission accorded to me to submit this work in the form of the present thesis. I am equally thankful to the Director General, Geological Survey of India, for permitting to work on the problem.

I am highly indebited to Prof. R.S. Mithal, M.Sc. Ph.D. D.I.C. (London.), Professor and Head of Geology and Geophysics, University of Roorkee, for the constant encouragement, valuable help and guidance throughout this work. I wish to acknowledge his generous assistance in many ways, including the time he has kindly spared to go through the entire manuscript and offer useful suggestions.

It is a great pleasure to thank Sri M.P. Pandey, Superintending Engineer, Exploratory Tubewells Organisation, for the constant encouragement, help and facilities he extended during the course of this work without which it would have been very difficult to complete the work. I am highly grateful for the same.

I owe my special thanks to Sri Mahavir Prasad, M.I.E., M.ASCE, Irrigation Adviser to the Government of India for his interest in the problem and for the encouragements.

During the course of his work, the writer had the benefi of exchange of views in the field with eminent workers in hydr geology and groundwater hydrology. To quote a few, he is hi grateful to Drs. J.B. Auden, Engineer-Geologist, FAO, Rome, Ambroggi, Chief Hydrogeologist, FAO, Rome, Prof. D.K. Todd Professor in Civil Engineering, Water Resources Centre, U of California, USA, Professor Leo Piccard, Professor of

Hebrew University, Jerusalem and Z.L. Shiftan, Technical Adviser (Hydrogeology), U.N. Special Fund. As a result of these discussions the general treatment of the data is greatly improved.

Besides the above, the author has the pleasure to place on record his sincere thanks to Mr. O.M. Hackett, Chief Co-ordination, Ground water Branch, U.S.G.S. and W.C. Walton, Director, Water Resources Centre, Washington for the help they have extended in furnishing the latest literature on analytical methods of aquifer evaluation and groundwater assessment studies.

My special gratitude is to Sri T.S. Raju, Geologist, Exploratory Tubewells Organisation whose assiduous assistance, including technical discussions, has helped greatly in the preparation of the present thesis.

I also express my sincere thanks to Dr. R. Vaidhyanathan of Geology Department of Andhra University and Dr. B.B.S. Shinghal, Reader in Geology, University of Roorkee for their ready co-operation and assistance in going through critically some of the selective topics of the thesis and offering their useful suggestions

It is my pleasant duty to acknowledge and thank the authorities of the Oil and Natural Gas Commission (India) and the 'Terrain Evaluation Cell', Ministry of Defence for the numerous courtesies and help extended in furnishing useful and pertinent data without which the studies would have been incomplete.

Lastly but not the least in importance, my warmest thanks are due to S/Shri Om Prakash Singh and Rajinder Pal Sharma for their help in the preparation of the type script and drawing up of the various maps and plates incorporated herein.

---- .... ----

CONTENTS

HYDROGEOLOGICAL STUDIES OF ALLUVIAL AREAS IN PARTS OF SAHARANPUR DISTRICT (U.P.): INDIA.

LIST OF PLATES

--- ... ---

LIST OF TABLES:

--- ... ---

HYDROGEOLOGICAL STUDIES OF ALLUVIAL AREAS IN PARTS OF SAHARANPUR DISTRICT (U.P), INDIA:

Abstract:

Groundwater is a major replenishable resource of the earth. Keeping in view its ever increasing demand, it would be difficult to divorce researches on sub-surface water regimes from their closely knitted national economic problems.

The present investigation is a scientific and methodological study of the ground water problems of the Indo-Gangetic alluvium. Ground water data of the alluvial areas in parts of the Saharanpur District (U.P.) collected by the author over a period of four years (1960-1964), form the basis of the study. Quantitative aspects of the study are given preference. Special emphasis has been laid for the collection and interpretation of a large number of observations rather than a critical analysis of limited ground water data.

Under this study, the regional geology and structure of the formations, techniques of collection of basic data and sedimentalogical aspects of soils and aquifer sands are described. Evaluation of palaeogeographical drainage trends with the aid of aerial photographs, interpretation of anomalous ground water observations in the light of the geomorphic history of the area and deciphering the nature of ground water reservoirs through isopach maps in localised areas, constitute an important part of these studies. This is followed by an analysis of the nature of occurrence and movement of ground water. Computation of the rate of ground water recharge through flow-net analysis also comprises an important item of the study. This last item of the study has been attempted for the first time in the country.

The hydrological parameters such as transmissibility, field permeability and storage coefficients of the alluvial aquifers, well characteristics and effects of geohydrologic boundaries on the performance of water wells under pumping conditions have been worked out. The limitations of such analyses are reviewed. A hydrogeological map showing the variations in the specific capacities of the alluvial aquifers has been brought out for Roorkee area and it has been shown that such maps are valuable for interpretation of ground water conditions.

Statistical analyses of water level data have been attempted to establish the various factors governing the ground water regime. The method of linear correlations has been successfully applied to ground water data in the country probably for the first time. The results embodying the effects of meteorological and man made factors on ground water regime close to the Upper Ganges Canal in Roorkee area have been especially examined.

Ground water thermographs to show the effects of canal water temperature and air temperature on the ground waters close to land surface, have been obtained over a period of four years.

Chemical nature of ground water is also studied. Areal study of the mineralised ground waters is brought out by means of chemical quality maps. The reaction of water to soil in irrigated areas is ascertained by the use of the sodium-adsorption ratio diagrams. The changes in the chemical regime from areas of ground water recharge to areas of withdrawal have also been studied.

In order to establish the functional conditions of ground water reservoirs, computations have been made on the total storage, inflow and outflow, recharge and draft of the ground water bodies. The ground water balance of the confined reservoir has also been worked out.

--- ... ---

CHAPTER I:

INTRODUCTION:

1) General:

Galileo said "I can learn more of the movement of Jupiter's sattellites than I can of the flow of a stream of water". A few centuries back, it was not only true of the surface water bodies but also equally true about ground water reservoirs. Since a couple of decades the science of ground water is no more a frustratingly inexact technology. It has reached almost a state of predictable and exact science.

In India, since thirties, studies on ground water problems have been attempted in a systematic and scientific manner. A poineering attempt in this direction was made when Sir William Stampe (1934) introduced the large tubewell scheme for irrigation in the Ganges Valley. Ground water situations in diverse hydrogeological settings are being worked out for some time by the Officers of the Geological Survey of India and Exploratory Tubewells Organisation. These studies are mainly directed towards collection of preliminary data from the existing wells and through exploratory drilling operations. As far as Gangetic Alluvium is concerned, studies related to ground water regime analysis embracing data on hydrology, hydrogeology, hydrometeorology and hydrochemistry for projected periods are lacking.

With this in view, the writer attempted an analytical study of the ground water situation in parts of the alluvial deposits of the Gangetic Valley in Saharanpur District, Uttar Pradesh. Though the Valley fill deposits constitute many types of unconsolidated sediments such as integrated piedmont alluvial fan deposits (Bhabars), marshy fine textured sediments (Terai), sands, clays and silts of the plains, the present studies are mainly concentrated on the last category of alluvial formations close to Roorkee town. However, brief references are also made at appropriate places to the ground water conditions in other alluvial deposits of the district. The area under study lies between longitudes E 77°44' and 78°0' and latitudes N 29°43' and 30°0'. It covers an area of 260 sq. miles (Plate Nos. I and II).

Being closely associated with the technical aspects of the ground water exploration programme of the Government of India in the virgin areas of 'Terai' and 'Bhabar' belts of Uttar Pradesh, the author utilised the scientific data as a background study for the present analysis of intensive inventory and field data collected from the area which is close to the above said belts. The field observations were commenced in July, 1960 and ended in July 1964. Hydrogeological interpretations and statistical analysis of ground water data are more realistic and dependable if based on long periods of observation.

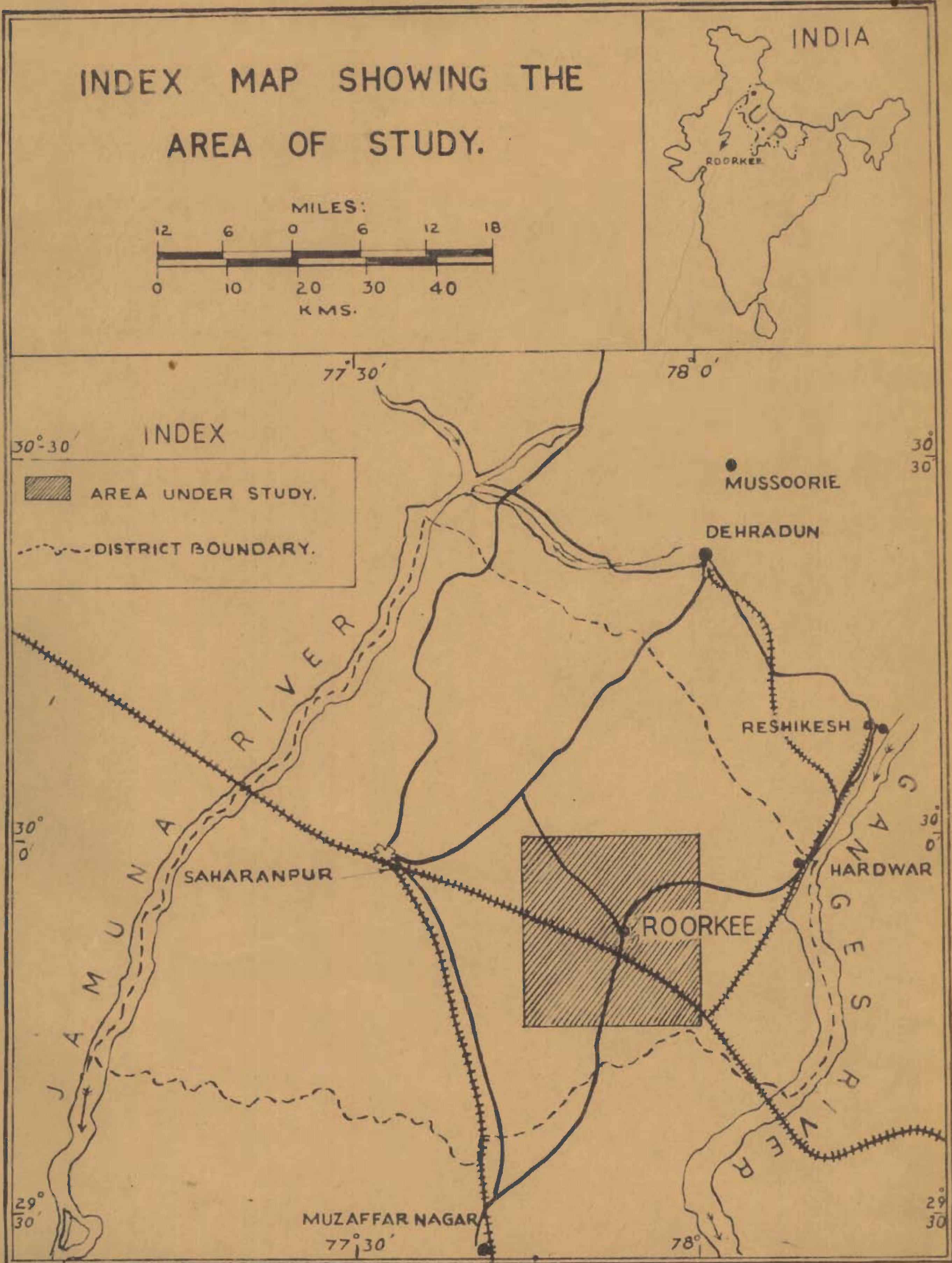
Though investigations for water supply and ground water inventory have been carried out by the officers of the Geological Survey of India from time to time in areas close to the present study, no attempt has been made so far to collect and interpret hydrogeological data on a long term basis. Apart from this, the inventory type of studies undertaken in the adjoining areas do not fulfill all the needs of an applied study on ground water situations. As such, the present area is considered almost as untouched by any ground water geologist or hydrologist.

ii) Previous Work:

To mention a few such earlier investigations, Auden (1934-1936),[1,2] retired Superintending Geologist, Geological Survey of India, submitted to the then United Provinces State Government, number of technical reports related to ground water occurrence and suitability for sinking irrigation tubewells in the Gangetic

3

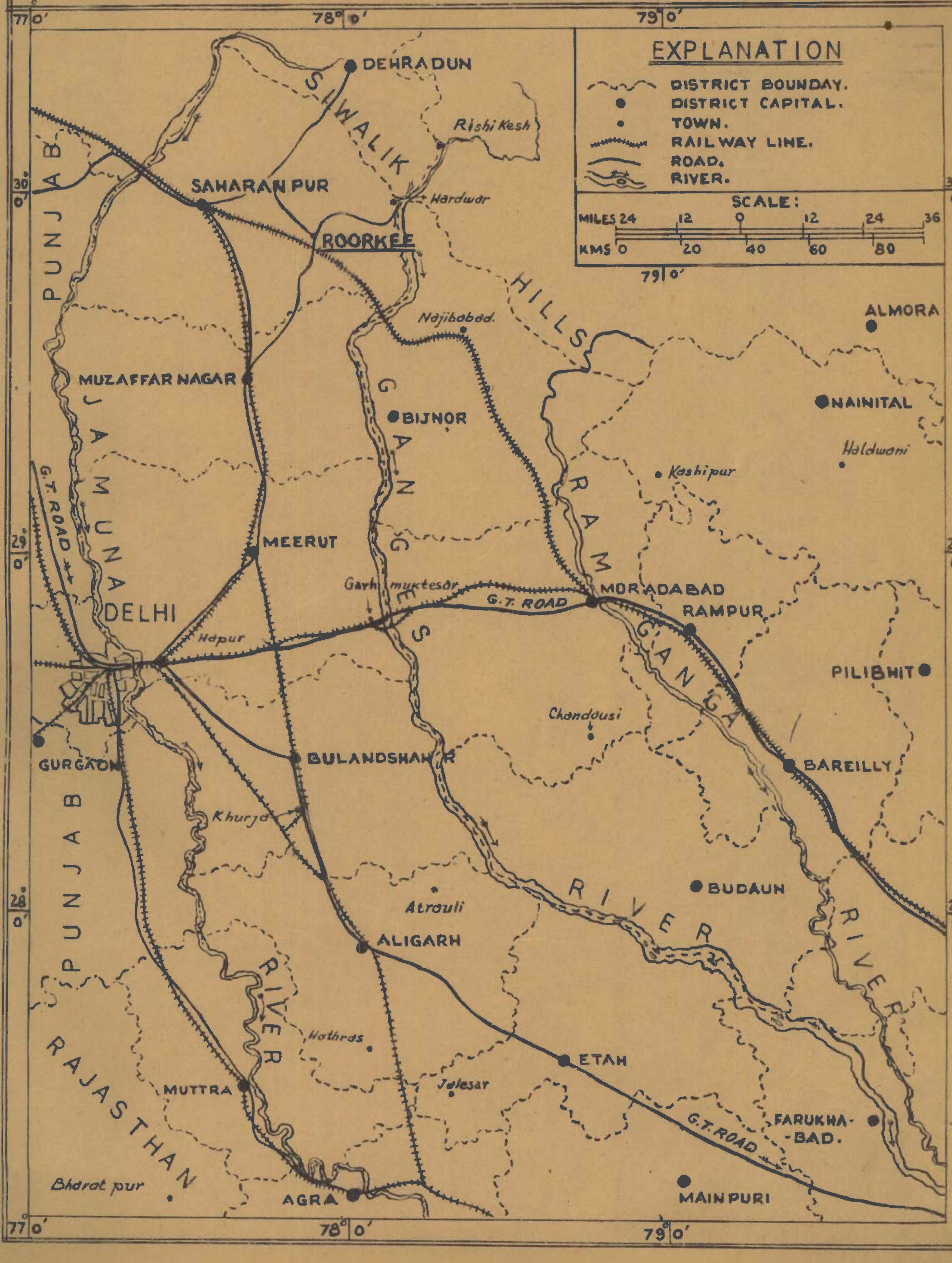
PLATE No I



INDEX MAP SHOWING THE AREA OF STUDY.
MILES:
12 6 0 6 12 18
0 10 20 30 40
KMS.
INDIA
U.P.
ROORKEE
INDEX
AREA UNDER STUDY.
DISTRICT BOUNDARY.
77°30′
78°0′
30°30′
30°0′
29°30′
MUSSOORIE
DEHRADUN
RESHIKESH
HARDWAR
SAHARANPUR
ROORKEE
MUZAFFAR NAGAR
JAMUNA RIVER
GANGES RIVER

PLATE № II

GEOGRAPHICAL LOCATION MAP OF WESTERN UTTAR PRADESH.



alluvial tract of the United Provinces (present Uttar Pradesh State). As part of the field investigations under 'Ganges Valley State Tubewell Irrigation Scheme', Mackenzi Tylor (1934)[1] has conducted field experiments to study the transmitting capacities of the water bearing formations in selective regions of the Gangetic Valley and came to the conclusion that in this alluvial valley tubewells of 1.5 cusecs capacity spaced a mile to a mile and half apart can safely be operated without any appreciable depletion in the regional water table. In the year 1943,[3] Nautiyal, Superintend-ing Geologist, Geological Survey of India, carried out investigations on the water supplies of the Terai-Bhabar belt of Nainital District, Uttar Pradesh which lies about 100 miles East of the present area of study and reviewed the reasons for the decline of artesian pressure heads in some of the flowing wells close to Kichha Farm. Later, in the same area, Shah (1959-60 and 1960-61),[4] Geologist, Geological Survey of India, continued the ground water inventory as a follow-up work of exploratory drilling operations (1958-60) in Nainital District. From this study, he has brought out the water table maps for this region and observed that the difference in the elevation of the Bhabar and Terai belts and the slope of the water bearing granular beds towards the Terai (where these pinch out), appear to build artesian head in these beds. From the study he has also inferred that the Terai aquifers maintain hydraulic continuity with the Bhabar deposits upgradient.

The results of ground water exploration in the Terai-Bhabar belts and intermontane Doon Valley of Western Uttar Pradesh conducted by the Exploratory Tubewells Organisation, Ministry of Food and Agriculture, Government of India, were embodied in a Technical Bulletin (1962)[5] of the Organisation entitled 'Ground Water Resources of Terai-Bhabar Belts and Intermontane Doon Valley of

Western Uttar Pradesh' (in press). The authors reviewed, in this publication, the potentialities of the Bhabar and Terai aquifers for construction of heavy duty irrigation wells and also indicated that in the Terai belt of Saharanpur district the confined aquifers did not reach fully the equilibrium stage.

Ground water inventory traverses were under taken by Dubey[6] (1959-60 and 1960-61), Geologist, Geological Survey of India, in the Doon Valley and parts of the foothills region of Saharanpur District. He concluded that the water table follows the master slope of the country or the local configuration of the topography and the general ground water gradient of the region is southwardly i.e. from Bhabar to Terai. He further observed that the recession of the water level in the open wells in the Doon Valley during the year 1960 was of the order of ½ of a foot to 28 ft.

Pathak, Geologist (Sr.), Geological Survey of India, carried out traverses in the Indo-Gangetic Valley in connection with the selection of sites for ground water exploration (1958-1961).[7] He also worked in detail on the ground water conditions in Azamgarh-Balia Districts of Eastern Uttar Pradesh as part fulfillment of a doctoral thesis.

Mathur[8] (1957-58) of the Banaras Hindu University covered the study on the ground water conditions in parts of the Meerut District lying 60 miles South of the present area of investigation. The study emphasises the disposition of the regional water table in the highly tubewell developed well field areas and also the movement of ground water in the area lying between the major rivers Ganges and Yamuna. Ahmad[9] (1959), Geologist (Sr.), Geological Survey of India, also carried out short term investigations pertaining to problems suggested by the Irrigation authorities of the Uttar Pradesh Government in Saharanpur District and close to Muzaffarnagar and Meerut towns.

Chaturvedi and Mittal (1963) in their paper[10] described the ground water conditions in Ganges-Ramganga 'Doab'* of Bijnor District, Uttar Pradesh. This area lies adjacent to District Saharanpur and is 35 miles in S.S.E. direction. The study bears emphasis on the chemical quality of ground waters for irrigational purposes. It also brought to light the gradual enrichment in the alkalinity, chloride and bicarbonate content of the ground waters from north to south in the region.

Besides the above, the engineers attached to the Irrigation Research Institute, Roorkee, are also engaged in ground water studies of the alluvial tracts lying between Ganges and Yamuna rivers in the districts of Muzaffarnagar, Meerut and Bullandshahr of Uttar Pradesh. In one of their noted[11] Technical Memorandum (I.R.I.No.31, 1961) Dwivedi and Gupta reviewed the behaviour of ground water table in Ganga-Yamuna Doab and estimated the ground water potential of different areas in the doab for future utilisation. In this study methods have also been suggested to control the water-logging conditions in parts of the doab area. Bhattacharya (1954) of the Irrigation Research Institute based on a statistical approach also studied the regional depletion of the water table in the doab area and the rate of penetration of the rain water to the ground[13] water table in western Uttar Pradesh.

The authors of the technical Bulletin entitled 'Groundwater Studies with special reference to quantitative Assessment in parts of Aligarh, Etah, and Bullandshahr Districts, Uttar Pradesh(India)'

---

* Alluvial area lying between two major river courses and holds promise as a water container especially for sinking irrigational tubewells.

E.T.O., (1965; under submission to press) also indicated through studies on sub-surface correlations and hydrological test data analysis, the presence of water table conditions in Atrauli and Khurja areas within 300 ft. depth and in Aligarh-Hathras area leaky confined conditions. Quantitative ground water studies were also attempted in the areas mentioned above; the recharge and draft in the areas mentioned above; the recharge and draft effecting the ground water reservoir have also been worked out.

Besides the above, the geologists attached to the Oil and Natural Gas Commission, Dehra Dun, worked out in detail the geology and structure of the Siwalik hill range, bordering the northern fringe of the area under consideration. Most of their reports are confidential and have not been published so far. However, whatever is available have been referred at the appropriate places. (14)

iii) Scope of the Present Studies:

Generally alluvial formations do not reckon as significant geological units. This becomes paradoxically the reverse case for ground water prospecting as the unconsolidated alluvial formations act as excellent repositories for ground water resources. In the district of Saharanpur, three distinct alluvial deposits, namely the '<u>Bhabars</u>', the '<u>Terai</u>' and Gangetic 'alluvial' formations constitute the 'Recent' Geological formations of the region. The diversity of ground water conditions, the wide disparity in the hydraulic characteristics of the aquifers in the individual alluvial units mentioned above and the vastness of the problem in analysing the ground water regimes in detail in each of these units, has necessitated an intensive study only in the area close to Roorkee in Saharanpur district. The research aimed at being of applied nature, quantitative approach to studies on ground water hydrology, have been given due importance. The coverage of the study has been done under eight chapters.

In this present chapter, the introductory aspects and the previous works have been touched while the second forms a basis for obtaining an idea regarding the geology and general ground water conditions against a regional back-ground. Under this, the field techniques governing the collection of basic data, regional geology and structure, geology of the alluvial formations including the soils with special reference to their sub-surface disposition and texture, general water yielding properties of the rock formations have been outlined. The evaluation of drainage trends as part of geomorphic history of the area with the help of aerial photographs and construction of isopach maps of the water bearing formations constitute an important part of these studies.

Chapter III, deals with the nature and occurrence of ground water in the alluvial formations, the movement of shallow and deep ground waters, the pressure heads of the confined aquifers, rise or decline of the water table in the near surface ground water reservoirs, effects of canal drainage on the ground water situation, establishment of the well field areas and computation of the rate of ground water recharge to the well field areas through flow-net analysis. The last item is a new attempt as far as Gangetic alluvium is considered and may find a wide application in the quantitative ground water studies elsewhere in the country.

The geohydrologic parameters such as transmissibility, field permeability and storage coefficients of the aquifers, the well characteristics such as well losses, formation losses and entrance velocities have been covered in the fourth Chapter. The influence of the geohydrologic boundaries on the well performance has been discussed and it has been observed that the ultimate ground water development of the Ganges Valley is hinged to the careful analysis of such parameters including the vertical drainage or permeability and thickness of the aquicludes.

Besides the above, special techniques such as mapping of specific capacities on a regional basis, application of the science of geomorphology for the solution of the apparently anomolous ground water situations have been introduced for the first time in the Indo-Gangetic alluvium, which is considered as one of the rich ground water reservoirs.

Under Chapter V, the results embodying the effects of meteorological and artificial factors on ground water regime close to the Upper Ganges Canal in Roorkee area have been reviewed. The water level data are interpreted in the light of the statistical methods which are in vogue to establish the relationship between the various dependencies governing the overall ground water regime. The second statistical method covering the linear correlation elaborated in the text has been applied to ground water data in the country for the first time.

In Chapter VI a further attempt, to what has been described in the preceeding chapter, has been made to study the effects of canal water temperature and air temperature on the near surface ground waters. The study on the relationship of thermal regime to depth of water table and depth of hydrogeological stations has also been covered.

The chemical nature of ground waters are discussed in Chapter VII. Since deep ground waters are mainly used for irrigational purposes in the area, their suitability for such purposes and also for allied purposes is demonstrated through graphing procedures. Areal study of water quality is brought out through chemical quality maps. The reaction of water to soil in irrigated areas is predicted by use of the sodium - adsorption ratio diagrams. Relations of chemical variables to hydrologic variables is attempted by studying the changes in the chemical regime from areas of recharge to areas of ground water extraction.

Attempts on the quantitative ground water studies in the Indo-Gangetic alluvium are highterto very limited. In order to identify the functional conditions of the reservoirs the studies attempted in Chapter VIII include measurements on total storage, inflow and outflow, recharge and draft to the ground water body. This study is based on the pump test data and well log data together with the hydrological and hydrometeorological components (hydrographs, precipitation, evapotranspération data etc.). These have permitted an assessment and partly budgeting of ground water resources in the Roorkee area.

In the end it may be added here that ground water studies generally demand long periods of observation and data collection before subjecting the same to multiple ways of analysis. In view of this, routine collection of data after preliminary establishment of the hydrogeological stations is imperative. The entire interpretation of the hydrogeological data and even most of the collection of data are that of the author himself. However, some field data collected by the E.T.O. on the lines suggested by the writer has also been utilised.

— ••• —

CHAPTER II:

GEOLOGY AND GENERAL GROUND WATER CONDITIONS:

Location:

The alluvial area under study, covers nearly 250 sq. miles in the Saharanpur District and falls around Roorkee. It lies between 29°43' and 30°0', north latitudes and 77°44' and 78°0' east longitudes (Plate I) included in the Survey of India one inch to a mile topographic sheet No.53G/13. Roorkee is the principal town in the region. Hardwar, a famous pilgrim centre is 20 miles northeast of it and Dehradun, the seat of quite a number of important Federal Government Offices is 42 miles north-west of it. The road connecting Delhi and Dehradun and passing through Roorkee, runs almost north-south. It is also well connected by rail communications. The rest of the area is communicable through unmetalled roads and cart tracts. The Upper Ganges irrgation canal crosses the area roughly in a N.N.E. to S.S.W. direction and is more than a century (1845) old.

Natural Features:

Physiography:

Physiographically this region can be divided into four distinct units, namely, the lofty 'Lesser Himalayan belt' rising to an average altitude of 10,000 ft. at the northern extremity, the 'Intermontane Valley' located between the Lesser Himalayan ranges and the 'Foot-Hills zone' of the Siwaliks, this 'Foot-Hills zone' ranges upto an elevation of 3000 ft. and the sloping submontane tract south of the foot-hills almost merging with the Indo-gangetic plains. The picturesque intermontane valley called as the Doon Valley is at an altitude of 2000ft. above mean sea level -- and stretches roughly in a N.W. - S.E. direction. It is 50 miles long and has a maximum width of 12 miles.

Photograph No.1.

A general view of River Solani close to Roorkee (Upstream).

Photograph No.2.

A general view of the Upper Ganges Canal close to Roorkee.

The sub-montane tract close to and just south of the Siwalik hills is made up of the Bhabar and Terai belts. In this area these belts exhibit a general slope towards the south roughly with a gradient of 80 ft. and 40 ft. per mile respectively. The elevation of the Bhabar belt is between 1100 to 1300 ft. above mean sea level (MSL) and the Terai belt is 1000 - 1100 ft. above MSL. The slope gradually decreases and the ground becomes almost flat towards Roorkee and forms part of Gangetic plains. The general elevation of the plains close to the southern boundary of the Terai belt is of the order of 900 - 950 ft. It grades to 850 - 900 ft. further 10 miles south.

Drainage:

River Solani flows through the area from the north-west to the southeast. North of Roorkee town there are drainage lines of other small rivers or streamlets such as Sipia, Haljora and Ratmau Rao. The river Solani which is the main river draining the area, cuts across the canal close to Roorkee town. The river bed is much lower to the canal base in this part of the river course. Similarly, some of the tributaries of the river Solani cross the canal almost at the same elevation in the higher reaches of the canal. The River Ganges emerges out into the plains at Hardwar. The confluence of the river Solani with the Ganges takes place 25 miles south-southeast of Roorkee town proper.

Flora and Fauna:

The foot-hills region and the hill ranges are clothed in thick green vegetation constituting the dense and rich Himalayan Sal (Shorea robusta) forest. In the valley, besides the tea plantation, the important nursery plantation is the Lichi (Lichi Chinensis). The Bhabar slopes present thick, shrub jungle. The Terai region is a marshy land with the Savannahs of grass and reeds. The Gangetic plains present comparatively sparse natural vegetation.

The wild life in the area is well represented in the sanctuary situated in the Siwalik Hills close to Mohand and 22 miles due north of Roorkee. Tiger (Panthara Tigris), leopard (Panthara Pardus), elephant (Elephus maximus), barking deer (Muntiacus muntjak), spotted deer (Axis axis) Sambhar (Rusa Unicolour), blue bull (Bocalephus tragocamelus), peacock (Pava cristacus) and fowls (Gallus gallus), represent the general fauna of the area.

Climate:

The winter season begins towards the end of October and extends upto March. The peak summer months are May and June. Rainy season extends from the middle of June to the end of September. The minimum temperature touches (-)2°C occasionally, though the maximum is 46°C. In general, compared to the plains the Valley presents an embracing climate for most part of the year except for the hot months of May and June.

Rainfall:

The rain fall is not uniform in its areal distribution. The sub-montane and inter-montane tracts enjoy the heaviest precipitation, the annual mean being 55 (1400 mm) and 85 (2160mm) inches respectively. In the plains close to Roorkee the precipitation is of the order of 40 (1010 mm) inches per annum. More details on the distribution and intensity of rainfall on a monthly and daily basis close to Roorkee are presented under relevant chapters (V and VI).

Run-off:

The run-off map of the Meteorological Department, India shows the area under study lying between 10" and 15" run-off lines.

This forms about 30 percent of rain fall in the plains, 25 percent in the sub-montane and 15% in inter-montane tracts.

Field Canvassing techniques:

In regional studies, ground water inventory of shallow dug wells and deep tubewells constitutes one of the essential surveys. Under this field study the area has been canvassed for collection of water level, temperature and chemical data for summer months (low water-level period) for three years (1961-1963). The contemplated survey also covers the pumpage inventory of the existing irrigation tubewells in the area. The data pertaining to the nature, intensity and magnitude of rainfall, humidity, air temperature, evaporation and other meteorological observations have been collected from observatories situated, as far as possible, close to the well stations used for repeat measurements. The spacing of the inventoried wells was generally kept at a distance of one to one and half miles apart.

Field work was carried out with the help of Survey of India toposheets on one inch to a mile scale. For well numbering, the standard notation adopted by the Geological Survey of India is as follows. Each 1" - toposheet is divided into 9 quadrants by the latitudes and longitudes drawn at 5' intervals; the latitudinal ones are 1, 2 and 3 from top to bottom and the longitudinals A, B and C from left to right. Thus under each head of A, B and C there are three quadrants 1A, 2A and 3A etc. The wells falling under these quadrants are numbered as 1A1, 1A2 and so on, for all the quadrants. Since all the one inch to a mile topo-sheets have the same quadrants, for identification of individual wells, the number of the topo-sheet is always indicated before the well number, e.g. 53G/13-1A3 and 53F/15-2A1 etc. But

PLATE No III

MAP SHOWING THE LOCATION OF THE OPEN WELLS INVENTORIED IN ROORKEE AREA.

SCALE 1:126,720

0 1 2 3 4 5 6 7 8 KILOMETRES.

0 1 2 3 4 5 MILES.

EXPLANATION

35 ⊙ OPEN WELL INVENTORIED.

RAILWAY LINE.

ROAD.

RIVER.

CANAL.

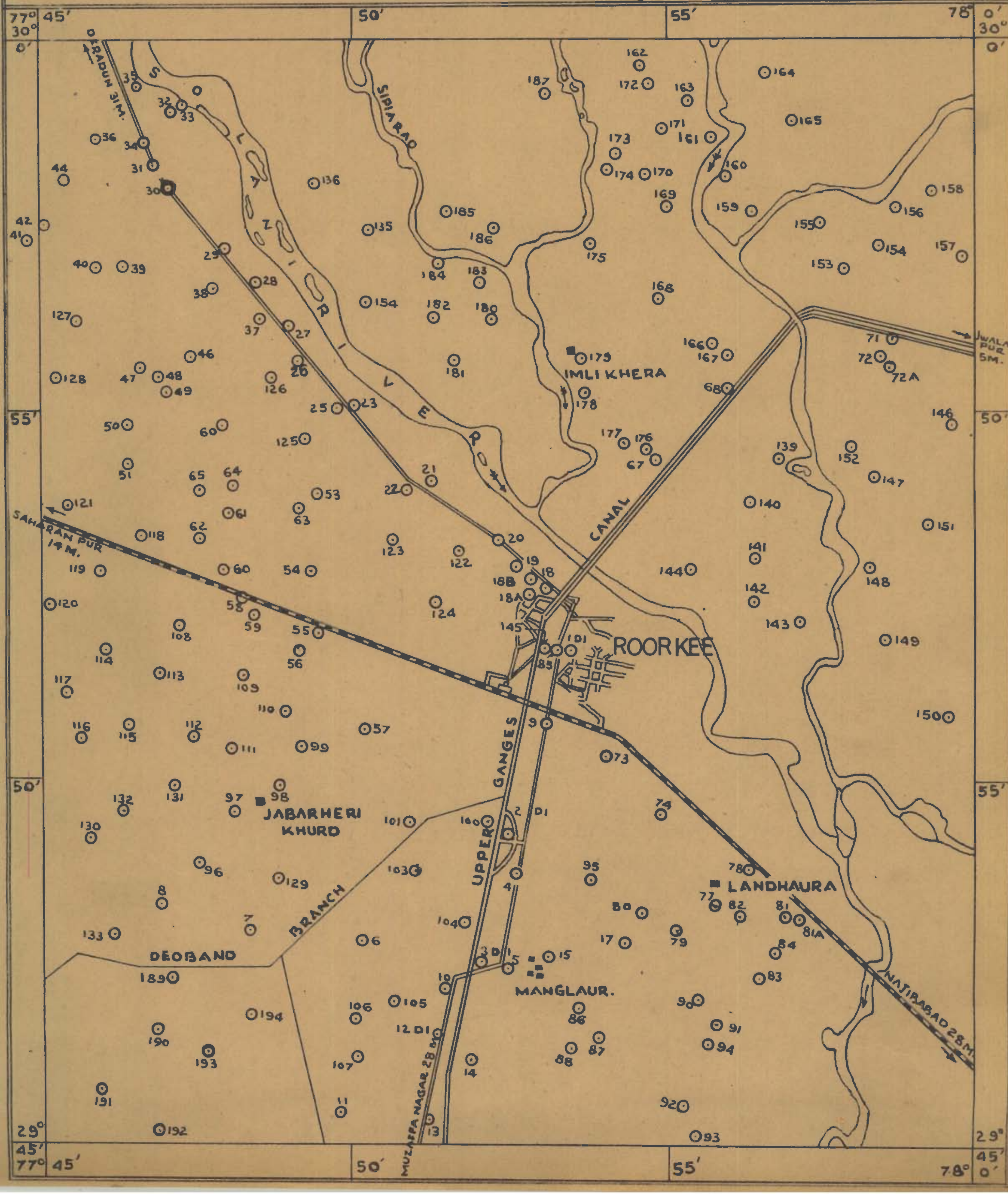
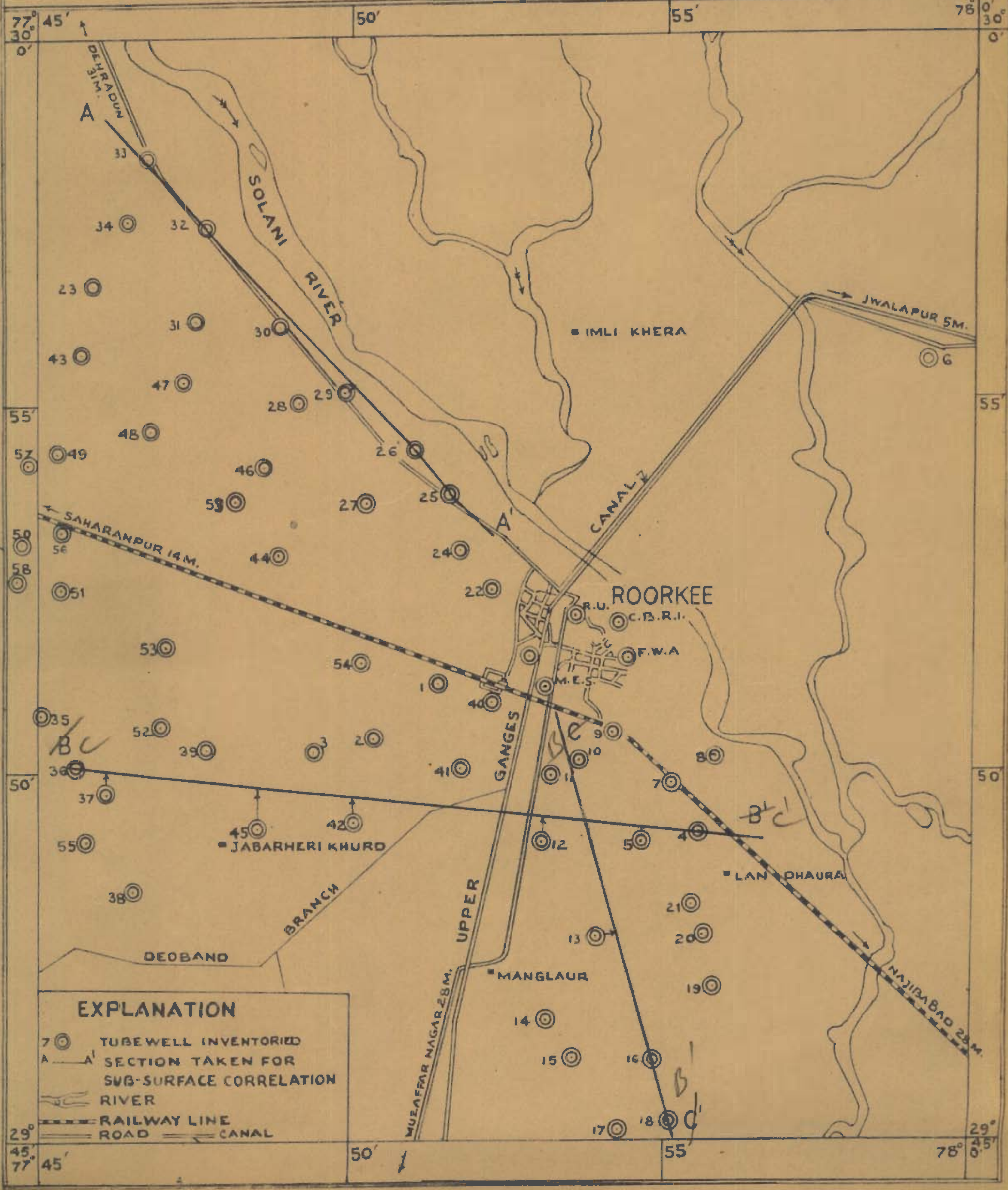


PLATE No IV

MAP SHOWING THE LOCATION OF TUBE WELLS INVENTORIED IN ROORKEE AREA AND SECTIONS TAKEN FOR SUB-SURFACE CORELATION



in the present area the wells have been numbered in series except for a few of the hydrogeological stations utilised for repeat water level measurements. These have been selected initially on a quarter inch topo-sheet (scale : 1 inch to 4 miles) and as such their numbers relate to sixteen quadrants (A,B,C and D and 1,2,3 and 4) alongwith the number of the topo-sheet prefixed to the well number e.g. 53G-1D1. The numbering of the State Tubewells have been retained as originally proposed by the State authorities.

Field collection of water level data was not restricted to seasonal measurements only. Some of the hydrogeological stations (open wells) were utilised for daily or monthly measurements too. The wells covered under the inventory were connected by level survey, and the reduced levels of the measuring points and water table were computed. Nearly 194 open wells, and 56 tubewells have been inventoried in the area for the present study (Plate Nos. III and IV).

The basic idea in the collection of this data was to bring out the ground water contour maps and evaluate ground water flow situations, recharge and discharge. Quality maps could also be prepared from such data. The same would further help in visualising the change in ground water regimes and storage. The relationship between ground water hydrology and meteorological factors could also be studied through hydrographs prepared with the help of systematic seasonal data.

GEOLOGY OF THE AREA:

a) Regional Geology:

In order to give an over all picture of the general succession of the geological formations from the Himalayan belt to the Gangetic alluvial plains, the regional geology has been presented in the following pages. In the region, the geological formations constituting the foot-hills Himalayas belong to the Tertiary and further south they are of Quarternery age. Along the northern fringe of the Doon Valley older rocks constitute the Himalayan complex. These formations range in age from Algonkian to Middle Miocene (Plate No.V). The foot-hills Himalayas display a great sequence of fresh water deposits.

The Bhabar formation, lying south of the Siwalik hills constitute the integrated alluvial fan deposits of streams emerging from Himalays. It would be difficult to define the Terai formation strictly in a geological sense, except for its individuality as a zone of recently formed Gangetic alluvium. The intermontane Doon Valley is covered by recent alluvial fill which conceals the underlying Siwalik formations. The general succession of the formations is given below:

	Plains and Foot-hills Area	Inter Montane Valley (Doon Valley).	Lithology
RECENT	Bhabar Deposits Terai Deposits Gangetic Alluvium	Dun and Recent deposits	Dun and Recent Deposits: Clays (brown to light grey) sandy clays, sands and gravel (angular)associated with boulders, cobbles and pebbles Bhabar Deposits: Integrated alluvial fans deposits, essentially constituted of sand-boulder, clay-boulder beds with gravels. Terai Deposits: Clay, sandy clays, sands with gravels and pebbles. Gangetic Alluvium: Sands, Silts, clays and kankars with occasional gravel beds and lenses of peaty organic matter.

	Plains and Foot-hills Area	Inter Montane Valley (Doon Valley).		Lithology
TERTIARY	Siwaliks Upper Siwaliks Middle Siwaliks Lower Siwaliks	Pliocene to Miocene	Upper Siwaliks	Upper Siwaliks: Pebble, boulder conglomerates, sand rocks and green and maroon clay beds.
			Middle Siwaliks	Middle Siwaliks: Massive sand rocks, light grey sandstones resembling 'flysch' deposits, associated with clay and calcareous beds.
			Lower Siwaliks	Lower Siwaliks: Hard massive, grey to brownish sand stones, grey to maroon clays and shale beds.
		Middle to Lower Miocene	Dagshai, Kasauli	Kasauli: essentially massive grey sandstones intercalated with violet and grey clays. Dagshai: Purple grey or green hard sandstones and bright red nodular clays.
		Lower Eocene	Nummulitic shales (Subathus)	Subathus: Pisolitic laterites, greenish grey and red gypseous shales, calcareous and arkosic sandstones; fossiliferous.
MESOZOIC		Jurassic	Lower and Upper Tals	Tals: Micaceous shales (fossiliferous) quartzites, dark limestones, dark greywackes and phyllites.
PALAEOZOIC		Triassic to Permian	Krols and Infra-krols	Krols: green and grey slates, red shales and massive limestones. Infra-Krols: dark slaty shales, sandstones and thin bands of quartzites.
		Upper Carboniferous	Blaini boulder bed	Blaini boulder bed: Dark grey to brown boulder bed with pebbles of slate, quartzite and sandstone, set in a fine clayey or gritty matrix.
PROTEROZOIC AND AZOIC		Algonkian to Archaeans	Jaunsars, Chandpur, Nagthat and Simla Slates	Jaunsars, Simla Slates etc: Phyllites, banded quartzites, tuffs and metamorphosed slates.

Photograph No.3.

A general view of the Siwalik Foot Hills Range with the Bhabar alluvial belt in the fore ground.

<u>Photograph No.4.</u>

The writer with Prof. Leo Piccard, Professor of Geology, Hebrew University, Jerusalem at one of the water well (ETO) drilling sites, Jwalapur (18 miles North-east of Roorkee). In the background Upper Siwalik hillocks are also seen.

b) Geological Structure:

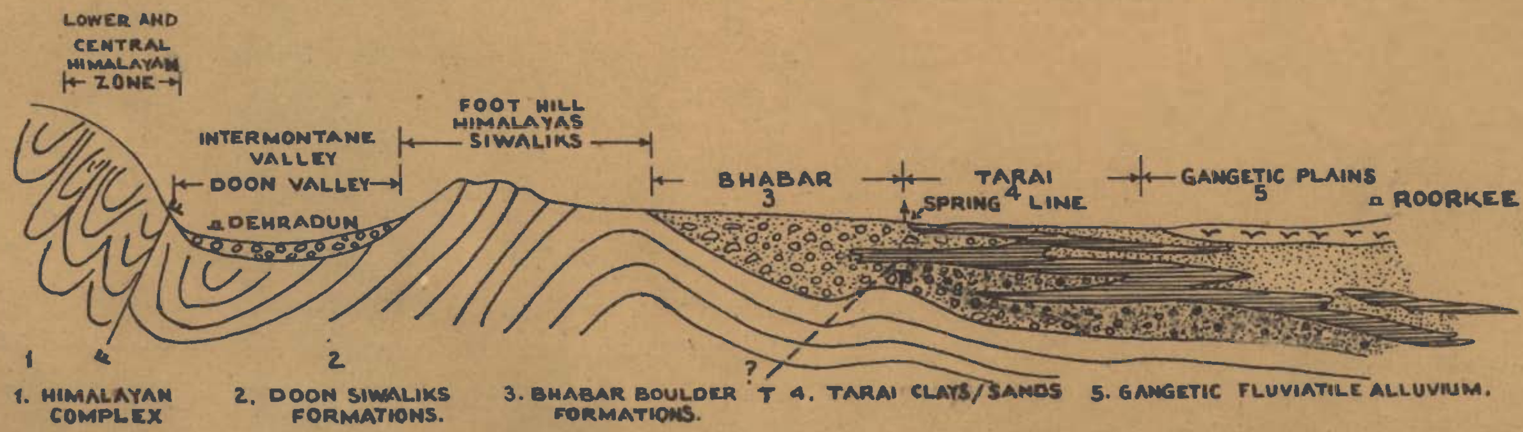
The main Himalayan zone north of the area is one of the highly disturbed regions and is also of considerable significance in the tectonic history of India. South of the Lesser Himalayan zone is the wide 'Dun Syncline' extending between Rishikesh and Nahan, containing folded Neogene and pliestocene sediments. In the plains the two units of the Indo-Gangetic alluvium (Ganges and Indus basins) are separated close to the present area of study by a narrow low ridge passing through Delhi and Ambala. This ridge is considered to be a continuation of one of the ancient mountain ranges named Aravallis. The same is not noticeable on the surface as it is covered by alluvial deposits of recent date.

In the above mentioned disturbed regions, the main Boundary Fault separates the Siwaliks from the Simla slates. The Tertiaries are separated by pre-Tertiary rocks by the Krol Thrust. Recent detailed studies in Siwaliks also indicate that these members of the Foot Hills Himalayan zone are often folded, faulted, over thrust and lie at steep angles against other formations.(14) Some of the thrust planes are reported as culminating into the foot-hills region and also into the alluvium. Deep seated major faults are reported in the plains of the Gangetic alluvium.(15and10 The Jamuna and Ganges rivers follow major structural weak zones (probable faults) in their courses through the lower Himalayan ranges. The Siwaliks hills between the Ganges and the Jamuna rivers are folded, and the structure is known as Mohand anticline. Near the Ganges, the southwestern limit of this anticline is thrusted over the north-eastern limit. It is not unlikely that this thrust axis continues into the alluvium and may pass in between Ganeshpur and Ismailpur wells as drilling at these

PLATE No VI

SKETCH MAP SHOWING THE STRUCTURE OF MAJOR GEOLOGICAL FORMATIONS ALONG ROORKEE-DEHRADUN SECTION.

(NOT TO SCALE)



sites indicated the presence of Siwaliks in the former at a depth of 250 ft. (?) and complete absence of the same down to 812 ft. depth at the later site (Plate No.V). Even in the recent alluvium along the river terraces in Doon Valley, evidences of slipping of strata on a minor scale are recorded (Photograph No.1). A schematic diagram (Plate No.VI - not to scale) has been brought out to show the disposition, structure and inter-relationship of the alluvial deposits to those of the adjoining hill ranges. Writing on the Indo-Gangetic Alluvium, Krishnan (16) recorded that the deposits of this tract belong, so to say, to the last chapter of earth's history and conceal beneath them the northern fringes of Peninsular formations and the southern fringes of the Extra-Peninsular formations. This alluvial tract is of the nature of a synclinal basin formed concomitantly with the elevation of the Himalayas to its north. The earliest view put forth by Eduard Suess, holds that it is a 'fore deep' formed in front of the resistant mass of the Peninsula when the Tethyan sediments were thrust southward and compressed against them. The Peninsula is regarded as a stable unmoving mass and Central Asia as the moving segment of the crust. A more recent view regards this region as a 'sag' in the crust formed between the northward drifting Indian continent and the comparatively soft sediments accumulated in the Tethyan basin when the latter were crumpled up and lifted up into a mountain system. (17) This depression perhaps began to form in the Upper Eocene and attained the greatest development during the third Himalayan upheaval in Middle Miocene. Since then it has been gradually filled up by sediments to form a level plain with a very gentle seaward slope. Earlier to the view of Wadia, Burrard and Haden (84) considered this fore deep as a 'Rift' and later this

Photograph No.5.

Faulting in Recent Sediments (River Alluvium) on a minor scale; Tons Nadi (Doon Valley).

idea of a'Longitudinal Rift' has been revived by Mittal and Srivastava (10A) and is based on the actual data available from west Bengal Gangetic Basin.

c) <u>Geology of the Alluvial Deposits:</u>

i) <u>Description of various alluvial formations:</u>

Descriptions of the semi-consolidated or unconsolidated rocks alone are given earlier. The geology of an area is incomplete without the description of the unconsolidated formations.

The Doon-alluvial fill (Dun gravels) is made up of clays (brown and light grey), sandy clays, sands and gravels (usually angular) associated with boulders, cobbles and pebbles of limestone, shale, phyllite and quartzite. The clays are occasionally hard. The thickness of the Dun gravels is about five hundred feet and they are thicker in the eastern part of the valley compared to the west where it is only about 150 ft. Some of the Recent deposits in the valley are similar to the Duns. They are mostly light grey and brown clays associated with gravels and pebbles of quartzites, limestones, occasionally phyllites, slates and a few granitic gneisses.

The <u>Bhabar</u> formations are generally considered as integrated alluvial fan deposits or piedmont deposits at the foot of the Siwaliks. They are made up of unconsolidated sand-boulder and clay-boulder beds. The cobbles,boulders and gravels are of heterogeneous nature -- various types of quartzites, basic rocks, granitic gneisses, granites etc. The boulders have a diameter of 0.5 to 5 feet and usually of the order of 1 to 2 ft. The intercalated thin clay bands are usually brown or light grey in colour and thin out in short distances. The northern boundary of this 'Bhabar' belt is in contact with the Siwalik hill ranges and the southern limit is generally the spring line which also

Photograph No.6.

Terrace Deposits of River Ganges at Rishikesh
(32 miles North-east of Roorkee).
A : Clay - Silt Bed.
B : Terrace Boulder - Pebble Bed.

defines the northern limit of the Terai sediments. The Bhabar formations are generally considered to be of fluviatile origin but it is worth while to examine the possibility of these deposits being of fluvioglacial origin as boulders with chatter marks, oriented striations, polished surfaces are not uncommon. The width of this belt in this area is unusually very limited to about 4 miles whereas in the Haldwani area it is more than 16 miles and in Punjab it varies from 10 miles to about 15 miles. The thickness of these bouldery sediments is also limited in this region to about 250 feet while further east in the Nainital district it is nearly 550 ft.

The term Terai is more geographical than geological in its derivation. The Terai formations consist chiefly of clays, sandy clays, sands and occasionally thin beds or lenses of gravels. As indicated above the northern limit of the Terai belt is the spring line occurring at the outer fringes of the Bhabar; whereas the southern limit of the belt is not clearly defined but generally accepted as the zone where flowing conditions of sub-surface water cease to exist in the tubewells. The clays of this belt are usually grey to brown and sometimes mottled, and generally the clayey beds predominate over the sandy beds both in extensions and thicknesses. The granular beds occur mostly as lenses and sometimes interfinger with the clastic and non-clastic sediments. In the area under study the width of the Terai is about 2 miles. Like the Bhabar belt, the Terai belt is also of similar magnitude in its width further east, in the Nainital district. The area under the present study is covered by Gangetic alluvium and quoting Gulatee, Dey[21] writes "the alluvium probably attains its maximum depth of about 10,000 feet near Roorkee". If the first event in the reflection seismogram is taken as the interface

Photograph No.7.

Photograph showing lenses of peaty organic matter associated with river terrace deposits near Saidpura Village, Roorkee area. P- Peaty Organic Material.

Photograph No.8.

A general view of the terrain close to Saidpura (3 miles North-east Roorkee).

between the alluvium and older deposits, the reflection seismic work carried out by the Oil and Natural Gas Commission (India) suggests the thickness of alluvium in and around Roorkee as of the order of 1300 to 1650 ft. (Personal Communication). The Gangetic alluvium is generally considered to be made of an older and an younger horizon. The sediments are sands, silts and clays with occasional gravel beds and lenses of peaty organic matter. The older alluvium is generally differentiated from the younger by its darker tone in colour and richness in concretionary nodular '<u>Kankar</u>' (impure calcium carbonate).

In and around Roorkee area, the Gangetic alluvium is essentially made up of clays, sands and kankar and small size gravel beds. The clays are usually grey to brown in colour and are occasionally hard and plastic too. They are invariably associated with '<u>Kankar</u>'. It is of interest to note that at the Roorkee University Tubewell site (E.T.O.) and C.B.R.I. Tubewell site (E.T.O.) separated by 1000 yds only, kankar beds were encountered at 161-165 and 49-51 feet depth below land surface respectively. Lenses of peaty organic material are not uncommon in the river Solani terrace deposits in the area (Photograph No.2). The sands are mostly grey to white in colour and are micaceous too. The relative abundance of the lithological units constituting the alluvium to an average depth of 350 ft. is indicated below:-

Clay, clay with '<u>kankar</u>'	40 %
Fine to medium sand	56 %
Coarse sand, gravel and pebbles	4 %

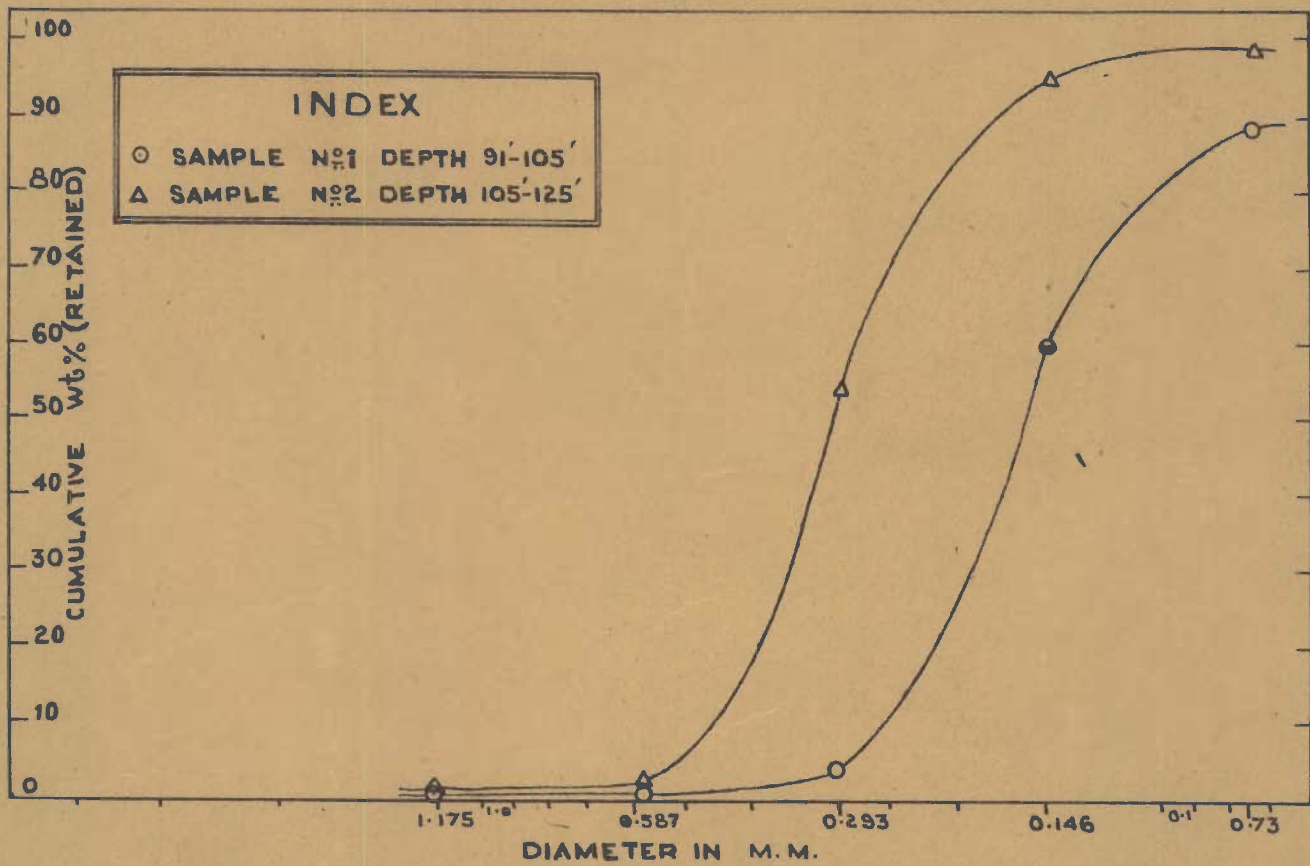
Though the colour of the sediments alone may not relegate these beds to the older alluvium, the rich <u>kankar</u> association and relatively higher elevation of the (terraces) sediments in relation to the flood plain deposits close to river Solani, place these nearer to the older alluvium category of the Indo-Gangetic sediments.

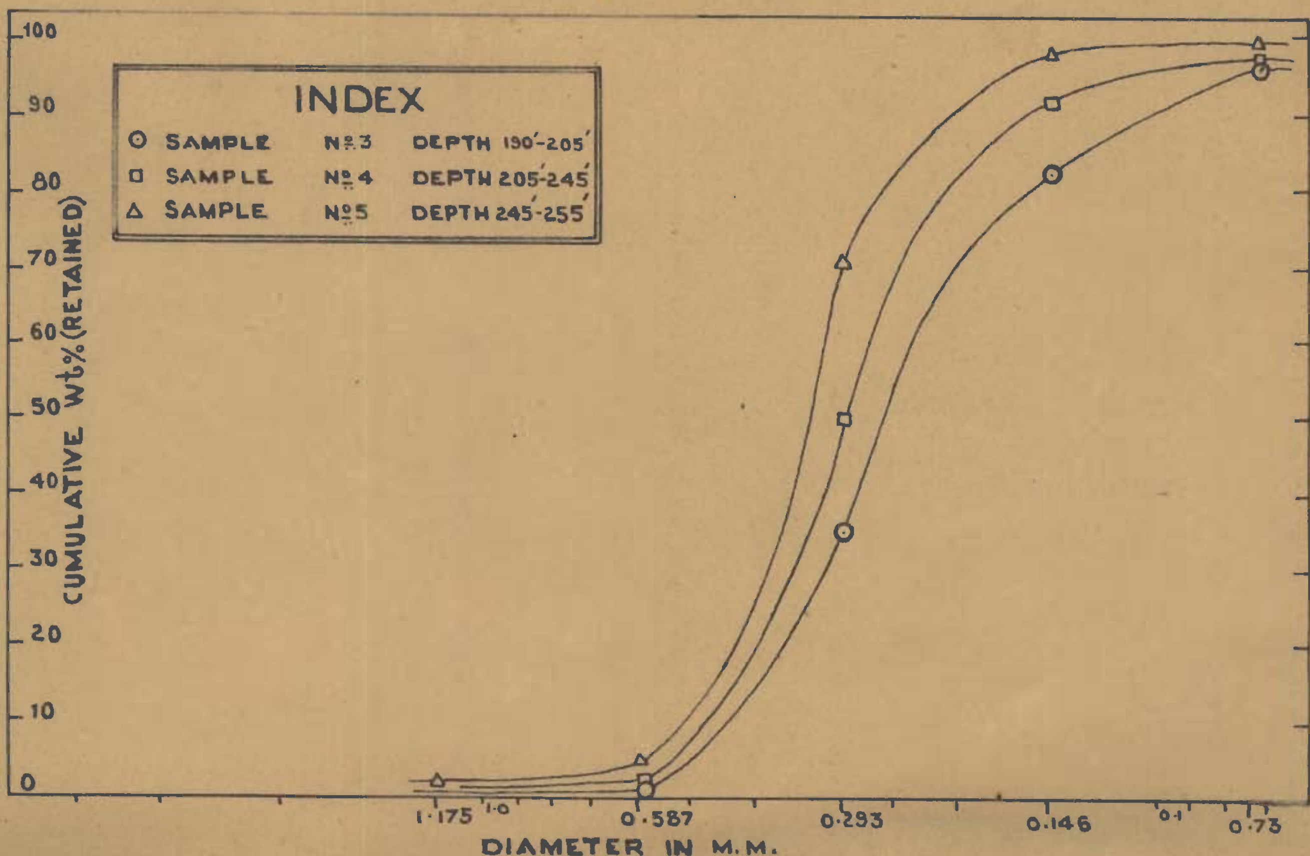
ii) Texture of Sands:

Studies on the mechanical analyses of the samples collected from different aquifer sands in Roorkee area will indicate the textural and other parameters of the water bearing formations associated with the Gangetic Alluvium. These studies will also help in evaluating partly the water bearing properties of these sediments. The sieve analyses were carried out on the samples taken from the Roorkee University, Military Cantonement and C.B.R.I. Tubewells (E.T.O.). Since these wells were drilled by reverse circulation method, the samples were clean enough for any analysis on the texture and parameters.

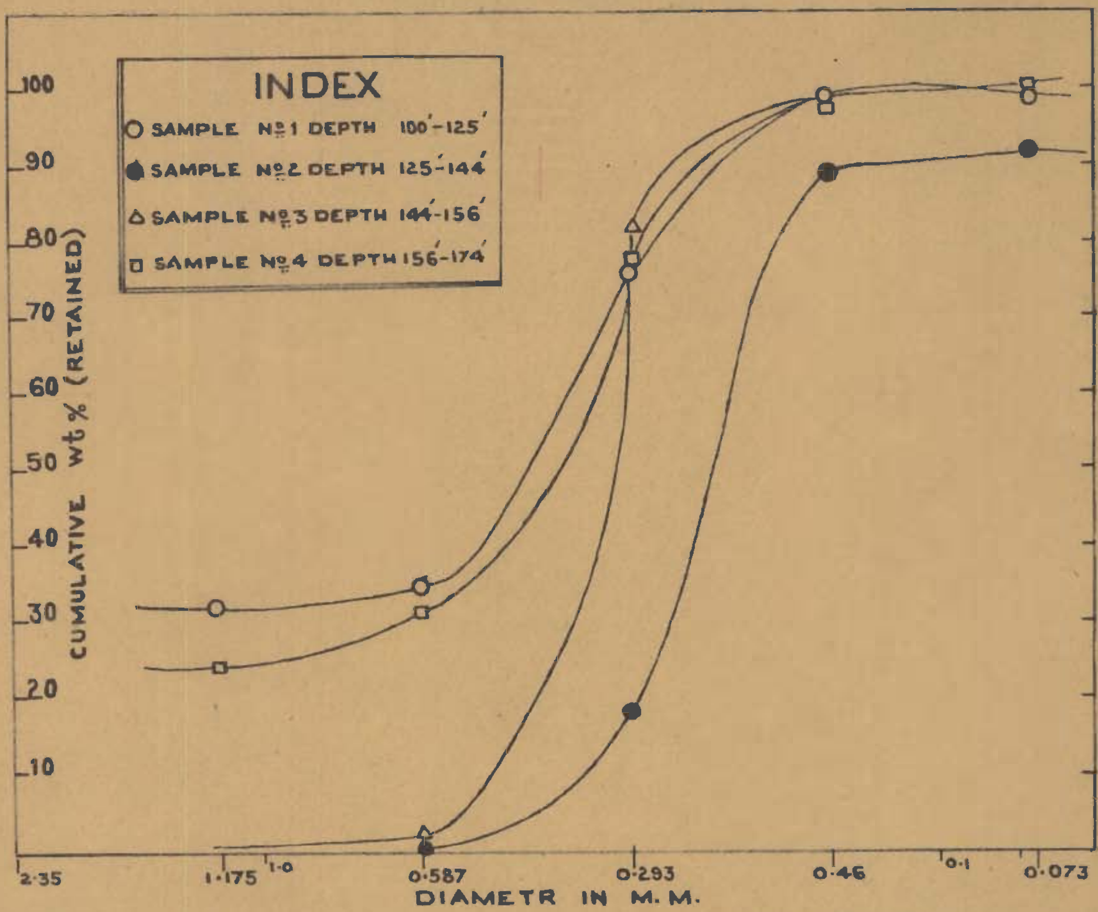
The grain size distribution curves (sand curves) for the samples of the aquifers within 255 feet are given in Plate Nos. VII A, B and C. The texture and parameters of the water bearing sands within this depth are also given in Table No.1., below:-

SAND CURVES OF AQUIFER MATERIALS, ROORKEE UNIVERSITY WELL (E.T.O), ROORKEE.





SAND CURVES OF AQUIFER MATERIALS, MILITARY CANTONMENT WELL (E.T.O), ROORKEE.



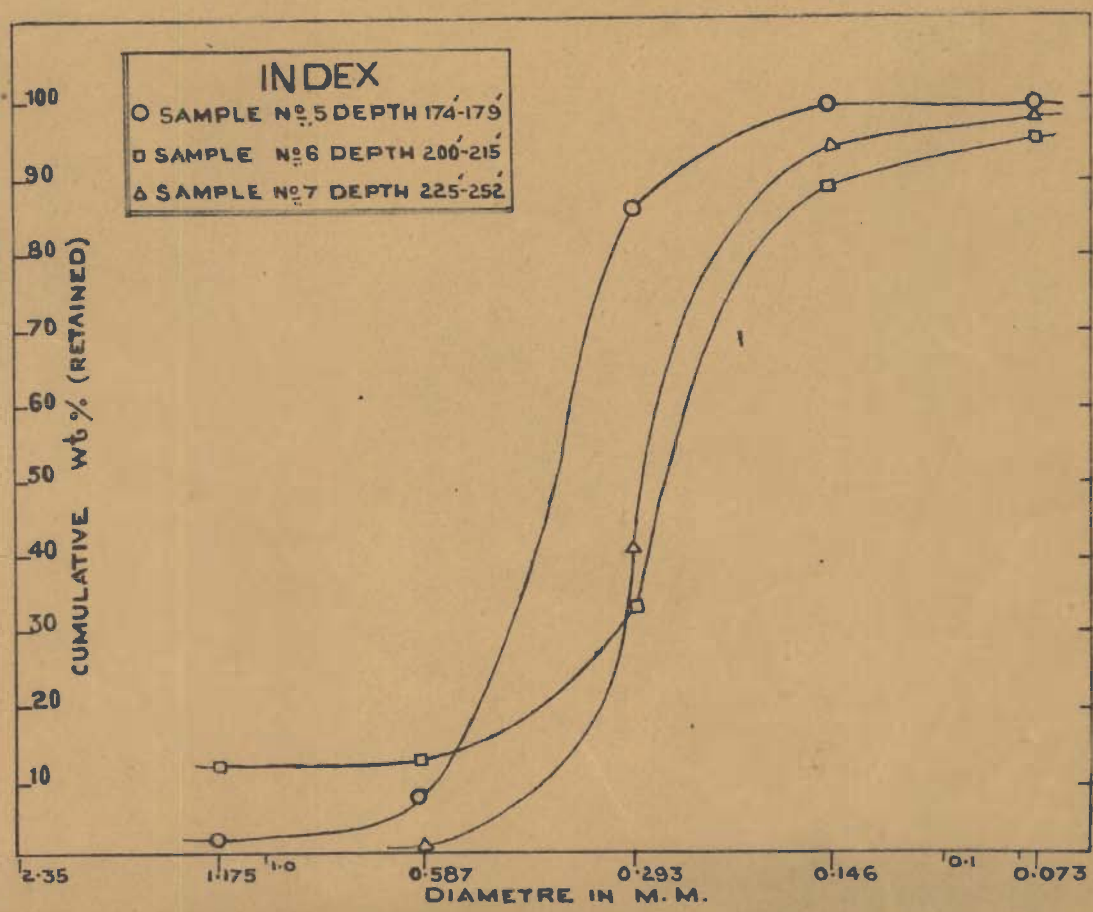


TABLE NO.1.

TEXTURE AND PARAMETERS OF THE WATER BEARING SANDS IN AND AROUND ROORKEE TOWN

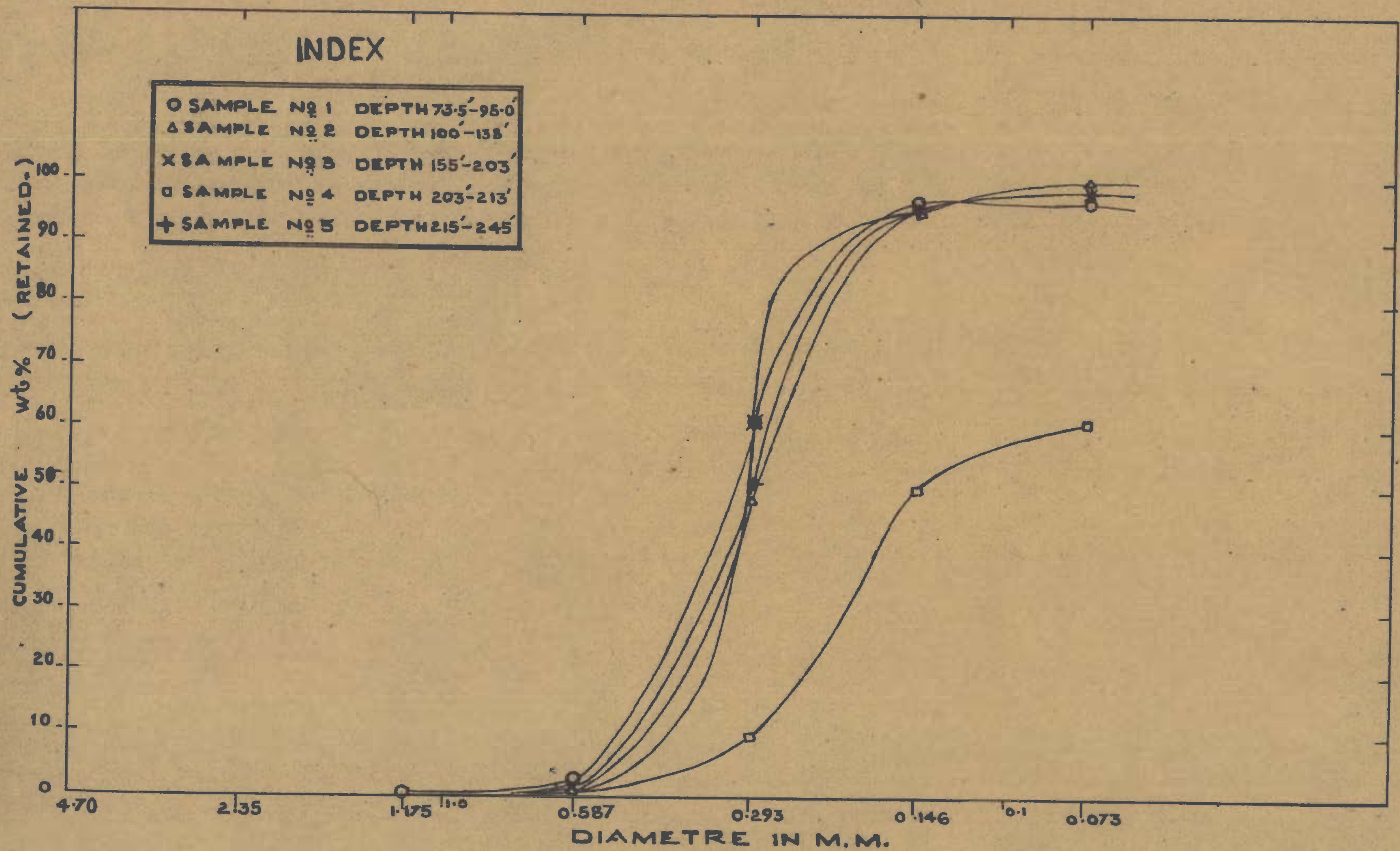
Location of well site	ROORKEE UNIVERSITY TUBEWELL (ETO)					MILITARY CANTONEMENT TUBEWELL (ETO)						
Sl.No. for the sample	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S6	S7
Depth Range (in feet)	91-105	105-125	190-205	205-245	245-255	100-125	125-144	148-156	156-174	174-179	200-215	225-25[illegible]
Parameters												
EFFECTIVE SIZE 90% (mm)	0.064	0.17	0.105	0.16	0.20	0.210	0.110	0.250	0.220	0.255	0.140	0.175
SCREEN SIZE 40% (mm)	0.173	0.325	0.285	0.32	0.35	0.475	0.230	0.320	0.440	0.400	0.275	0.290
UNIFORMITY COEFFICIENT	2.70	1.91	2.71	2.00	1.75	2.26	2.09	1.28	2.00	1.57	1.96	1.66
MEDIAN 50% (mm)	0.16	0.305	0.265	0.295	0.33	0.410	0.213	0.300	0.365	0.370	0.260	0.280
QUARTILE No.1.25% (mm)	0.204	0.37	0.34	0.37	0.41	-	0.260	0.375	1.075	0.460	0.335	0.300
QUARTILE NO.3. 75% (mm)	0.115	0.233	0.185	0.23	0.28	0.283	0.181	0.283	0.283	0.320	0.205	0.230
SORTING COEFFICIENT	1.33	1.24	1.13	1.26	1.20	-	1.20	1.16	2.43	1.20	1.27	1.14

Location of Well Site	C.B.R.I. TUBEWELL (E.T.O.)				
Sl.No. for the sample	S1	S2	S3	S4	S5
Depth Range (in feet)	73-95	100-138	155-203	203-213	215-245
Parameters					
EFFECTIVE SIZE 90% (mm)	0.200	0.180	0.220	-	0.190
SCREEN SIZE 40% (mm)	0.325	0.300	0.300	-	0.305
UNIFORMITY COEFFICIENT	1.63	1.66	1.36	-	1.61
MEDIAN 50% (mm)	0.310	0.280	0.300	0.146	0.283
QUARTILE NO.1. 25% (mm)	0.30	0.36	0.32	0.22	0.355
QUARTILE NO.3. 75% (mm)	0.25	0.22	0.275	-	0.233
SORTING COEFFICIENT	1.52	1.64	1.16	-	1.52

PLATE № VII C

SAND CURVES OF AQUIFER MATERIALS

C.B.R.I. WELL (E.T.O), ROORKEE.



From the data it could be seen that, in general, the uniformity coefficient of the granular sediments, within 70 - 255 feet depth range, varies from 1.28 to 2.71. In the area, most of the samples can be classified as medium sands as the 50% size of the material (mean diameter) falls in the grade size of 0.25 to 0.50 mm and the other samples are classified as fine sands (grade size being 0.25 to 0.125 mm). But for a few exceptions (Table No.1), based on the sorting coefficient value (2.0), it can be said that the sediments are well sorted in this area. It is noted that no relationship exists between the mean diameter or the sorting coefficient and the depth of the sediments.

iii) Texture of Soils:

In order to obtain an idea on the texture of the near surface sediments, soil samples were collected from a few locations shown on the map (Plate No.VIII). For purposes of sampling the soils, the area covering the Landhaura terrace is designated as 'A', the area west of Solani and Northwest of Roorkee town as 'B' and the area north of Roorkee town and east of Solani river as 'C'. The samples were collected from surface, at one and half feet depth and 3 feet depth and labelled as top, middle and bottom for purposes of further reference. Each sample was coned and quartered and 30 grams of the sample was further subjected to the mechanical analysis using sodium oxalate of 0.01 normalcy as the dispersing agent. Usual pipetting method has been used for separating the various grades of material and obtaining the residues. The percentage of the material in each grade size has been computed and plotted as mechanical analysis curves of the soils indicating their weight percentage relationship with that of the diameter (Plate Nos. IX A, B and C). For this purpose the grade sizes are defined as follows:

PLATE No VIII

MAP SHOWING THE LOCATION OF SOIL SAMPLES IN ROORKEE AREA

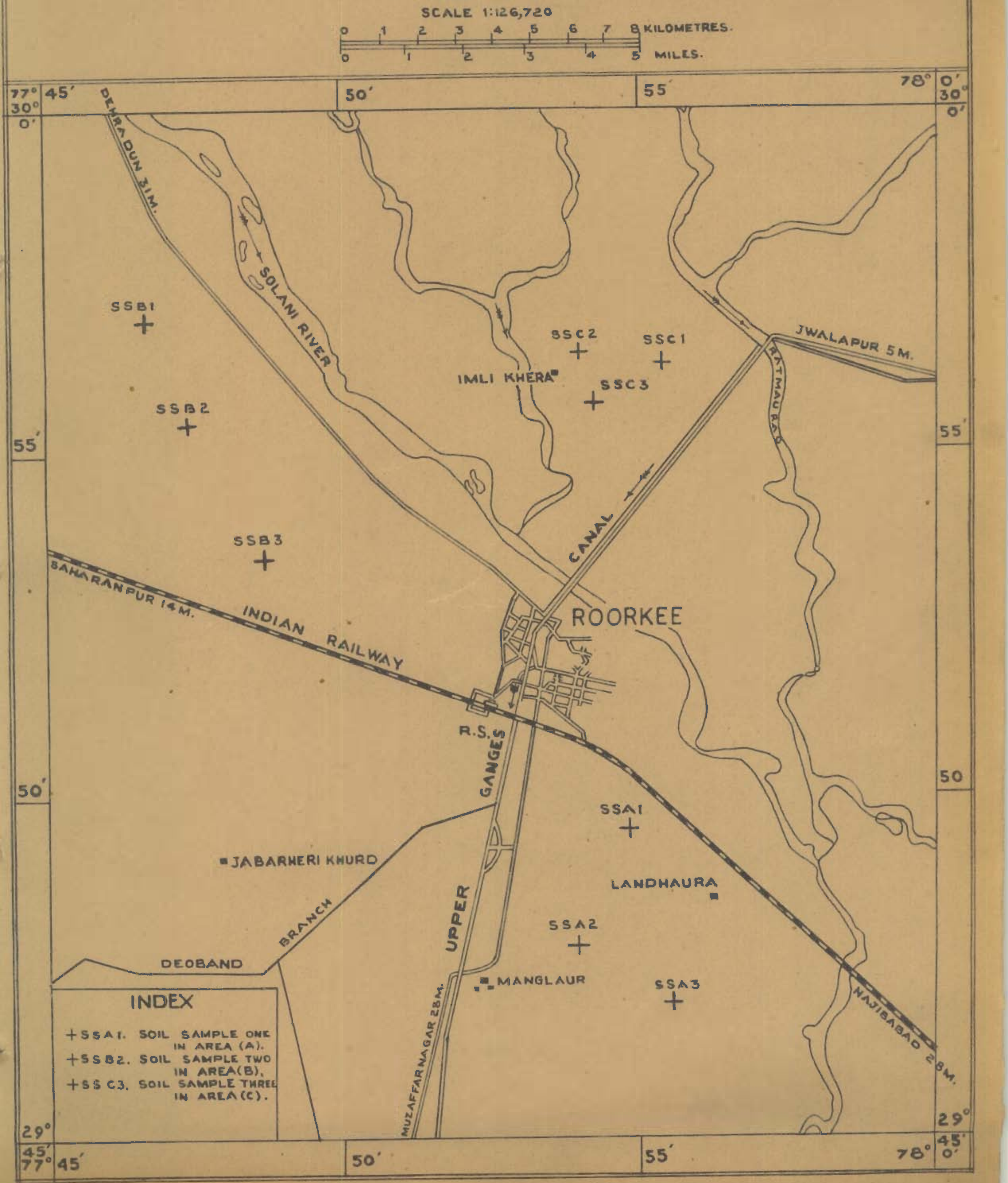


PLATE No IX A

MECHANICAL ANALYSES OF SOIL SAMPLES- ROORKEE AREA.

(A)

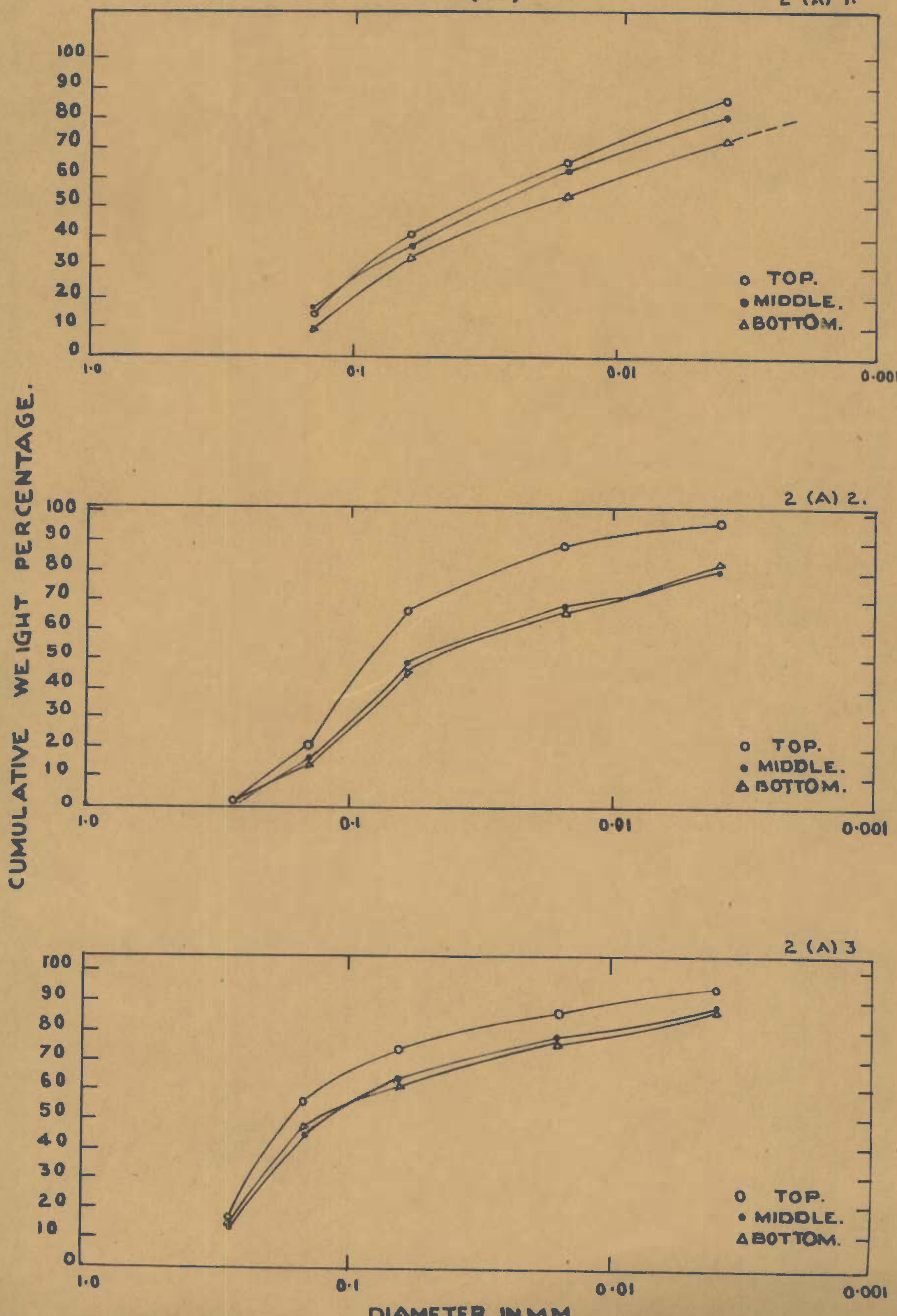


PLATE No. IX B

MECHANICAL ANALYSES OF SOIL SAMPLES— ROORKEE AREA. (B)

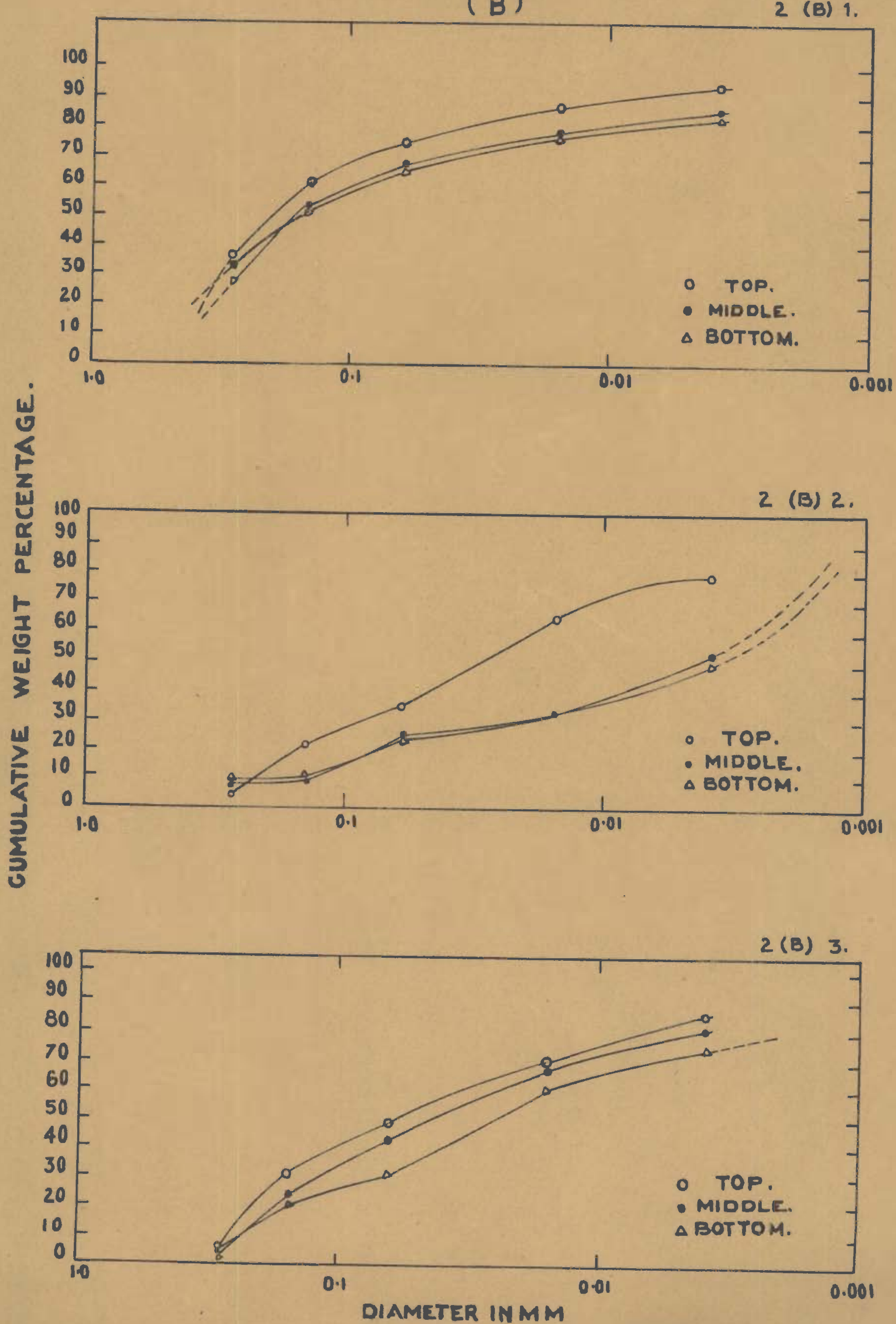
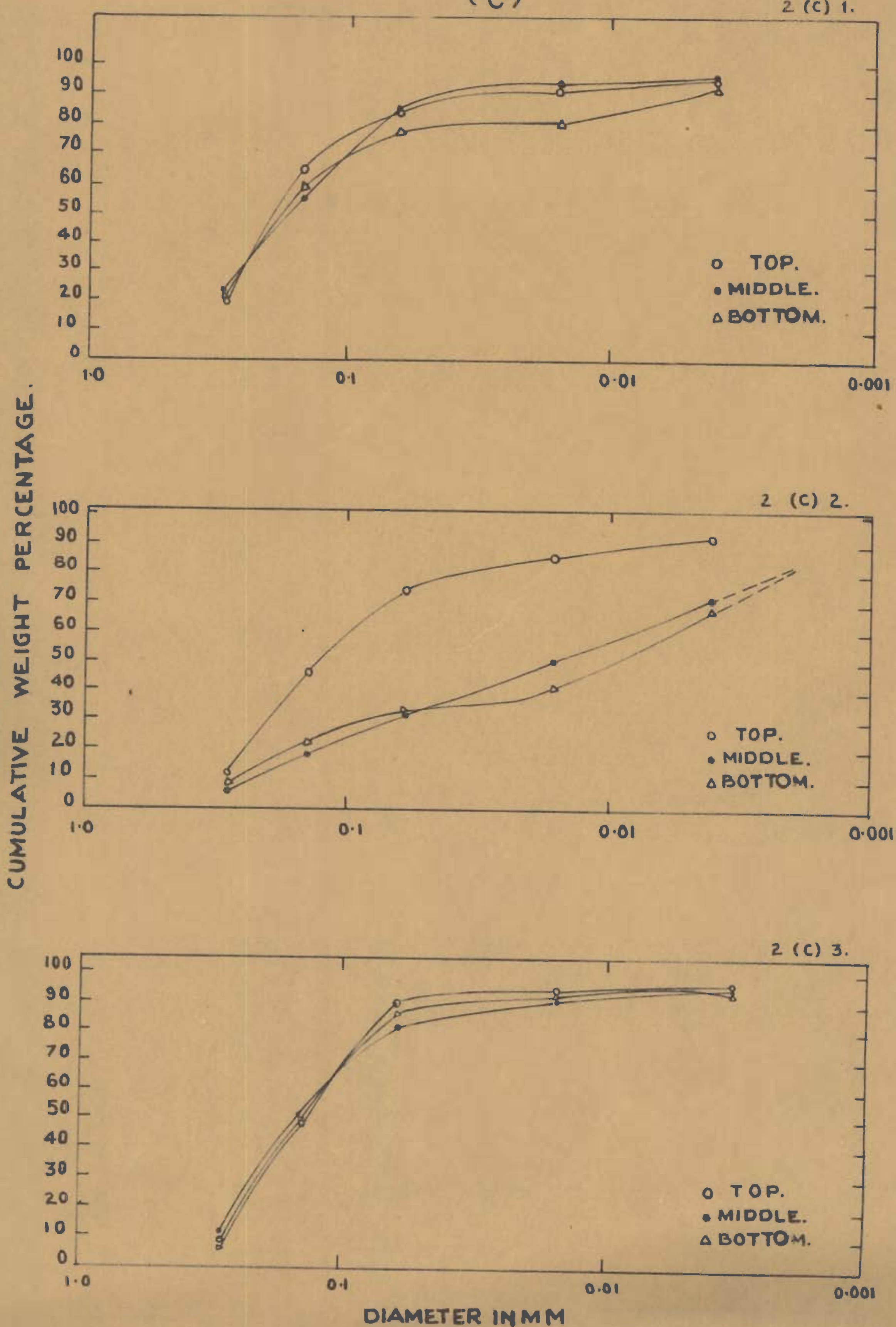


PLATE No IX C

MECHANICAL ANALYSES OF SOIL SAMPLES-
ROORKEE AREA.
(C)



+ 48	+ 0.283 mm
+ 100	+ 0.146 mm
+ 1/16	+ 0.0625 mm
+ 1/64	+ 0.0156 mm
+ 1/256	+ 0.0039 mm
- 1/256	- 0.0039 mm

The values of the three quartiles along with the sorting coefficient of the materials are recorded below in Table No.2(a).

TABLE NO.2 (a)

SUMMARY OF RESULTS ON MECHANICAL ANALYSIS OF SOIL SAMPLES, ROORKEE AREA:

Soil Sample No.		Q1 25 percentile (in mm)	Q2 50 percentile or Median (in mm)	Q3 75 percentile (in mm)	SO $\sqrt{Q1/Q3}$ Sorting Coefficient	
1		2	3	4	5	
A1	Top	0.108	0.040	0.0084	3.585	
	Middle	0.108	0.033	0.0062	4.174	
	Bottom	0.088	0.023	0.0032	5.244	
A2	Top	0.131	0.080	0.0440	1.726	
	Middle	0.108	0.059	0.0056	4.391	
	Bottom	0.102	0.052	0.0062	4.056	Explanation:
A3	Top	0.250	0.167	0.0550	2.083	* Graph extended
	Middle	0.222	0.128	0.0240	3.042	Top: Surface Sample
	Bottom	0.235	0.130	0.0106	4.709	Middle: Sample from 1½ feet depth.
B1	Top	0.340*	0.253	0.0660	2.270	
	Middle	0.300*	0.162	0.0350	2.927	Bottom: Sample from 3 ft. depth.
	Bottom	0.350*	0.160	0.0300	3.416	
B2	Top	0.115	0.0315	0.0090	3.575	
	Middle	0.054	0.0037*	0.0015*	5.902	
	Bottom	0.045	0.0045*	0.0018*	4.999	
B3	Top	0.165	0.054	0.0090	4.282	
	Middle	0.121	0.041	0.0064	4.348	
	Bottom	0.090	0.0225	0.0028*	5.669	

1		2	3	4	5
C1	Top	0.265	0.175	0.0960	1.662
	Middle	0.275	0.151	0.0830	1.820
	Bottom	0.270	0.165	0.0700	1.963
C2	Top	0.230	0.130	0.0560	2.026
	Middle	0.099	0.016	0.0290*	1.845
	Bottom	0.122	0.010	0.0260*	2.166
C3	Top	0.223	0.149	0.0920	1.557
	Middle	0.231	0.151	0.0840	1.658
	Bottom	0.220	0.148	0.0870	1.590

The highor percentage of fine textured materials in the top soils is well reflected in practically all the curves. The data further indicated that in the area just north of Roorkee (area C - Plate No.VIII) the sediments were better sorted compared to those in the other two places. This was due to the fact that the earlier and the present drainage in this area was responsible for considerable transhipment and resorting of sediments in water environments of a meander belt (Plate No.X). Besides the above, it could also be noted from Table 2(a), column5 that there is certain amount of ill-sorting in the sediments from northwest to southeast in the area marked 'B'. In the Terrace deposits (area 'A') the sediments sampled close to Solani river also exhibit ill-sorting with the depth of the deposit but this change appears to be gradual. Whereas, in the soils sampled from the higher elevations of the river cuts, it has been observed that this type of change is random and maintains no relationship to the depth of the sediments.

From the cumulative weight percentages of the materials, a broad generalisation on the constituents of the soils has been attempted in Table No. 2(b). Here it can be noted that in this classification the material retained in mesh 48 is mainly kankar and sand.

TABLE NO.2(b)

Area	Sand with gravelly kankar	Silt	Clay
A	52 %	32 %	16 %
B	46 %	30 %	24 %
C	71 %	17 %	12 %

From the above analysis, it could be inferred that the soils in Roorkee area are predominantly sandy in nature and the clay fraction is low.

iv) Sub-surface geology and disposition of aquifers:

The basic idea in attempting the sub-surface correlation of the lithologic units is to establish the continuity of the water bearing formations, their disposition and areal extent. Normally, such correlations become extremely difficult in unconsolidated formations. Purely lithogenetic aspects of the arenaceous and argillaceous beds are taken as the basis for the above stated study.

The formations being of Recent origin, the depositional trends influence the choice of the section along which sub-surface correlation should be attempted. Based on this three selected sections have been taken in the area (Plate No.IV). The section A-A' in the northern part of the area covers the wells which are almost parallel to the present course of river Solani. Similarly, the line B-B' represents a parallel section to the drainage pattern in the southern part of the area. The section C-C' is in west-east direction. In this attempt, only broad lithological units (such as sands, clays, sandstone and kankar) have been recognised as individual units and the finer units (such as clayey sands, sandy clays, fine sand)have been ignored for the purposes of correlation (Plate No.XI A, B, and C).

Besides the existence of persistent and predominant clay beds in the region, their occurrence as limited lenticular and lens shaped beds in the aquifers is noticed in the N.W.-S.E. Section (AA'). Some of the sand beds occur as 'cut outs' in the clays. The percentage of sands and cemented sands increase towards the southeast direction.

Similarly, the section BB' (NNW-SSE direction) indicates marked increase in the sand content of the alluvial formations in a SSE direction. Though limited in thickness,the clay beds persist laterally for distances of nearly six to eight miles. Many of these taper towards the south. Contrary to what has been observed in Section AA', in this section it is observed that some of the clays pinch out as 'cut outs' in the sandy horizons. A noteworthy feature of the section C-C' is the marked variation in the disposition of the clay sand beds in the area west of the Upper Ganges Canal to that on the east (i.e. west of State Tubewell No.12). In the western part the argillaceous and arenaceous members almost exhibit interfingering phenomenon. The clay bands bulge and thin out considerably at short distances. East of State Tubewell No.12 the argillaceous bands become insignificant and the sand horizons increase enormously and this trend continues almost upto State Tubewell No.4, which is close to the present Solani river course. The alluvial deposits east of Tubewell No.5 show some tendency to dip towards the river moderately. This has an influence on the local occurrence of ground water under confined and flowing conditions at a few places in this part of the area (cf: Chapter III, page 41). The marked change in lithology as well as sedimentation east of State Tubewell No.12, points out that this must have been the 'cut out' part of an elevated terrace of river Solani and as such it would form the western limit of the meandering belt of Solani.

ROCK UNITS AND THEIR WATER YIELDING PROPERTIES:

The Algonkian to middle Miocene formations are essentially made up of phyllites, slates, shales, quartzites and limestones. Except for a few cavernous limestones these formations are impervious and exhibit minimum pore space. As such, they do not act as good reservoirs to hold water on a large scale. The sand stones, 'sand rock' and conglomeratic gravel and pebble beds of Siwalik formations constitute the aquifers in these formations. The texture and compaction of the sand stone beds are so variable that their water yielding capacity differs. The Lower Siwalik sandstones, being generally hard and indurated, bear less water transmitting and storage capacity than the middle and Upper Siwalik sandstones. The Middle Siwalik sandstones are moderate to good aquifers. The Upper Siwaliks are the most permeable and porous of the entire Siwalik sequence.

The sands and gravels associated with the Terai formations are the principal aquifers. These formations are generally in continuity with the Bhabar formations and as such receive ground water by downward percolation and lateral flow from the Bhabar belt. The latter belt consists of coarse alluvial fan deposits and exhibit high porosity and permeability. The ground water storage capacity is large in this belt. The sand and gravel beds associated with the Doon alluvial fill are also good repositories of ground water due to their porous and permeable nature.

The present area under study is covered essentially with the unconsolidated sediments of the Indo-Gangetic alluvium. The sand and gravel beds associated with these sediments constitute the main water bearing horizons. The texture and compaction of the beds being variable, the water yielding capacity of the individual beds varies significantly. In general, the water transmitting and storage capacity of the sand beds are moderate to good and as such they act as dependable aquifers. The clays and clayey sands also absorb large qualities of water but exhibit low transmission capacity. Due to their absorbative and permeable nature, the sandy tracts of the alluvium allow precipitation water to percolate to the water table. The coarse sands and gravels in the abandoned river channels in the area act as good repositories of ground water.

In general the ground water supply depends on the geology and climatic conditions in the region under study. The alluvial tracts of the area form the most important ground water reservoir. Since the alluvium varies greatly in texture, its water yielding capacity differs from place to place. The water bearing beds or aquifers are the lenticular sands and gravels, that occur at several depths below land surface. The shallow ground water of the alluvium is unconfined or under water table conditions. The water in the deep permeable beds of the alluvium is under confined conditions. Adequate quantities of water are being withdrawn from this reservoir by means of irrigation tubewells as considerable storage and recharge conditions exist in the area. The general slope of ground water table in the area is in NW-SE direction.

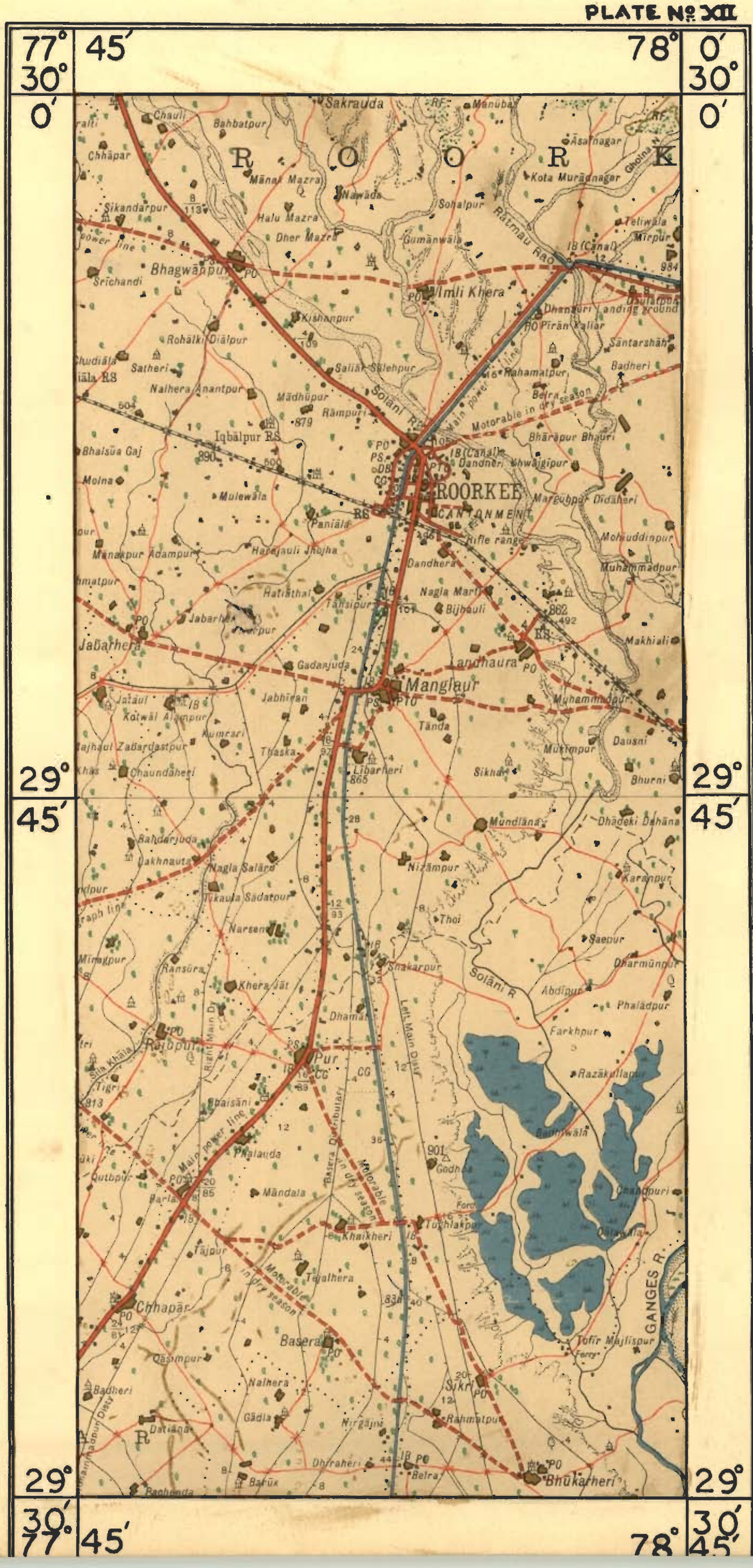
GEOMORPHIC FEATURES OF THE AREA

From a study of the topographic sheets, the drainage pattern in the area, the ground water conditions and from the foregoing account, it is clear that the region under investi-

TOPOGRAPHIC MAP OF THE AREA SOUTH OF ROORKEE SHOWING THE SWAMPY REGION

SCALE: 1 INCH = 1 MILES.

PLATE No. XII



gation indicates a peculiar setting. With this in view several traverses have been taken in all directions. As a result of these studies it is noted that apart from the existence of high and low grounds, the area does not show any marked geomorphic features. In short, in the western half of the region, the ground slope is to the south and the drainage parallels the flow of the River Jamuna, while in the eastern half the River Solani and its tributaries after flowing to the south for about 15 miles suddenly takes a turn to the east and flows into a swampy low land. Just east of this swamp the river Ganges also seem to be flowing around it and not into this (Plate No.XII). As not much could be made out through these traverses, a recourse had to be taken to the study of the aerial photographs of the area around Roorkee. Since, only a small aerial cover around the town of Roorkee was available the study of the fluvial morphology had to be confined to this area alone. Using the mirror stereoscopes and 36 aerial photographs (uncontrolled mosaics) a 'Drainage Trend Map' (4" = 1 mile) of the chosen area has been prepared (Plate No.X).

From the above mosaic and the topo-map it is seen that the area has suffered from many a meandering in the west, north and northeast of Roorkee town apart from those present now close to the Solani river course. From the nature and levels of the terraces, natural levels and the ground slope directions, meanderings north and north-east of the town are due to the earlier courses of the Solani river and its tributories, those to the west of the town and farther in the south-west around Hatiathal Village the meanders could be due to some still earlier drainage flowing down south. There is a conspicuous absence of any drainage trends in an oval shaped area south-east of Roorkee, extending upto Landhaura town. There is another line of drainage around Hasan

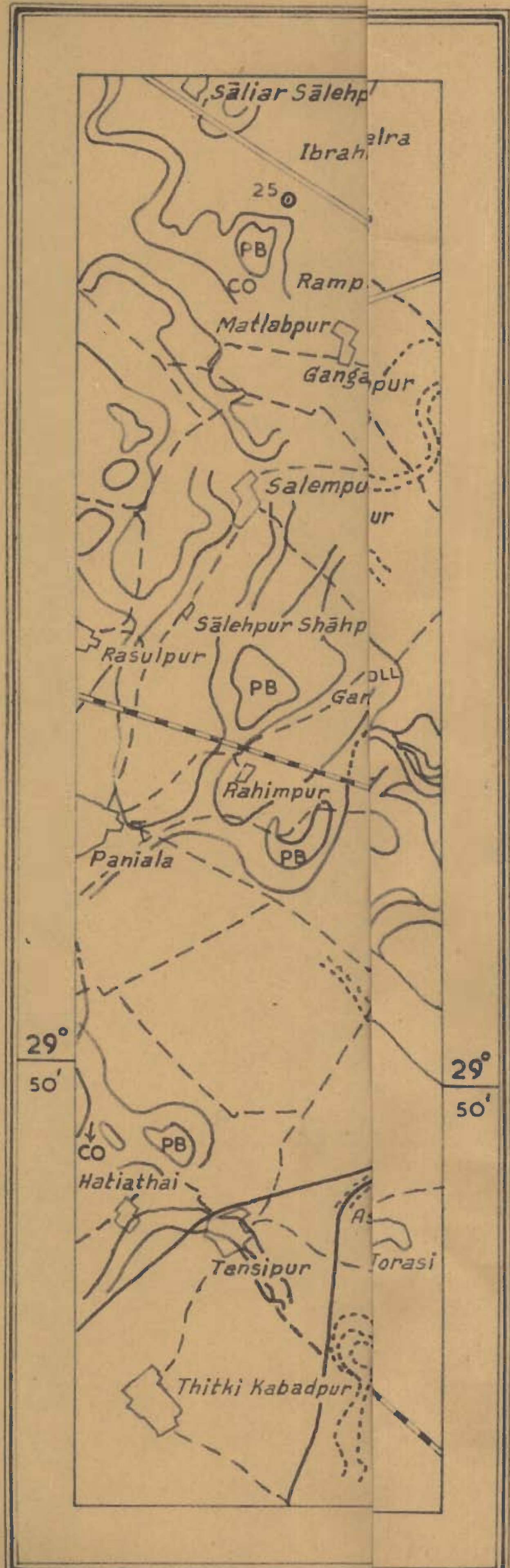


PLATE No X

RAILWAY LINE
METALLED ROAD
CART TRACK
CANAL AND DISTRIBUTARY
FORMER DRAINAGE TREND
TUBE WELL
POINT BAR .... PB
CUT OFF .... CO

SCALE IN MILES
0 1 2
(APPROXIMATE)

Alipur village in a north west-southeast direction.

From a further perusal of the topographic sheet nos.53G ~~and K~~ attached herewith, the following may be noted.

a) There are quite a number of longitudinal ridges marked by closely spaced brown dots on the sheet west of Upper Ganges Canal and south-west of Roorkee extending upto a distance of not less than twenty miles. In the field these are generally recognised as longitudinal sandy ridges with relative elevation of 10 - 15 feet above ground level.

b) An intensively dissected platform can be recognised close to and more or less parallel to the Solani river course for a distance of nearly twenty miles from Roorkee southwards. This platform is found to be a sandy terrace in the field usually with a cliff of 20 - 25 feet. There are innumerable gullies dissecting this terrace and ultimately discharging into the Solani River.

c) A swampy region occupying an area of about 40 sq. miles can be seen at a distance of 15 miles south-south-east of Roorkee and immediately west of Ganges River and close to the confluence of Solani River with the Ganges.

The sandy ridges are perhaps the meander scars left over by an earlier drainage channel flowing west of Roorkee but due southwards. The drainage trend map drawn from the aerial photographs also substantiates this.

In all likelihood a minor consequent stream on the slopes of the sandy region just east and south of Roorkee must have caught up the waters of Solani flowing south and west of Roorkee due to headward erosion. It is well established that in piracies of this nature the discharge of a great volume of water from a major river results in the deepening and widening of the stream channel. (23) This has naturally resulted in river-cut terraces (instead of the river-built terrace) as is seen at present from Roorkee southwards and prominently at Landhaura. The extensive dissection of the terrace is due to the unconsolidated nature of the sediments constituting the terrace. Attention may be drawn to the fact that a drainage trend has been observed on the same slopes south of river Solani around the village of Hasan Alipur in Plate No.X. It is not unlikely that this stream was also consequent in nature but not powerful enought to erode headwards and accomplish another piracy. The absence of drainage trends south-east of Roorkee fits in with the Isopach data (for the 50 ft. thickness of sediments below land surface - Plate No.XIIIA) for the same area quite well.

While it may be very difficult to infer what could have been the drainage trends at the time when sediments were being deposited in this area, below 100 ft. to the present topography, a projection can be attempted from the Isopach map of the sandy horizon between 100 - 300 feet (Plate No.XIIIB). Since, even here the area southeast of Roorkee continues to be a major sandy horizon with changes in lithology only to the west of Roorkee; it is therefore inferred that the areas of drainage trends were the same even during the earlier time when the sediments lying between 100 - 300 feet depth below land surface were deposited.

The swamp referred above may be a result of a gradual filling up of a large lake in the course of the Solani River close to Ganges. It is not unlikely that the swampy conditions may continue to exist since a large area around this swamp is a monotonous plain without any quick outlet to the water except to the Ganges River. Here the river bed is almost at the same elevation if not a slightly higher level.

ISOPACH MAPS

Isopach Map for near Surface Sandy horizon (50 feet depth below land surface):

The borehole logs have been utilised to prepare a 'pack' map (Plate No. XIII A) for the sandy horizon encountered within 50 feet depth from the surface as this represents usually the imprints of past and present drainage, vegetation and soil features.

A study of this map indicates a distinct sandy horizon south-east of Roorkee, presumably a mixed one south-west of it and a predominantly clayey one Northwest of the town proper. The last factor can easily be attributed to the alluvial clayey or sandy clay materials brought in by the frequent meanderings of Solani River (or any other older rivers) west of Roorkee town.

ii) **Isopach Map for the Cumulative thickness of aquifers in depth zone 100 - 300 feet:**

In an area of 125 sq. miles west of Solani river, nearly fifty seven tubewells have been drilled to an average depth of 350 feet below land surface. The logs of these wells are dependable as reverse circulation method of drilling was adopted at these sites for construction of the wells. The major productive aquifers in the region lie within 300 feet depth (cf: Plate Nos. XIA, B, C). The aquifers occurring generally within the depth zone 300 - 350 ft. are of minor thickness. Any aquiclude bed of less than ten feet thickness has not been considered as an effective impervious layer separating the two major water bearing beds. As the aquifers occurring within hundred feet depth are not usually screened in the production tubewells in the area to accommodate the housing part of the tubewell assembly, it may conveniently be considered that the total thickness of the productive aquifers in the depth zone 100 - 300 feet may be

PLATE Nº XIII A

ISOPACH MAP OF NEAR SURFACE SANDY HORIZON WITHIN 50FEET DEPTH, ROORKEE AREA.

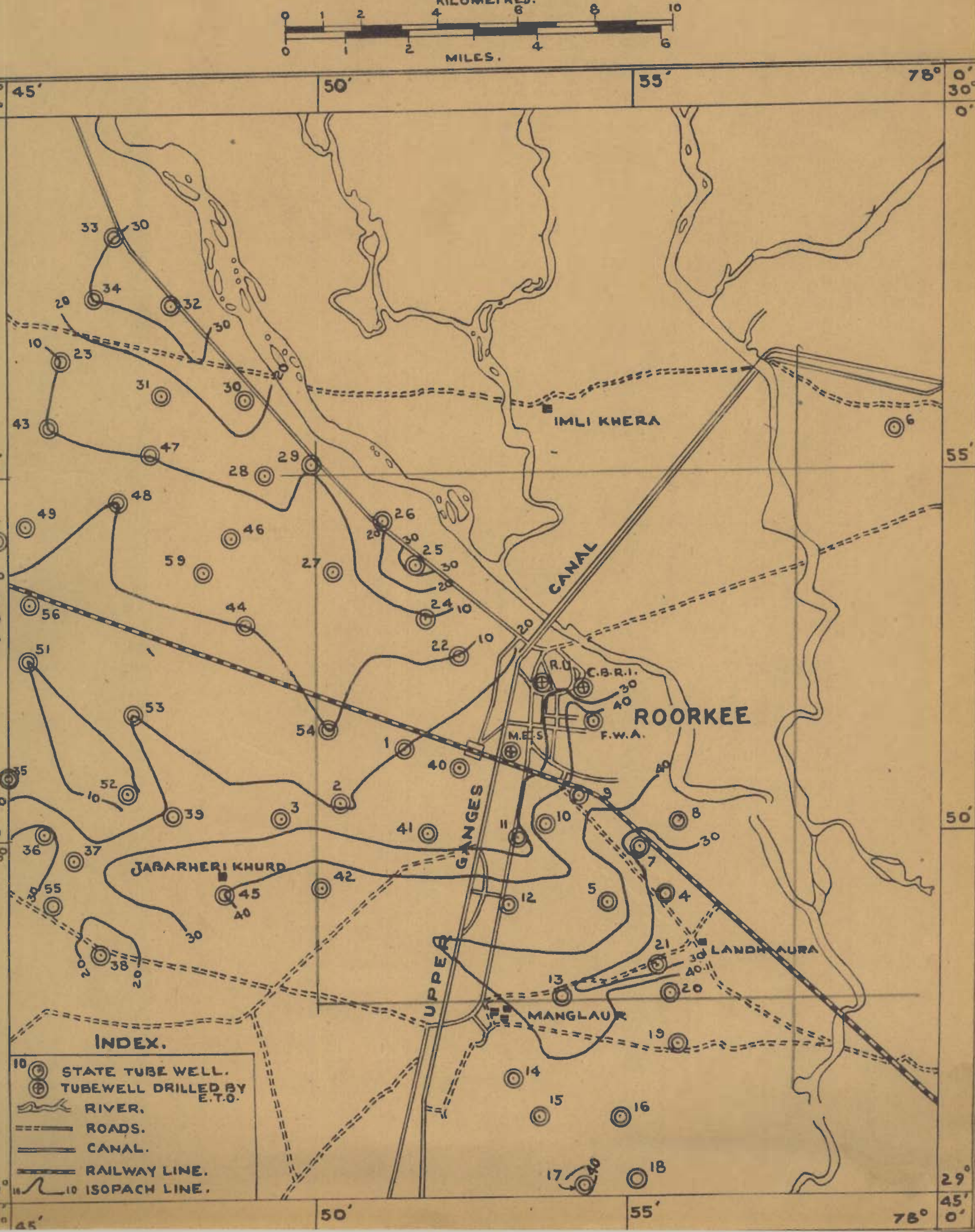
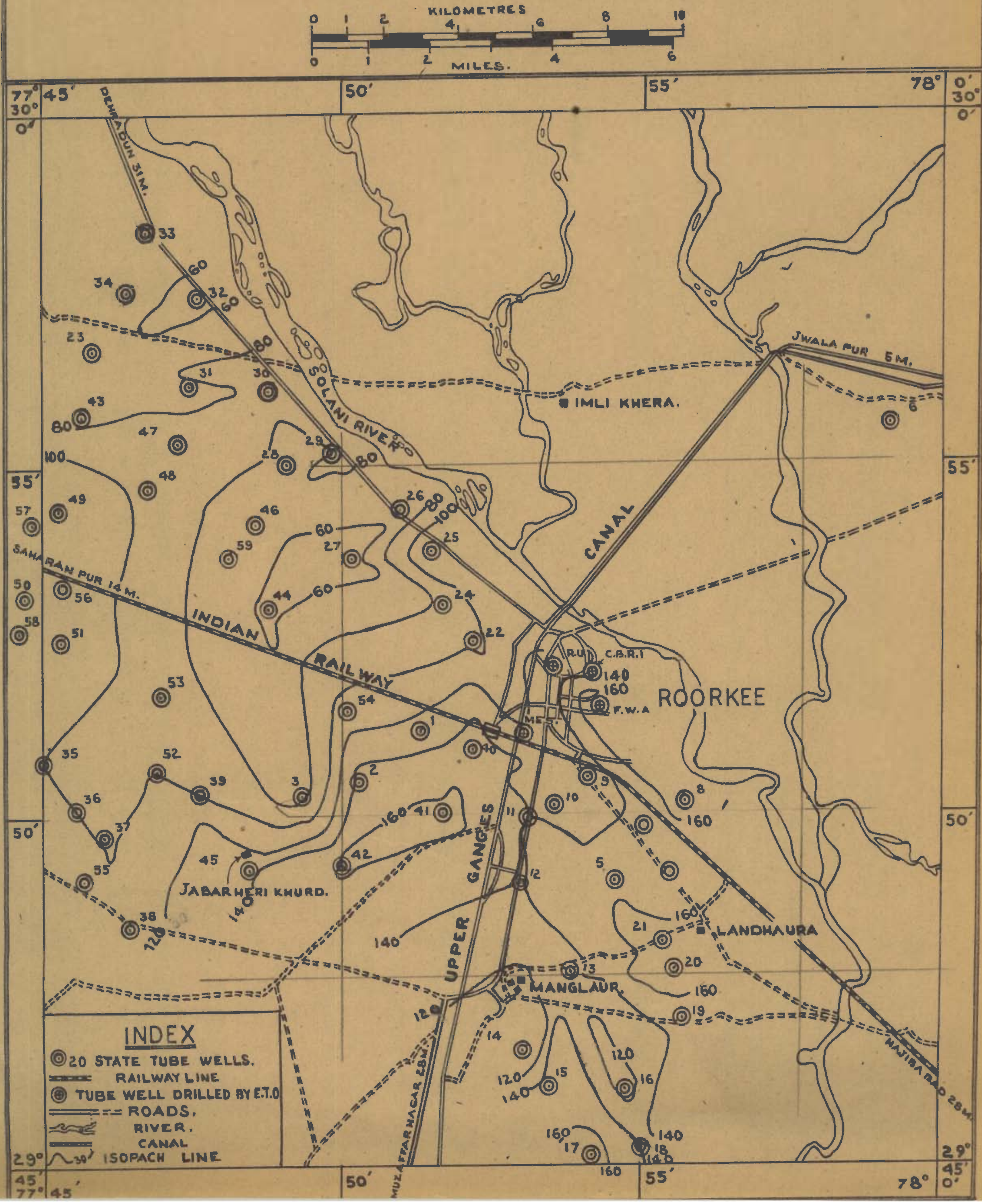


PLATE No. XIII B

ISOPACH MAP FOR THE CUMULATIVE THICKNESS OF AQUIFERS IN THE DEPTH ZONE 100—300 FEET IN, ROORKEE AREA.



taken as a single unit to represent hydrologically the water bearing formation in the region for all practical purposes. This cumulative thickness of the productive aquifers (screened in the wells) has been utilised in bringing out an isopach map of the area (Plate No.XIII B). In bringing out this map, the hundred feet depth surface has been taken as the datum on which (downwards) the thickness of the aquifers is projected.

The table No.3 below gives the position of the major aquifers screened in the individual wells to a depth of 300 feet and the thickness of the sandy horizon within 50 feet depth.

TABLE NO.3.

Thickness of Aquifers within 50 feet and 100 - 300 feet. depth zones in Roorkee area:

Sl. No.	State Tubewell Number	Total thickness of aquifers in feet down to 50 ft. depth	Total thickness of the aquifers in feet between 100 - 300 feet depth
1	2	3	4
1.	1	20	128
2.	2	19	150
3.	3	26	72
4.	4	22	138
5.	5	50	91
6.	6	16	50
7.	7	27	147
8.	8	35	169
9.	9	45	127
10.	10	50	126
11.	11	25	140
12.	12	50	139
13.	13	31	133

1	2	3	4
14.	14	50	102
15.	15	50	150
16.	16	50	115
17.	17	37	174
18.	18	50	138
19.	19	50	149
20.	20	50	178
21.	21	24	169
22.	22	10	96
23.	23	10	64
24.	24	5	82
25.	25	35	120
26.	26	21	65
27.	27	0	50
28.	28	15	58
29.	29	11	86
30.	30	Data not available	97
31.	31	11	60
32.	32	37	55
33.	33	30	72
34.	34	31	66
35.	35	16	100
36.	36	33	100
37.	37	27	96
38.	38	15	112
39.	39	24	100
40.	40	30	150
41.	41	25	167

1	2	3	4
42.	42	48	162
43.	43	10	79
44.	44	10	57
45.	45	40	97
46.	46	0	66
47.	47	10	101
48.	48	10	97
49.	49	0	121
50.	51	10	112
51.	52	4	101
52.	53	20	90
53.	54	10	107
54.	55	28	119
55.	57	17	113
56.	CBRI Well, Roorkee (ETO)	26	131
57.	MES Well Roorkee (ETO)	18	121
58.	Roorkee University Well (ETO)	28	131
59.	Military Field Works Area, Roorkee	50	181

[A noteworthy feature of the Isopach map representing the productive formations in the depth zone 100 to 300 feet (in the area under study) is their limited thickness in the north-western part and a gradual increase in thickness in the Southeastern end. The relatively good thickness of aquifers east and south-east of the area of study supports the idea that the river in recent times adopted a drifting pattern towards east or south-east. The increase in the cumulative thickness of the aquifers in south-southwest direction of Bhagwanpur village (77° 49' : 29° 56' 30") for about a ten miles stretch is gradual.

— ... —

CHAPTER III:

GROUND WATER FLOW ANALYSIS:

Occurrence of Ground Water:

The sub-surface disposition of the aquifers in the alluvial tracts of the area is well brought out in the correlation charts described in the earlier chapter (refer page 29). These sections showing the sub-surface lithological facies demonstrate that the sandy stratum in the top horizon sometimes attains a considerable thickness. They constitute by virtue of their absorbtive nature, a potential water bearing horizon intervening with the occasional lenticular bands of clay. Ground water occurs under non-confined conditions (water table conditions) in these formations. Besides the above, sands also occur as confined beds with reasonably persistent and thick clay beds over-lying them. In these beds ground water occurs under confined conditions. The confined nature of the aquifer is defined as follows:

i) The hydraulic head is sufficient for the deeper aquifers to allow the water to rise to considerable height from the upper surface of the aquifers in which it occurs but does not allow free flow over the land surface.

ii) The hydraulic head is sufficiently high to bring the water level above land surface and create flowing conditions.

The latter type are rare and of limited occurrence in the Roorkee area. They are only reported in the terrace deposits of the Landhaura region. This is essentially a localised phenomenon, resulting probably due to favourable structures (warping in the beds on a minor scale) during the depositional history of the alluvium along the banks of the river. These structures aid further in the building up of a pressure head in the water bearing granular beds and favour on a limited scale the flowing conditions in the area close to the river beds.

The pressure heads of aquifers between 100 - 450 feet depth in this belt vary from 20 - 30 feet below land surface. Very few wells record pressure heads between 40 - 50 feet depth. (State Tubewell Nos. 21 and 35). It is not uncommon to observe in many places of the area, confined beds maintaining pressure heads which almost coincide with that of the water table aquifer or of slightly lower level. The number of confined beds encountered within 100 - 450 feet depth is usually three to four. An exception to this is Tubewell site no.43 where a maximum of six confined beds are recognised. Generally the confined productive aquifers in the region occur in the depth zones 100 - 175; 220 - 300 and 400 - 460 feet.

WATER TABLE CONTOUR AND PIEZOMETRIC MAPS OF THE AREA:

The level of free ground water with reference to a known datum can be represented by contours. Such contour lines joining points of equal altitude on the potential surface of water in an aquifer produce the Water Table Contour Map. Maps of pressure surfaces can be made just the same way as that of water table and are generally known as the piezometric maps. These indicate not only the distribution of pressure head in the aquifer but also the direction of ground water flow, areas of ground water recharge and discharge and also ground water troughs and divides. Through the studies of these maps one can infer the rate of water movement and the changes in ground water storage. Profile changes in the permeability can also be recognised by studying the water table maps.

In the area under consideration, the water table maps for the near surface aquifers were prepared for the low water table periods (summer months) for the years 1961, 1962 and 1963 (Plate Nos. XIV A, B, C). The piezometric map for the summer period of 1963 has been prepared using the cumulative pressure head of the aquifers within 300 feet depth (Plate No. XIV D).

The water table maps mentioned above and [the flow lines indicate that ground water moves in general towards the effluent stream Solani and its tributaries in the area.] The disposition of the permanent water table is in north-west to south-east direction in the area west of Solani River and north-to south in the area east of Solani River. It slopes with and towards the main drainage system in the area of study. In the southern part of the region the flow direction is almost west to east and contributes to the river discharge.

The average hydraulic gradients of near surface ground waters during low water table period (summers) for the years 1961, 1962 and 1963 are tabulated below:-

TABLE NO.4.

Hydraulic Gradients (feet per mile) in Roorkee Area:

	Area N-W of Roorkee town	Area N-E of Roorkee town	Area S-E of Roorkee town
1	2	3	4
Summer 1961	9.33	No record	10.84
Summer 1962	9.72	15.25	9.44
Summer 1963	9.80	13.53	11.85

PLATE No XIV A

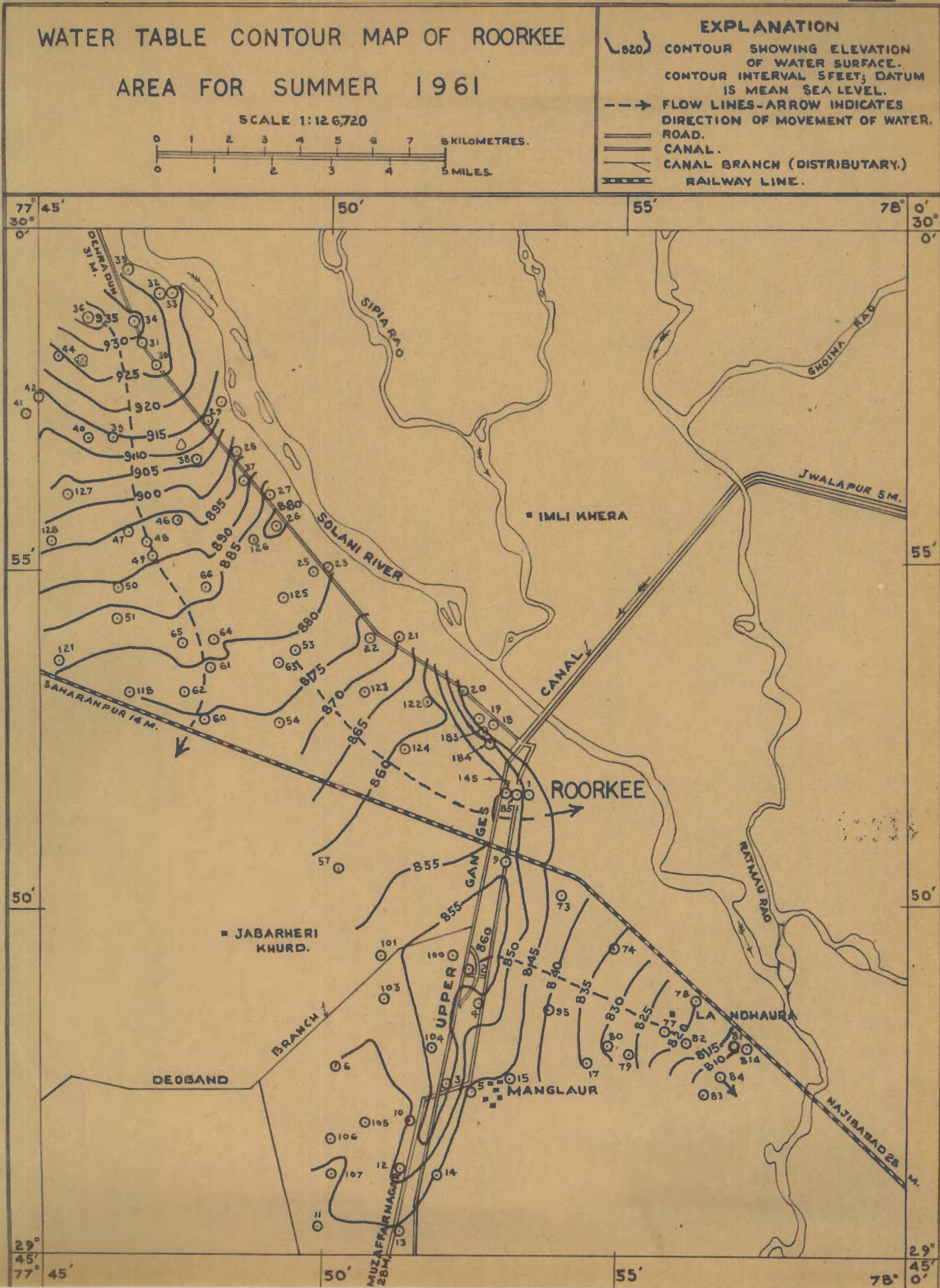


PLATE No XIV B

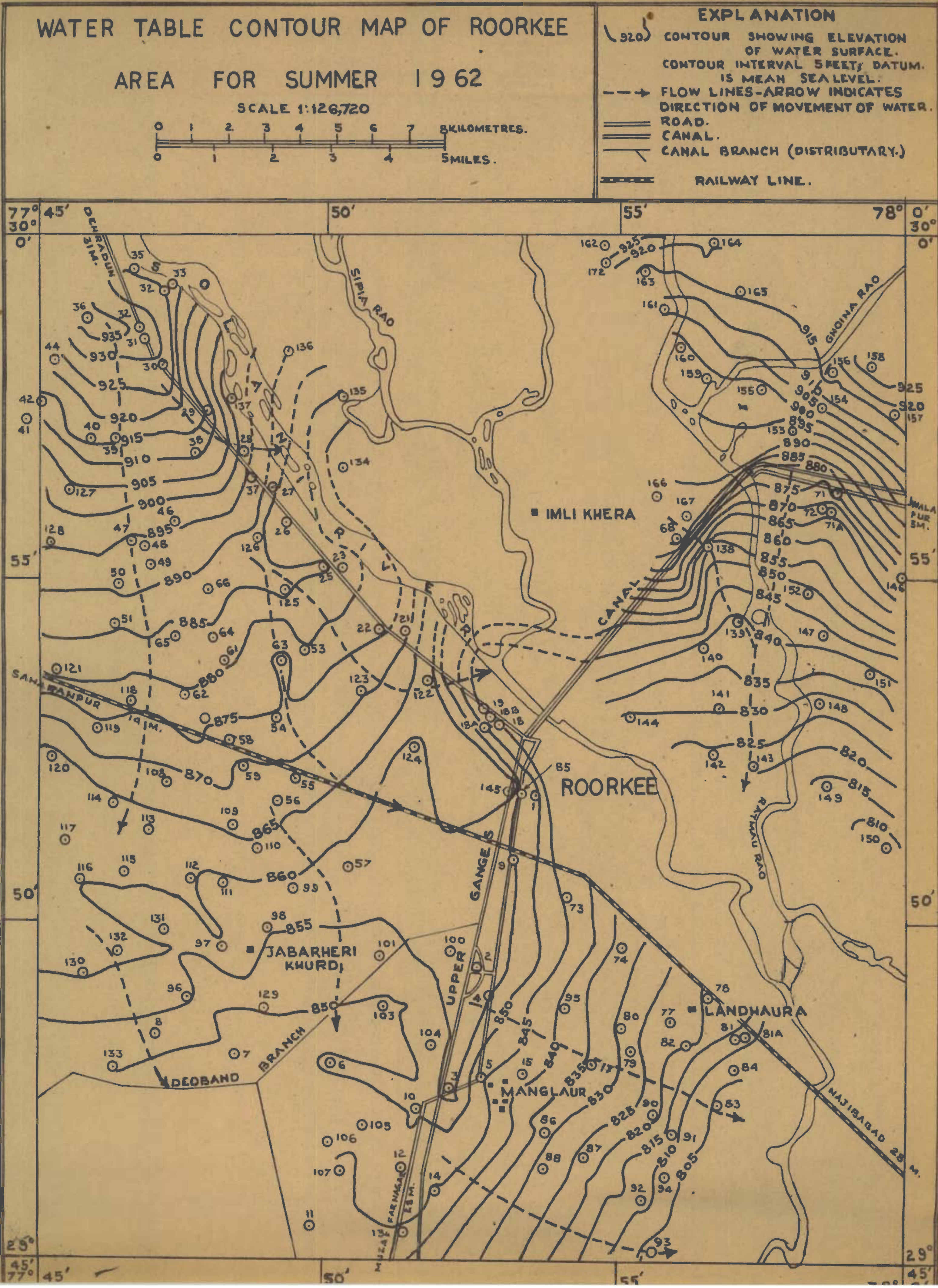


PLATE No XIV C

WATER TABLE CONTOUR MAP OF ROORKEE AREA FOR SUMMER 1963

SCALE 1:126,720

0 1 2 3 4 5 6 7 8 KILOMETRES.

0 1 2 3 4 5 MILES.

EXPLANATION

(920) CONTOUR SHOWING ELEVATION OF WATER SURFACE. CONTOUR INTERVAL 5 FEET, DATUM IS MEAN SEA LEVEL.

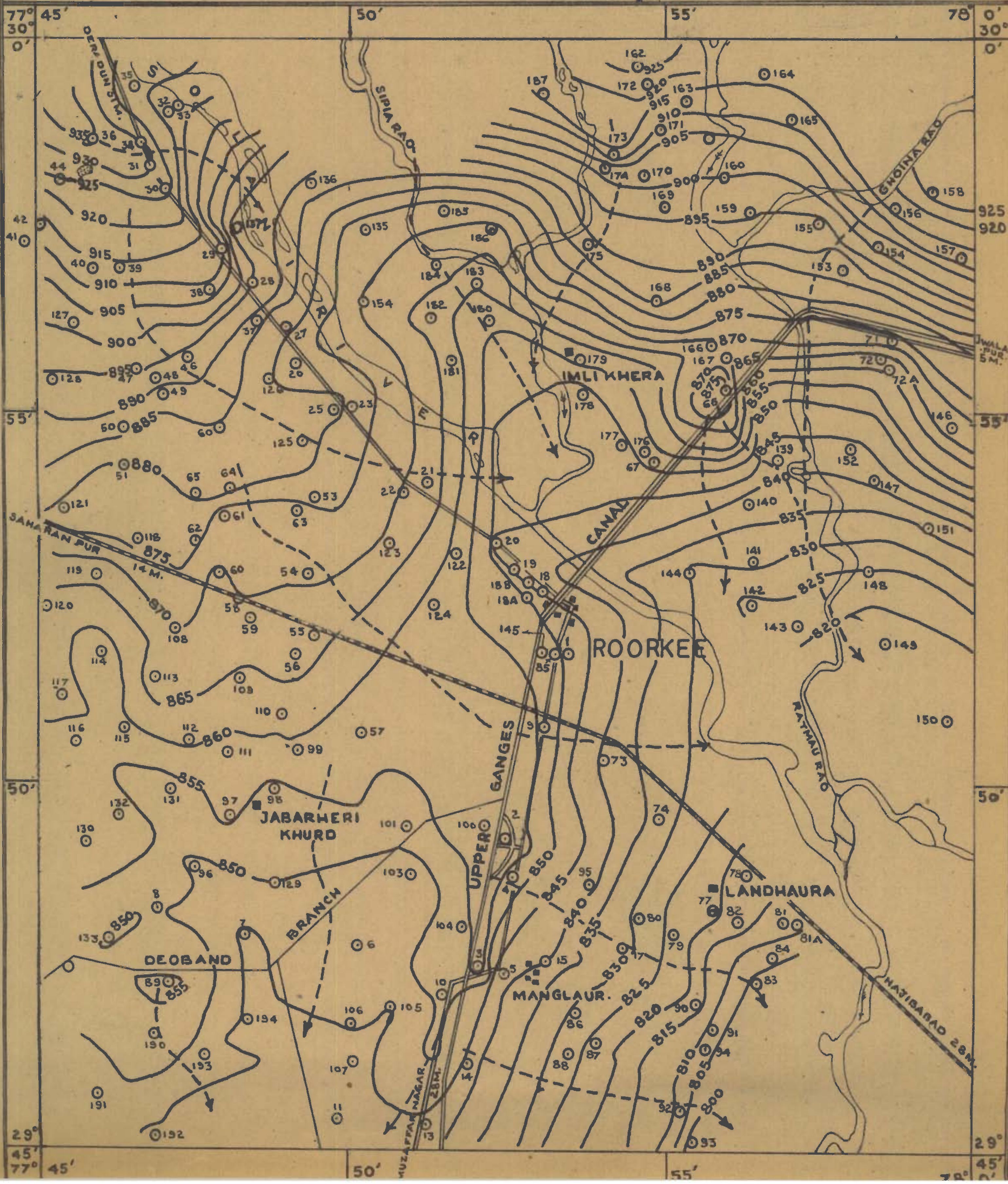
- - → FLOW LINES-ARROW INDICATES DIRECTION OF MOVEMENT OF WATER.

ROAD.

CANAL.

CANAL BRANCH (DISTRIBUTARY.)

RAILWAY LINE.



This indicates that the ground water gradient in the main direction of flow in the region (north-west to south-east) is becoming steeper with time (1961-63) and the same in the terrace deposits of Solani River close to Landhaura, varies from year to year. Apart from this, the water table contours are closer in the north-eastern part of the area compared to their layout west of the Solani river. This might have some bearing to the texture of the granular sediments constituting the shallow aquifers (10 to 50 feet) tapped in the open wells. The close spaced water table contours in the north-eastern part of the area may be indicative of fine grained nature of the shallow aquifers and similarly the widely spaced ground water contours in the area west of Solani river suggest the presence of coarser aquifer material than in the north-eastern part of the area.

The difference in the water levels in the successive years for the period 1961-63 is noted at each well station and averaged for the selective parts of the area (Table No.5):

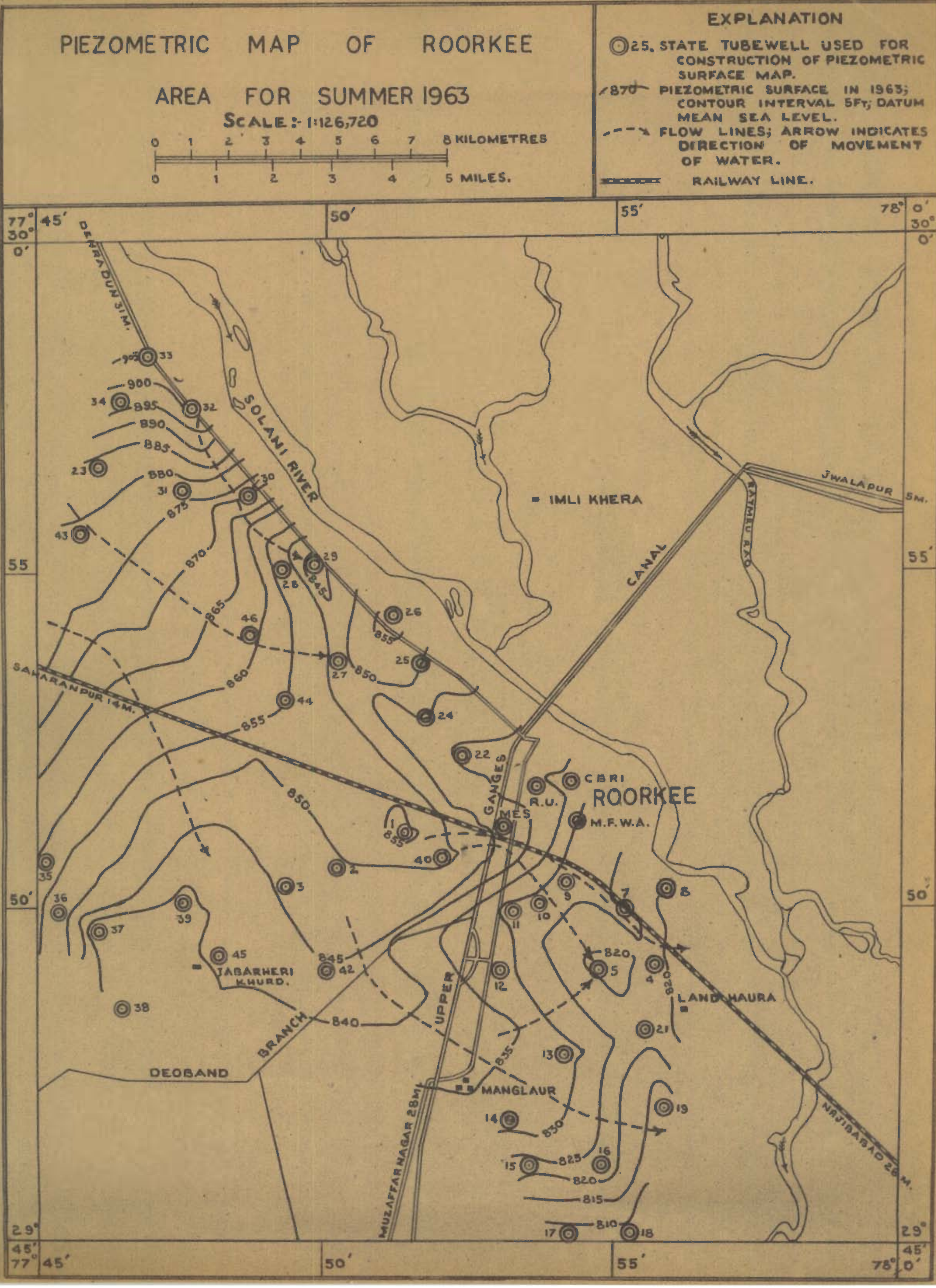
TABLE NO.5.

Rise or Fall of Water Levels in Roorkee Area:

Nature of the area	Rise or Fall of W.L. in ft. 1961-'62	Rise or Fall of W.L. in ft. 1962-'63
1	2	3
1. Area irrigated by Tubewells	+ 1.35	- 2.79
2. Area irrigated by Canals	- 0.205	- 1.13
3. Area irrigated by natural rain water	-	- 2.24

Comparative study of the water table maps and the water

PLATE No. XIV D



levels for the low water level period for the years of study indicates that there is on an average a rise (1.35 ft.) in the regional water table in the year 1962 compared to 1961 in the area irrigated by tubewells. A slight lowering of water table is recorded in the canal irrigated tracts. But this situation is different in 1963 as compared to 1962. During this period, on a regional basis, in all the individual areas (e.g. tubewell irrigated, canal irrigated and rain fed areas) there is a general decline in the regional water table to the tune of 2.08 ft. From this it is, therefore, evident that the water levels are affected in certain years only on a limited scale at localised well points. The development of miniature ground water mounds during different seasons (e.g. 2 miles south of Roorkee Railway crossing in 1961 and at well points 68 and 69 in 1963) and their disappearance during the subsequent years, is indicative of possible localised recharge to the ground water body at selective places.

Uniquely in the South-Western part of Roorkee town the hydraulic gradients are low. This area is strewn with maximum number of unlined canal distributaries also.

The piezometric map (Plate No.XIV D) of the area drawn for Summer 1963 indicates that close to areas of continuous ground water extraction by way of pumping initial stages of ground water troughs have been delineated. This is noticed especially around State Tubewell No.5 of Landhaura group and State Tubewell No.25 of Bhagwanpur group. The map also indicates development of ground water mounds on a small scale one mile west-southwest of Roorkee Railway Station and partly around State Tubewell no.26 of Bhagwanpur group. The hydraulic gradients as revealed by the piezometric map especially along the flow line sections indicate that the same ranges from 5.71 to 16.36 feet per mile. Usually it is from 5 to 8 ft. per mile for this area.

GROUND WATER FLOW LINES AND FLOW NET ANALYSIS:

Flow lines are defined by the paths followed by particles of water as they move through an aquifer in the direction of decreasing head. These are drawn always at right angles to piezometric surface or water table contours. Of late, the flow nets have been most effectively employed towards quantitative ground water studies. Their usefulness is felt for the expression of different geologic controls on the hydraulic regime.

The flow lines have been indicated on the water table contour maps (Plates XIV A, B, C) in order to show the contribution of the near surface ground water to the surface drainage flow in the region. The flow lines on the piezometric map indicate the subterranean movement of ground water in the confined aquifers in the region. (From a study of the disposition of the flow lines on the piezometric map three significant points emerge:-

a) the ground water flow in the confined or deeper aquifers is essentially in a north-west to south-east direction.

b) a major part of this ground water moves towards the river Solani and contributes to the base flow of the river.

c) recharge to ground water occurring in the deeper aquifers comes from a source northwest of the area.)

The flow net analysis, attempted here for the first time for the alluvial deposits of this part of the Gangetic Basin indicates the rate of recharge to the aquifers in the well field area close to Landhaura. This is particularly chosen for analysis as it is a developing well field area in the region. The application of this study would be of practical importance to other similar areas of the Gangetic alluvium.

Plate XV shows flow lines drawn on the piezometric surface map from the recharge area to the developing cone of depression around Landhaura. The quantity of water moving through the section AA' and BB' were computed using Darcy's equation.

$$Q = TIL \quad \ldots \quad (1)$$

Q = Quantity of water passing through a given flow cross section in gallons per day (gpd).

T = Coefficient of transmissibility in gpd/ft.

I = Hydraulic gradient at flow cross section in ft/mile

L = Width of flow section in miles.

Based on actual pump test data (given in the following chapter) the average coefficient of transmissibility of the aquifer at AA' is 61,000 and at BB' is 85,000 gpd/ft. and the average storage coefficient of the aquifers between the flow lines is 3.70×10^{-4}.

Based on the above map, the average hydraulic gradients and the widths of flow cross sections have been computed and given below in Table No.6.

PLATE No XV

FLOWNET ANALYSIS OF THE PIEZOMETRIC MAP OF ROORKEE AREA (1963) FOR RATE OF RECHARGE TO THE CONFINED AQUIFERS

0 1 2 3 4 5 6 7 8 KILOMETRES.

0 1 2 3 4 5 MILES.

INDEX

27 ◎ STATE TUBE WELLS USED FOR CONSTRUCTION OF PIEZOMETRIC SURFACE MAP.

900 PIEZOMETRIC SURFACEC IN (1963) CONTOUR INTERVAL 5FT; DATUM MEAN SEA LEVEL.

A' B' LIMITING FLOW LINES.

A B FLOW CROSS SECTIONS.

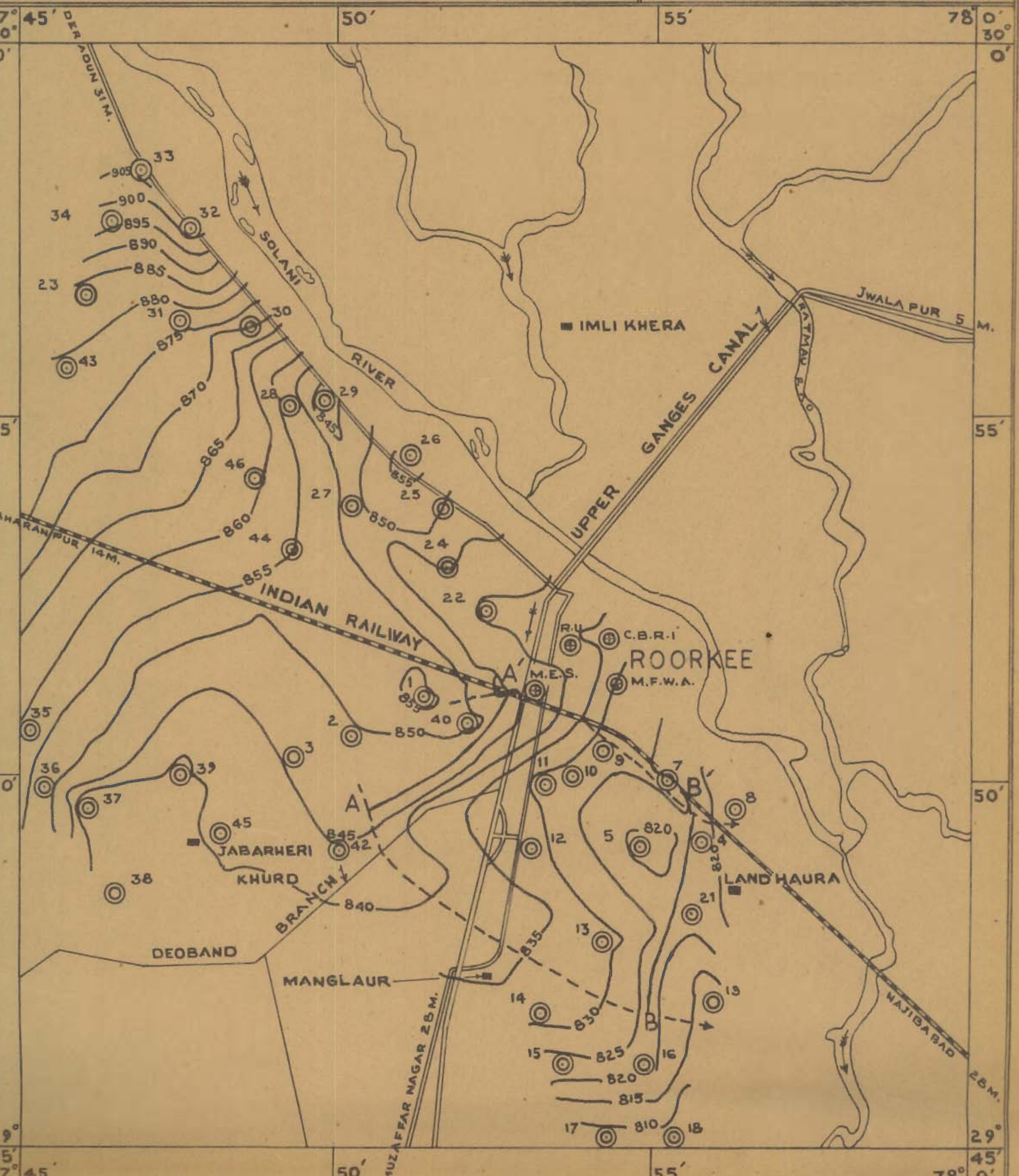


TABLE NO.6.

Results of Flow net Analysis for the well Field area west of Landhaura.

Flow Cross Section	Coefficient of transmi-ssibility(gpd/ft.)	Hydraulic Gradient (ft./mile)	Width of flow cross section (Miles)	Discharge through flow cross section (gpd).
1	2	3	4	5
A-A'	61,000 (Value obtained from MES Well, Roorkee, being close to the section is taken)	8	3	1.46 Million
B-B'	1,85,000 (Value obtained from State T/W No.4, close to the section is taken)	10	3.5	6.47 Million

The difference of 5.01 million gallons per day between the quantity of water moving through sections AA' and BB', is equal to the amount of recharge to the aquifer plus the amount of water taken from storage within the aquifer lying between the flow cross sections. Data given under Table No.7, indicate that the average water level declined in the area between flow cross sections AA' and BB' was about 0.0095 ft./ day during 1963.

TABLE NO.7.

Average Water Level Decline for the State Tubewells lying close to and within the limiting flow lines AA'-BB' for the period 1962-'63 Summers.

Tubewells Year/Date and W.L. in ft.	Tubewell No.4.	Tubewell No.5.	Tubewell No.7.	Tubewell No.10.	Tubewell No.11.	Tubewell No.12.	Tubewell No.21	Tubewell No.40
1	2	3	4	5	6	7	8	9
1962 (Summer)	48.0 22-5-62	41.0 22-5-62	46.0 1-6-62	25.0 1-6-62	29.0 25-5-62	28.0 25-5-62	45.0 22-5-62	25.0 9-6-62
1963 (Summer)	50.0 28-5-63	48.0 20-5-63	43.0 28-5-63	27.0 28-5-63	40.0 28.5-63	38.0 28-5-63	45.0 28-5-63	24.0 31-5-63
Rise of Fall (in ft.)	(-)2	(-)7	(+)3	(-)2	(-)11	(-)10	nil	(+)1

Average decline in 1963 3.5 feet

Average decline in ft./day 0.0095

The area lying between the flow cross section AA' and BB' is 14.75 sq. miles. Recharge to the area between AA' and BB' could be computed by substituting the above data in the following equation.(25)

$$R = \left[(Q_2 - Q_1) \pm \Delta ht \quad SA_1 (2.1 \times 10^8)\right] / A1 \quad \ldots (11)$$

Where R = rate of recharge, in gpd/sq. mile

$Q_2 - Q_1$ = difference in quantity of water crossing successive contour lines between limiting flow lines, in gpd.

ht = average rate of water level decline or rise in area lying between limiting flow lines and successive contours, in gpd.

A1 = area between limiting flow lines and successive contours, in sq. miles.

S = Coefficient of storage, fraction.

Substituting the above data:-

$$R = (50,10,000) - (0.0095 \times 0.00037 \times 14.75) \times (2.10 \times 10^8)/14.75$$

$$= 3,38,300 \text{ gpd/sq. mile.}$$

The rate of recharge to the well field area between flow cross sections would be 340,000 gpd/sq. mile and the withdrawl from the storage at this stage is very negligible.

INFLUENCE OF CANAL DRAINAGE ON GROUNDWATER FLOW:

In an earlier study the author has indicated the (13a) influence of canal flow on the ground water regime especially close to the banks of the canal. In the localities south and south-west of Roorkee town, west of the main Upper Ganges Canal and its distributaries (Deoband Branch), the ground water contours are fairly spread out and the hydraulic gradients are significantly low. The water table tends to be horizontal. This is not only observed on the near surface ground water flow situation but also in the disposition of the pressure surface of the deeper aquifers (Plate No.XIV D).

The Deoband Canal distributory region depicts a flow-pattern in the movement of shallow ground water which is significantly different from that noticed on the eastern (Solani river side) part of the main Upper Ganges Canal alignment in the area of study -- the flow pattern is almost north to south in the former and west to east in the latter (Plate No.XIV C).

The inhibition to the flow pattern and spread of contours may even be attributed to the lateral seepage from the unlined canal banks. This feature of flat or hori-zontal disposition of the water table may even be due to difference in the texture of the water bearing formations in this region. However, the present data is insufficient to permit any generalisation in this regard.

DISCUSSION:

The flow lines indicated on the water table of shallow aquifers and also on the piezometric map of the confined deep aquifers show a general northwest to southeast and north-south flow direction of sub-surface water. This is suggestive of the fact that the recharge area to the ground water body in Roorkee area lies towards north west and north of the region. Especially in the former area, the perennial source of water is available in rivers Hindan and Kali with the catchment of the later. The base flow of the perennial drainage system might be in hydraulic continuity with the confined aquifers extending from Roorkee towards west and northwest. This seems to be the main source of recharge. Further north of the area under study, the 'Terai' and 'Bhabar' alluvial belts are present.

Confined ground water conditions exist in the Terai and free ground water movement is noticed in the Bhabars. This belt is more absorbtive as it consists of coarse textured alluvial materials. It is possible that these belts act as intake areas for the ground water available in and around Roorkee area also.

The low values for decline or rise in the regional water table as revealed by the water table maps for three consequent years, especially for the summer periods, point out that the withdrawls are not much from the open wells tapping the shallow aquifers in the region. Most of it is contributed to the effluent streams.

The study of the piezometric surface contours indicated that the well field areas in the region are just being developed to their capacity. It has also been observed that considerable part of the sub-surface water moves towards river Solani and contributes to the base flow of the river. If the well field areas west of river Solani are developed in a planned way in the near future there is every likelihood of the flow lines close to the river being reversed and their contribution to the river flow can be inhibited or minimised. This would help contribution of ground water from the river towards the well field areas.

The phenomenon of recharge from the canal may be due to the effect of canal drainage not only on the near surface ground waters but also on the aquifers below 100 ft. depth. It is to be noted that the cumulative effects of vertical percolation from the canal bed in course of years (the canal is in operation for the last 120 years) and its influence on the ground water body cannot be ignored.

The rate of recharge to the developing well field areas around Landhaura as computed through flow net analysis is of a fairly high magnitude and at this stage of ground water development withdrawal from storage is negligible.

On the basis of the above, it may be emphasised that the area holds promise for further ground water development that what has been hitherto considered.

CONCLUSIONS:

An analysis of the ground water flow situation with the help of water level data, pressure heads, flow lines, flow nets, and effects of surface drainage on ground water body, is suggestive of the following conclusions:

i) Ground water occurs both in confined and non-confined (water table) conditions in the alluvial formations of the region.

ii) Generally confined productive aquifers in the region occur in the depth zones 100 - 175, 220 - 300 and 400 - 460 feet below land surface. The cumulative pressure heads of these aquifers vary from 20 - 30 feet below land surface.

iii) The disposition of the water table is northwest to southeast in the area west of Solani River and north-south in the area east of Solani River. It slopes with and towards the main drainage of the area. The hydraulic gradients of near surface ground waters range from 9.33 to 15.25 ft. per mile. The hydraulic gradients as revealed by the piezometric map indicate that the same ranges from 5.71 to 16.36 feet per mile, though usually it is from 5 to 8 feet per mile.

iv) The study of the flow lines on the water table and piezometric maps indicates that the main recharge to the ground water body in the area is from a source north and north west of the region. The Kali and Hindan rivers north-west of the area act as a source point of recharge to the confined aquifers encountered in Roorkee area. The 'Terai' and the 'Bhabar' alluvial belts lying north of the area also act as the possible intake areas for the ground water available in and around Roorkee.

v) The rate of recharge to the well field area around Landhaura as computed through flow net analysis amounts to 340,000 gpd/sq. mile and the withdrawal from the storage at this stage is very negligible.

vi) The area holds promise for further ground water development than what has been hitherto considered.

— ... —

CHAPTER IV:

HYDROLOGICAL CHARACTERISTICS OF THE ALLUVIAL AQUIFERS:

Before actually discussing the hydrological characteristics of the alluvial aquifers, it is considered proper that the terms prevalent in the modern ground water literature are defined and explained in view of their limited usage and also due to the absence of certain terms in the common ground water technical literature. In addition, the subject matter of this chapter also includes the formulae used and the methods employed to arrive at the hydrological characteristics of the alluvial aquifers in the area. These are used further to understand the response of the aquifers to heavy pumping. The hydraulic properties of the confined aquifers have been worked from the pump test data and the limitations of such analytical methods are reviewed. The specific capacity map for the area has been prepared based on the production tests conducted on the water wells. The step test data has also been utilised to work out the well characteristics such as well losses, formation losses and entrance velocities.

DEFINITIONS:

In analysing the data the following conventional definitions have been adhered to:-

Coefficient of transmissibility: is defined as the amount of water in gallons that will move in one day through a vertical strip of an aquifer one foot wide and having the height equal to the thickness of the aquifer, under a hydraulic gradient of 100 percent, or one foot per foot. It is expressed in gallons per day per foot (GPD/ft) or cubic meters per day per meter (m^3/d.m.). Recently in ground water terminology the word

"Transmissibility" is used to mean Coefficient of Transmissibility.

<u>Coefficient of Storage:-</u> is defined as the volume of water, measured as a fraction of a cubic foot, released from storage in each column of the aquifer having a base of one square foot and height equal to the thickness of the aquifer, when the head is lowered by one foot. It is ordinarily expressed as an absolute decimal. For artesian conditions the value ranges from 10^{-5} to 10^{-3} and in the unconfined aquifers the value is from about 0.05 to 0.40. For phreatic ground water (water table conditions) it is equal to the specific yield i.e. the quantity of water yielded by gravity drainage from saturated water bearing material and is expressed as a percentage of the total volume of the material drained. Intermediate values for the storage Coefficient imply semi-confined conditions in the aquifers. Recently, in ground water terminology the word 'Storativity' also implies storage Coefficient.

<u>Coefficient of Permeability:-</u> is expressed as the rate of flow of water in gallons per day through a cross sectional area of one square foot of the aquifer under a unit hydraulic gradient, or one foot per foot, at a temperature of 60°F. In field practice the adjustment to the standard temperature of 60°F is commonly ignored and permeability is then understood to be a field coefficient at the prevailing water temperature. Of these the transmissibility is equal to the field permeability multiplied by the thickness of the aquifer in feet.

<u>Pumping level:-</u> is the water level observed inside a well when it is under discharge.

<u>Static level:-</u> is the water level observed inside a well when the water table is not disturbed by pumping in or around the well.

Specific Capacity:- is the ratio of the discharge to the draw down it produces, measured inside the well and expressed in gallons per minute per foot of draw-down for a known period of pumping (gpm/ft. of draw down) or cubic meters per day per meter draw-down ($m^3/d/m$).

Specific Drawdown:- is the ratio of draw-down to the discharge that produces it. It is the reciprocal of specific capacity and is expressed in feet/gallons per minute (or in $m/(m^3/d)$ for a known period of pumping.

Residual Drawdown:- is the difference between the static water level and the water level observed in a well at any time of recovery after the pumping of the same well or a neighbouring well has been shut down.

LIMITATIONS OF THE STUDY:

In all the hydrological tests, measurements for the quantity of water pumped from the discharging wells were made with an orifice-manometer combination device and the 'wetted-tape' or 'electric sounder' method were used to measure the water levels in the observation wells. The derivation of the various formulae used to compute the results are omitted to simplify the presentation of the data. The bibliography contains a number of articles on this subject referred to in the course of the work.

Pumping tests are made primarily to obtain the coefficients of transmissibility and storage of the water bearing formations. As a part of this study six controlled pump tests were made in Roorkee area. The tests were run for limited periods -- no test was conducted for more than 23 hours duration. The available and existing close by tubewells and open wells have been used as observation stations while running the hydrological tests as it was not possible to construct new wells for this purpose. The pumping equipment used included a deep well turbine pump.

METHODS AND HYDROLOGICAL TEST PROCEDURES:

Certain fundamental principles, methods and formulae for the analyses of problems related to ground water from aquifer test data were developed by Gunther Thiem,[37] Theis,[32] Cooper and Jacob.[28] Apart from these methods, for solving particular type of ground water problems such as leakance during pumping have been developed by M.S. Hantush.[38, 38a] The data collected during the hydrological tests were analysed essentially by means of three methods suggested by Theis,[32] Jacob[29] and Chow.[30] Since these methods are scattered in the literatures, a concise account of the methods used appears to be essential and hence is given in brief. Average values of 'Storage Coefficient' and 'Transmissibility' are determined in the vicinity of the pumped wells by measuring the decline of head with time under the influence of a constant pumping rate. Measurements were taken both in the discharging as well as in the observation wells.

Theis Non-Equilibrium Formula for Pump Tests:

Theis non-equilibrium formula has been developed to determine the drawdown in the vicinity of a discharging well, taking into account the removal of water from storage. It does not depend on the hydraulic system reaching a state of equilibrium. According to him the formula is written as under:

$$s = \frac{114.60}{T} \int_{\frac{1.87 r^2 S}{Tt}}^{\infty} \frac{e^{-u}}{u} \, du \qquad \ldots \text{(iii)}$$

Where $u = \frac{1.87 r^2 S}{Tt}$

s = drawdown in feet at any point in the vicinity of the well pumped at uniform rate.

Q = discharge of the well in gallons per minute

T = Coefficient of Transmissibility of the aquifer in gallons per day per foot.

r = the distance, in feet, of the pumped well to the point of observation.

S = dimensionless Storage Coefficient.

t = time, in days, that the well has been pumped.

This formula has been developed on the assumption that the aquifer is infinite in extent, that it is homogenous, that its transmissibility is constant, that it is confined between impermeable beds, that the coefficient of storage is constant and that water is released from storage instantaneously with a decline in artesian head.

The formula though derived to satisfy strictly the artesian conditions, it is also applicable according to Theis, to phreatic horizons (water table conditions) where the thickness of the saturated material is great. However, in the latter case the observations should not be made too near the well where the vertical component in the water movement is particularly important. In the area under study, the non-equilibrium formula, in its complete and modified forms, finds wide application. Since only one observation well was used during the long duration pump tests, the scope regarding the application of Thiems' (37) equilibrium formula is limited. No corrections have been made for the effect of partial penetration of the alluvial aquifers. It may be added according to Todd, (34a) the error introduced by not conforming to this assumption would be insignificant.

The actual derivation of the formation constants in this method are obtained through graphical application by plotting the values of drawdown against the values of the r^2/t on logarithmic paper. The formula in its simplified form is written as:

$$s = \frac{114.6Q}{T} W(u) \quad \ldots \quad (iv)$$

where W (u) is the exponential integral termed 'Well Function'.

A plot on the logarithmic paper of W(u) versus u, is known as the type curve. The draw-down versus r^2/t plot from test data should conform to the same scale as the type curve and the former plot is superimposed on the type curve and adjusted (keeping the co-ordinate axes of the two curves parallel) till the points on the observed data fall on a segment of the type curve. An arbitrary point is selected on the coincident segment or outside the segment and the coordinates of this matching point are recorded. With values of W(u), u, s , and r^2/t thus obtained, storage coefficient and transmissibility ('S' and 'T') can be calculated from the following equations.

$$T = \frac{114.6\,Q}{s} W(u) \quad \ldots \quad (v)$$

$$S = \frac{T(t/r^2)}{1.87\,(1/u)} \quad \ldots \quad (vi)$$

The above non-equilibrium formula is theoretically applicable from the very start of the pumping test, but the initial data may be unreliable owing to the assumptions of instantaneous release of water from storage and constant value of 'S'. As such, pumping should be allowed as long as possible in order that 'S' becomes fairly stable.

The non-equilibrium formula has been modified or the procedures in its application are simplified for rapid analysis of the test data. Though these methods are not commonly in vogue, they are described in literature related to this subject.

Theis Modified Method for Pump Test Data (Recovery Formula):

For the determination of transmissibility from the recovery of water level in a pumped well Theis introduced another formula. This is an alternate method of application of the non-equilibrium equation on the assumption that if a well is pumped for a known period of time and shut down, the draw-down thereafter will be the same as if the discharge had been continued and a recharge well with the same flow were superposed on the discharging well at the instant the discharge is shut down. The assumptions are the same for both the euqations.

By measuring the rate of recovery of water level in a pumped well or a near by observation well, transmissibility (T) can be determined by rewriting the non-equilibrium formula:

$$T = \frac{264\,Q}{s'} \log_{10} t/t'$$

$$\text{or } T = \frac{264\,Q}{\Delta s'} \qquad \ldots \text{(vii)}$$

where T = is in gals/day/ft. t = time since pump started

Q = is in gals/minute t' = time since pump stopped

s' = is the residual drawdown in feet.

and $\Delta s'$ = change in residual drawdown in feet per log cycle of time.

To obtain a solution, residual draw-down "s" is plotted on a linear scale against t/t' on a logarithmic scale. From the slope of this plot, the change in residual draw-down for one log cycle of time should be determined and introduced into the modified formula to determine the 'T' value.

In the absence of sufficient number of observation wells and for reasons stated in previous paragraphs, this method has been extensively used in the present study to determine the coefficients of transmissibility of the water bearing formations.

Jacob Method of solution for Pump Test Data:

Jacob (29) noted that for small values of r and large values of t, u (in non-equilibrium formula) is small and as such a plot of draw down versus the logarithm of 't' forms a straight line. By plotting the draw down relationship against the time for an observation well during a pumping period, the formation constants can be computed by the application of the modified Theis formula:

$$T = \frac{264\,Q}{\Delta s'}$$

$$S = \frac{0.3T\,t_o}{\gamma 2} \qquad \ldots \text{(viii)}$$

Where $\Delta s'$ is the draw down difference per log cycle of time

t_o is the time intercept on the zero - drawdown axis.

Q, T and γ are as expressed earlier (equation vii and iii).

The straight line approximation for this method should be restricted to values of 'u' generally less than 0.02 to avoid large errors.

Chow Method of Solution for Pump Test Data:

The drawdown data from an observation well are plotted against time (in days) on semilogarithmic paper. On the plotted curve, co-ordinates of an arbitrary point are recorded. With the help of a tangent to the curve at the chosen point, the draw down difference (Δs), per log cycle of time is determined. From this data F(u) is computed using the following formula:

$$F(u) = \frac{\text{Drawdown (in feet)}}{\Delta s.} \qquad \ldots \text{(ix)}$$

The values of W(u) and u for F(u) are determined from Chow's type curve indicating the relation between F(u), W(u) and u. The formation constants 'T' and 'S' are computed by using equations (v) and (vi) described earlier.

Besides the above, the procedure for step-tests and its analysis are given at the appropriate place.

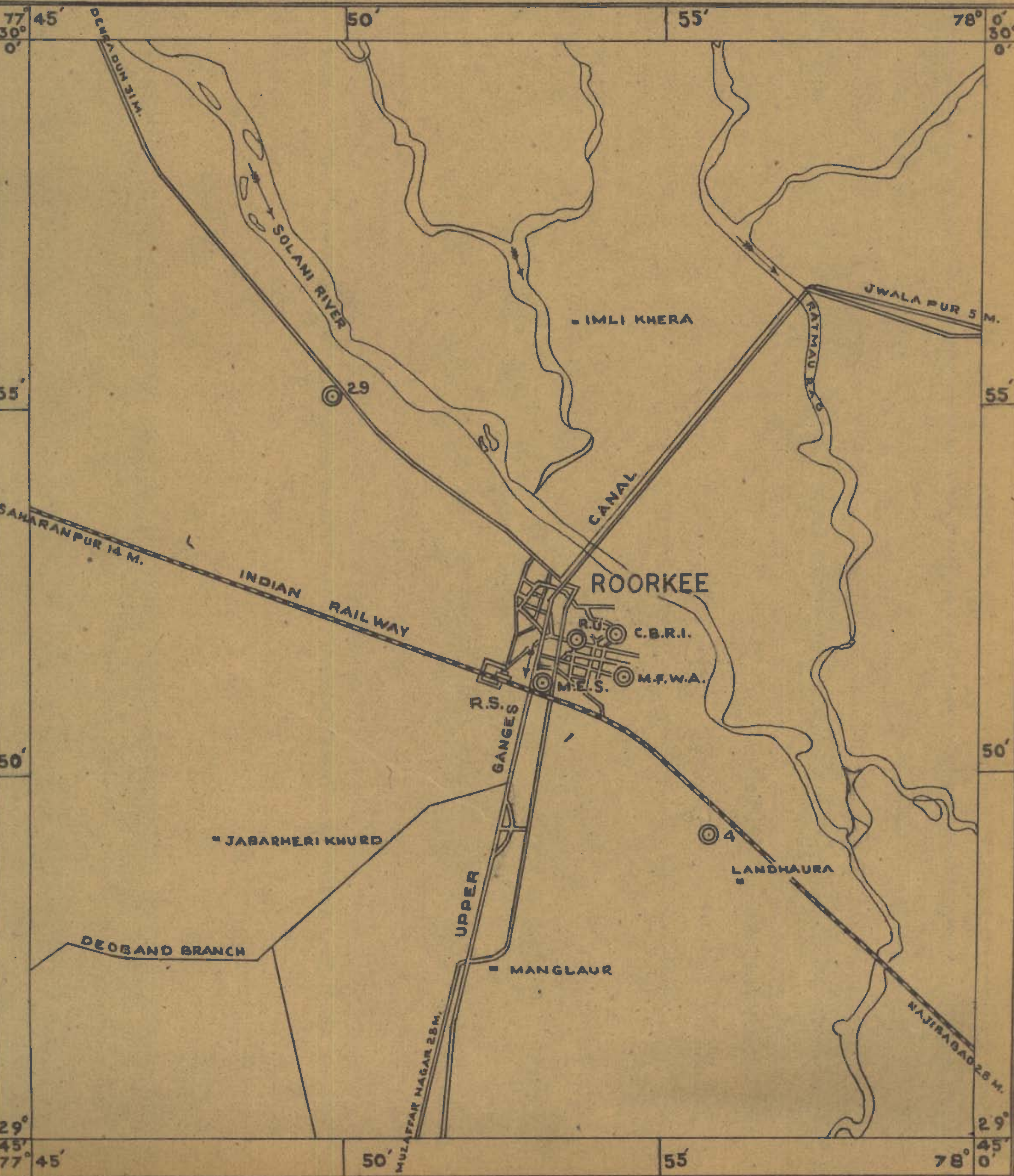
MAP SHOWING THE LOCATION OF TUBEWELLS IN ROORKEE AREA UTILISED FOR CONTROLLED PUMP TESTS.

SCALE:- 1:126,720

0 1 2 3 4 5 6 7 8 KILOMETRES.

0 1 2 3 4 5 MILES.

◎ TUBE WELL UTILISED FOR RUNNING CONTROLLED PUMP TESTS.



FORMATION CONSTANTS:

The hydrological parameters (Coefficient of Transmissibility, Coefficient of Storage and Coefficient of Field Permeability) of the water bearing formations in the region which are considered of fundamental importance in evaluating potentialities of well field area or ground water reservoirs, are determined by running controlled and constant discharge pump tests on the completed tubewells located in different parts of the area under study. Six such tests were conducted on the following wells - (i) Roorkee Military Field Works Area Tubewell (ii) Roorkee University Well (ETO) (iii) Military Engineering Services (MES) Cantonement Well (iv) CBRI Premises Tubewell (ETO) (v) State Tubewell No.4, Landhaura and (vi) State Tubewell No.29, Bhagwanpur. (Plate No.XVI).

The hydrological test data of the wells are recorded below:-

TABLE NO.8.

HYDROLOGICAL TEST DATA OF PUMPED WELLS IN ROORKEE AREA

Sl. No.	Location of pump tested well	Date of test	Hour	Depth to Water level (in ft)	t	t'	t/t'	Residual Draw down (in ft.)	REMAR
1	2	3	4	5	6	7	8	9	10
1.	Tubewell in the Military Field Works Area Roorkee (M.F.W.A)	6th Sept. 1962	10:48	48.20					All values of water level are with reference to the Measuring Point which is 0.25 ft. above land surface.
			10:55	48.20					
			11:00	Pump started; constant discharge 448 (US)GPM					
			11:03	55.75					
			11:05	55.90					

1	2	3	4	5	6	7	8	9	10
			11:10	56.21					
			11:15	56.34					
			11:20	56.25(?)					
			11:25	56.33					
			11:30	56.34					
			11:35	56.39					
			11:40	56.39					
			11:45	56.42					
			11:50	56.45					
			11:55	56.47					
			12:00	56.50					
			12:10	56.50					
			12:20	56.55					
			12:30	56.64					
			12:40	56.64					
			12:50	56.68					
			13:00	56.67					
			13:10	56.76					
			13:20	56.75					
			13:30	56.72					
			13:40	56.77					
			13:50	56.75					
			13:58	56.75					
			14:00	Pump Stopped					
			14:01	50.85	181	1	181	2.65	
			14:01:30	49.79	181.5	1.5	121	1.59	
			14:03	49.47	183	3	61	1.27	
			14:04	49.37	184	4	46	1.17	

1	2	3	4	5	6	7	8	9	10
			14:05	49.30	185	5	37	1.10	
			14:06:30	49.22	186.5	6.5	28.70	1.02	
			14:08	49.17	188	8	23.50	0.97	
			14:09:15	49.09	189.25	9.25	20.46	0.89	
			14:10:30	49.04	190.5	10.50	18.14	0.84	
			14:12	49.03	192	12	16.00	0.83	
			14:14	48.97	194	14	13.85	0.77	
			14:16	48.95	196	16	12.25	0.75	
			14:18	48.93	198	18	11.00	0.73	
			14:20	48.89	200	20	10.00	0.69	
			14:23	48.84	203	23	8.82	0.64	
			14:26	48.81	206	26	7.92	0.61	
			14:30	48.77	210	30	7.00	0.57	
			14:35	48.73	215	35	6.14	0.53	
			14:40	48.68	220	40	5.50	0.48	
			14:45	48.65	225	45	5.00	0.45	
			14:50	48.62	230	50	4.60	0.42	
			14:55	48.61	235	55	4.27	0.41	
			15:00	48.58	240	60	4.00	0.38	
			15:10	48.55	250	70	3.57	0.35	
			15:20	48.52	260	80	3.25	0.32	
			15:30	48.50	270	90	3.00	0.30	
			15:40	48.48	280	100	2.80	0.28	
			15:50	48.45	290	110	2.63	0.25	
			16:00	48.43	300	120	2.50	0.23	
			16:15	48.42	315	135	2.33	0.22	
			16:30	48.40	330	150	2.20	0.20	
			16:45	48.39	345	165	2.09	0.19	

1	2	3	4	5	6	7	8	9	10
			17:00	48.38	360	180	2.00	0.18	
			17:20	48.37	380	200	1.90	0.17	
			17:40	48.36	400	220	1.81	0.16	
			18:00	48.35	420	240	1.75	0.15	
		7.9.62	09:00	48.24	-	-	-	-	
2.	Roorkee University Well (ETO)	6.11.62	09:50	37.25				All values of water level are with reference to the Measuring point which is 2.90 ft. above land surface.	
			09:55	37.25					
			10:00	Pump started;constant discharge 726 (US)GPM					
			10:03	47.10					
			10:05	47.32					
			10:07	47.59					
			10:10	47.90					
			10:15	48.05					
			10:20	48.06					
			10:26	48.18					
			10:32	48.40					
			10:38	48.60					
			10:45	48.68					
			10:53	48.70					
			11:01	48.74					
			11:10	48.85					
			11:21	48.87					
			11:32	48.96					
			11:43	49.00					
			11:54	49.02					
			12:05	49.10					
			12:17	49.10					
			12:29	49.15					

1	2	3	4	5	6	7	8	9	10
			12:41	49.26					
			12:55	49.26					
			13:10	49.35					
			13:25	49.35					
			13:40	49.35					
			13:56	49.50					
			15:00	Pump stopped					
			15:01	40.15	301	1	301	2.90	
			15:02	40.00	302	2	151	2.75	
			15:02:30	39.70	302.5	2.5	121	2.45	
			15:03:30	39.52	303.5	3.5	86.7	2.27	
			15:04	39.44	304	4	76	2.19	
			15:05	39.31	305	5	61	2.06	
			15:06	39.21	306	6	51	1.96	
			15:07	39.14	307	7	43.9	1.89	
			15:08	39.09	308	8	38.5	1.84	
			15:09	39.04	309	9	35.6	1.79	
			15:10	38.98	310	10	31.0	1.73	
			15:12	38.93	212	12	26.0	1.68	
			15:14	38.81	314	14	22.4	1.56	
			15:16	38.73	316	16	19.8	1.48	
			15:18	38.68	318	18	17.7	1.43	
			15:20	38.65	320	20	16.0	1.40	
			15:23	38.56	323	23	14.0	1.31	
			15:26	38.49	326	26	12.5	1.24	
			15:30	38.43	330	30	11.0	1.18	
			15:35	38.37	335	35	9.57	1.12	
			15:40	38.32	340	40	8.50	1.07	

1	2	3	4	5	6	7	8	9	10
			15:45	38.29	345	45	7.66	1.04	
			15:50	38.22	350	50	7.00	0.97	
			16:00	38.14	360	60	6.00	0.89	
			16:14	38.05	374	74	5.00	0.80	
			16:27	37.99	387	87	4.45	0.74	
			16:35	37.92	395	95	4.15	0.67	
			16:52	37.86	412	112	3.68	0.61	
			17:10	37.75	430	130	3.31	0.50	
			17:25	37.70	445	145	3.07	0.45	
			17:40	37.65	460	160	2.87	0.40	
			18:00	37.58	480	180	2.66	0.33	
			20.00	37.49	600	300	2.00	0.24	
3.	Military Engineer-ing Ser-vices (MES) Well (E.T.O.)	18th Dec. 1963	09:45	36.40			All values of water level are with reference to the measuring point which is 1.12 ft. above land surface.		
			09:49	36.38					
			09:51	36.38					
			09:54	36.38					
			10:00	Pump started; constant discharge 659 (US)GPM					
			10:02	50.65					
			10:05	50.75					
			10:07	50.95					
			10:10	51.13					
			10:13	51.16					
			10:15	51.28					
			10:17	51.40					
			10:20	51.46					
			10:25	51.63					
			10:30	51.87					

1	2	3	4	5	6	7	8	9	10
			10:35	51.98					
			10:40	52.02					
			10:45	52.14					
			10:50	52.26					
			10:55	52.31					
			11:00	52.68					
			11:10	52.69					
			11:30	52.70					
			11:40	52.82					
			11:50	53.03					
			12:00	53.12					
			12:10	53.18					
			12:20	53.20					
			12:30	53.25					
			12:50	53.28					
			13:00	53.33					
			13:10	53.34					
			13:20	53.33					
			13:30	53.42					
			13:40	53.56					
			14:00	53.57					
			14:20	53.67					
			14:30	53.71					
			14:40	53.76					
			14:50	53.78					
			14:58	53.82					
			15:00	Pump stopped					
			15:01	40.38	301	1	301	4.00	

1	2	3	4	5	6	7	8	9	10
			15:03	40.40(?)	303	3	101	4.02(?)	
			15:04	39.81	304	4	76	3.43	
			15:05	39.45	305	5	61	3.07	
			15:06	39.55	306	6	51	3.17	
			15:08	39.72(?)	308	8	38.5	3.34(?)	
			15:10	39.45	310	10	31.0	3.07	
			15:11	39.27	311	11	28.27	2.89	
			15:12	39.18	312	12	26.00	2.80	
			15:13	39.16	313	13	24.07	2.78	
			15:15	38.91	315	15	21.00	2.53	
			15:17	38.68	317	17	18.65	2.30	
			15:20	39.06(?)	320	20	16.00	2.68(?)	
			15:25	38.72	325	25	13.00	2.34	
			15:26	38.66	326	26	12.54	2.28	
			15:27	38.63	327	27	12.11	2.25	
			15:30	38.63	330	30	11.00	2.25	
			15:31	38.62	331	31	10.68	2.24	
			15:34	38.60	334	34	9.82	2.22	
			15:36	38.59	336	36	9.33	2.21	
			15:40	38.40	340	40	8.50	2.02	
			15:42	38.11	342	42	8.14	1.73	
			15:45	37.84	345	45	7.67	1.46	
			15:48	37.72	348	48	7.25	1.34	
			15:50	37.63	350	50	7.00	1.25	
			15:52	37.58	352	52	6.79	1.20	
			15:55	37.54	355	55	6.45	1.16	
			15:58	37.52	358	58	6.17	1.14	
			16:00	37.50	360	60	6.00	1.12	

1	2	3	4	5	6	7	8	9	10
			16:05	37.47	365	65	5.62	1.09	
			16:10	37.42	370	70	5.29	1.04	
			16:15	37.42	375	75	5.00	1.04	
			16:20	37.40	380	80	4.75	1.02	
			16:25	37.36	385	85	4.53	0.98	
			16:30	37.25	390	90	4.33	0.87	
			16:35	37.12	395	95	4.16	0.74	
			16:40	37.06	400	100	4.00	0.68	
			16:45	37.03	405	105	3.81	0.65	
			16:50	37.00	410	110	3.73	0.62	
			16:55	36.98	415	115	3.61	0.60	
			17:00	36.87	420	120	3.50	0.49	
			17:05	36.84	425	125	3.40	0.46	
			17:10	36.80	430	130	3.31	0.42	
			17:15	36.76	435	135	3.22	0.38	
			17:20	36.72	440	140	3.14	0.34	
			17:25	36.68	445	145	3.07	0.30	
			17:30	36.56	450	150	3.00	0.18	
			17:35	36.52	455	155	2.94	0.14	
			17:40	36.48	460	160	2.88	0.10	
			17:45	36.42	465	165	2.82	0.04	
			17:50	36.39	470	170	2.76	0.01	
			17:55	36.38	475	175	2.71	0.00	
4.	CBRI Premises Tubewell (ETO)	17-10-63	09:53	09.89			All values of water level are with refer-ence to the measur-ing point which is 2.42 ft. above land surface.		
			09:59	09.89					
			10:00	Pump started; constant discharge 876 (US) GPM.					
			10:02	21.59					

1	2	3	4	5	6	7	8	9	10
			10:04	21.98					
			10:06	22.25					
			10:08	22.43					
			10:10	22.44					
			10:13	22.79					
			10:15	22.80					
			10:17	22.96					
			10:19	22.99					
			10:21	23.01					
			10:23	23.10					
			10:25	23.19					
			10:27	23.20					
			10:29	23.29					
			10:32	23.38					
			10:35	23.53					
			10:41	23.59					
			10.44	23.60					
			10:47	23.67					
			10:50	23.68					
			10:56	23.72					
			11:00	23.92					
			11:05	23.97					
			11:15	24.00					
			11:20	24.10					
			11:30	24.15					
			11:40	24.25					
			11:50	24.35					
			12:00	24.41					

1	2	3	4	5	6	7	8	9	10
			12:10	24.45					
			12:20	24.54					
			12:30	24.61					
			12:40	24.60					
			12:50	24.60					
			13:00	24.68					
			13:10	24.68					
			13:20	24.70					
			13:30	24.75					
			13:40	24.78					
			13:50	24.80					
			14:00	24.80					
			14:10	24.69					
			14:20	24.78					
			14:30	24.83					
			14:40	24.84					
			14:55	24.85					
			14:59	24.95					
			15:00	Pump stopped					
			15:01	13.55	301	1	301	3.66	
			15:02	12.80	302	2	151	2.91	
			15:03	12.84	303	3	101	2.95	
			15:04	12.57	304	4	76	2.68	
			15:05	12.44	305	5	61	2.55	
			15:06	12.34	306	6	51	2.45	
			15:07	12.18	307	7	43.85	2.29	
			15:08	12.10	308	8	38.50	2.21	
			15:09	11.90	309	9	34.33	2.01	

1	2	3	4	5	6	7	8	9	10
			15:11	11.85	311	11	28.02	1.96	
			15:12	11.79	312	12	26.00	1.90	
			15:13	11.80	313	13	24.07	1.91	
			15:14	11.77	314	14	22.41	1.88	
			15:15	11.69	315	15	21.00	1.80	
			15:16	11.65	316	16	19.75	1.76	
			15:18	11.64	318	18	17.68	1.75	
			15:20	11.55	320	20	16.00	1.66	
			15:22	11.50	322	22	15.54	1.61	
			15:24	11.45	324	24	13.50	1.56	
			15:26	11.40	326	26	12.54	1.51	
			15:28	11.38	328	28	11.71	1.49	
			15:32	11.25	332	32	10.37	1.36	
			15:34	11.15	334	34	9.82	1.26	
			15:36	11.15	336	36	9.33	1.26	
			15:38	11.10	338	38	8.89	1.21	
			15:40	11.05	340	40	8.50	1.16	
			15:42	11.04	342	42	8.38	1.15	
			15:45	11.03	345	45	7.66	1.14	
			15:47	11.02	347	47	7.44	1.13	
			15:49	11.00	349	49	7.39	1.11	
			15:51	11.00	351	51	6.88	1.11	
			15:55	10.98	355	55	6.45	1.09	
			15:57	10.90	357	57	6.26	1.01	
			16:00	10.89	360	60	6.00	1.00	
			16:05	10.87	365	65	5.61	0.98	
			16:10	10.84	370	70	5.28	0.95	
			16:15	10.78	375	75	5.00	0.89	

1	2	3	4	5	6	7	8	9	10
			16:20	10.75	380	80	4.75	0.86	
			16:25	10.64	385	85	4.52	0.75	
			16:30	10.63	390	90	4.33	0.74	
			16:35	10.61	395	95	4.14	0.72	
			16:40	10.60	400	100	4.00	0.71	
			16:45	10.51	405	105	3.85	0.62	
			16:50	10.50	410	110	3.72	0.61	
			16:55	10.48	415	115	3.60	0.59	
			17:02	10.47	422	122	3.45	0.58	
			17:10	10.40	430	130	3.30	0.51	
			17:15	10.39	435	135	3.22	0.50	
			17:20	10.36	440	140	3.14	0.47	
			17:25	10.31	445	145	3.06	0.42	
			17:30	10.33	450	150	3.00	0.44	
5.	State Tubewell No.29, Bhagwan-pur; Roorkee, Group	28th Dec. 1964	11:18	23.85	-	-	-	-	All values of water level are with reference to the Measuring point which is 0.50 ft. above land surface.
			11:48	23.86					
			12:00	Pump started - constant discharge 694 USGPM.					
			12:10	46.49					
			12:22	47.90					
			12:40	48.60					
			13:03	49.24					
			13:26	49.65					
			13:45	49.80					
			14:15	50.09					
			14:45	49.60(?)					
			15:17	50.18					
			15:49	50.74					
			16:18	50.84					

1	2	3	4	5	6	7	8	9	10
			17:00	51.36					
			17:22	51.38					
			17:51	51.34(?)					
			18:15	51.54					
			18:40	51.34					
			19:08	52.04					
			20:07	52.18					
			20:33	52.44					
			21:00	52.67					
			21:30	52.38					
			22:00	52.46					
			22:35	52.60					
			23:00	52.90					
			23:37	53.00					
		29th Dec., 1964	01:15	53.02					
			02:00	53.14					
			02:48	53.28					
			03:00	53.28					
			03:30	53.40(?)					
			03:45	53.32					
			04:30	53.30					
			05:30	53.22					
			05:40	53.24					
			06:15	53.45					
			06:25	53.17					
			06:40	53.24					
			07:00	53.35					
			07:35	53.36					
			08:15	52.94 ?					

1	2	3	4	5	6	7	8	9	10
			09:00	52.39(?)					
			09:39	53.29					
			09:51	53.32					
			10:00	Pump stopped					
			10:02	35.62	1322	2	661	11.76	A shallow well (No.25, Plate No.III) 300 feet due East of the we did not react to pumping in the pumped well (State Tubewell No.29) for the entire period of testing; Details of the shallow well are given under Appendix No.1.
			10:03	35.08	1323	3	441	11.22	
			10:04	34.62	1324	4	331	10.76	
			10:06	34.01	1326	6	221	10.15	
			10:08:30	33.42	1328.5	8.5	156.2	9.56	
			10:11	33.00	1331	11	121	9.14	
			10:15	32.46	1335	15	89	8.60	
			10:20	31.98	1340	20	67	8.12	
			10:25	31.59	1345	25	53.8	7.73	
			10.30	31.27	1350	30	45.0	7.41	
			10.35	31.00	1355	35	38.6	7.14	
			10:40	30.77	1360	40	34.0	6.91	
			10:50	30.39	1370	50	27.4	6.53	
			11:00	30.06	1380	60	23.0	6.20	
			11:10	29.79	1390	70	19.8	5.93	
			11:21	29.51	1401	81	17.3	5.65	
			11:30	29.34	1410	90	15.6	5.48	
			11:45	29.05	1425	105	13.4	5.19	
			12:00	28.83	1440	120	12.0	4.93	
			12:20	28.52	1460	140	10.4	4.66	
			12:40	28.20	1480	160	10.1	4.34	
			13:01	28.04	1501	181	8.3	4.18	
			13:22	27.82	1522	202	7.5	3.96	
			13:41	27.65	1541	221	7.0	3.79	

1	2	3	4	5	6	7	8	9	10
			14:02	27.47	1562	242	6.4	3.61	
			14:30	27.27	1590	270	5.8	3.41	
			15:00	27.07	1620	300	5.4	3.21	
			15:32	26.87	1652	332	5.0	3.01	
			16:01	26.72	1681	361	4.6	2.76	
			16:45	26.52	1725	405	4.2	2.66	
			17:31	26.32	1771	451	3.9	2.46	
			18:15	26.15	1815	495	3.6	2.29	
			19:02	26.00	1862	542	3.4	2.14	
			20:01	25.84	1921	601	3.1	1.98	
			21:00	25.67	1980	660	3.0	1.81	
			22:00	25.52	2040	720	2.8	1.66	
			23:00	25.38	2100	780	2.7	1.52	
		30th Dec., 1964	00:00	25.25	2160	840	2.5	1.39	
			01:00	25.12	2220	900	2.4	1.26	
			02:00	25.02	2280	960	2.3	1.16	
			04:00	24.80	2400	1080	2.2	0.94	
			06:00	24.65	2520	1200	2.1	0.79	
			08:00	24.51	2640	1320	2.0	0.65	
			08:20	24.49	2660	1340	1.9	0.63	
6.	State Tube-well No.4; Landh-aura; Roorkee Group.	24th Sept. 1964.	09:05	46.30	-	-	-		All values of water level are with reference to the measuring point which is 1.50 ft. above land surface.
			09:32	46.32					
			09:35	46.32					
			09:55	46.32					
			10:00	Pump started; constant discharge 590 (US)GPM.					
			10:27	54.15					
			10:33	54.40					
			10:52	54.50					

1	2	3	4	5	6	7	8	9	10
			11:00	54.54					
			12:00	55.20					
			12:35	54.95 (?)					
			12:44	55.20					
			12:50	55.25					
			13:00	54.60					
			13:05	54.75					
			13:12	55.15					
			13:23	55.25					
			13:30	55.17					
			13:55	55.30					
			14:20	54.50					
			14:50	54.40					
			15:20	54.60					
			15:40	54.65					
			16:00	55.30					
			16:15	54.90					
			16:30	55.35					
			17:00	54.65					
			17:20	54.50					
			17:34	54.65					
			17:45	55.25					
			18:10	54.65					
			18:46	54.50					
			19:05	54.65					
			19:30	54.70					
			19:45	54.70					
			20:00	54.60					
			21:10	53.90					

Since the test has been taken on the well with the permanently installed electrical driven pump the voltage fluctuations are partly reflected on the discharge and water levels.

1	2	3	4	5	6	7	8	9	10
			22:00	53.93					
			23:05	54.13					
		25.9.64	24:00) to) 07:30)						Readings could not be taken as the electric sounder was not functioning satisfactorily.
			07:50	55.05					
			08:05	55.20					
			08:30	55.21					
			09:00	Pump stopped.					
			09:01:15	48.03	1381.25	1.25	1105	1.71	
			09:02:30	47.82	1382.50	2.50	553	1.50	
			09:04	47.66	1384	4.0	346	1.34	
			09:06	47.51	1386	6.0	231	1.19	
			09:08	47.42	1388	8.0	173.5	1.10	
			09:10	47.35	1390	10.0	139.0	1.03	
			09:12	47.27	1392	12.0	116.0	0.95	
			09:14	47.22	1394	14.0	99.5	0.90	
			09:17	47.15	1397	17.0	82.1	0.83	
			09:20	47.09	1400	20.0	70.0	0.77	
			09:25	47.01	1405	25	56.2	0.69	
			09:30	46.95	1410	30	47.0	0.63	
			09:35	46.88	1415	35	40.4	0.56	
			09:40	46.84	1420	40	35.5	0.52	
			09:50	46.76	1430	50	28.6	0.44	
			10:00	46.69	1440	60	24.0	0.37	
			10:10	46.64	1450	70	20.7	0.32	
			10:20	46.59	1460	80	18.2	0.27	
			10:30	46.55	1470	90	16.3	0.23	

1	2	3	4	5	6	7	8	9	10
			10:45	46.50	1485	105	14.1	0.18	
			11:00	46.45	1500	120	12.5	0.13	
			11:15	46.42	1515	135	11.2	0.10	
			11:30	46.39	1530	150	10.2	0.07	
			11:45	46.35	1545	165	9.4	0.03	
			12:00	46.33	1560	180	8.7	0.01	
			12:15	46.31	1575	195	8.1	0.01	Tubewell surroundings water logged due to excessive rain.

TABLE NO.9.

HYDROLOGICAL TEST DATA OF OBSERVATION WELL IN THE ROORKEE AREA

Observation Well 47 ft. in N 195° to State Tubewell No.4 (Discharging well), Landhaura, Roorkee Group.

Note:- Observation tubewell simulates the Discharging well in the screened zones.

r = 47 feet;

Water Level Prior to Pumping : 44.59 feet below measuring point which is 0.50 feet above land surface.

Date	Hour	Time since pumping Began t — Minutes	Time since pumping Began t — Days	Drawdown in observation well (in ft.)	Recovery in Observation Well (in ft)	r^2/t (feet²/day)
1	2	3		4	5	6
24-9-64	1000 hrs. Pump started on the discharg -ing well	7	4.8×10^{-3}	2.15	-	4.54×10^{5}
		11	7.6×10^{-3}	2.31	-	2.89×10^{5}
		16	1.1×10^{-2}	2.36	-	1.98×10^{5}
		26	1.8×10^{-2}	2.61	-	1.22×10^{5}
		31	2.1×10^{-2}	2.71	-	1.02×10^{5}
		35	2.4×10^{-2}	2.75	-	9.08×10^{4}
		40	2.7×10^{-2}	2.81	-	7.95×10^{4}
		45	3.1×10^{-2}	2.85	-	7.06×10^{4}
		50	3.4×10^{-2}	2.89	-	6.36×10^{4}
		60	4.1×10^{-2}	2.99	-	5.30×10^{4}
		70	4.8×10^{-2}	3.05	-	4.50×10^{4}
		80	5.5×10^{-2}	3.13	-	3.97×10^{4}
		90	6.2×10^{-2}	3.16	-	3.53×10^{4}
		110	7.6×10^{-2}	3.22	-	2.89×10^{4}
		130	9.0×10^{-2}	3.28	-	2.44×10^{4}
		150	1.0×10^{-1}	3.32	-	2.12×10^{4}
		170	1.1×10^{-1}	3.39	-	1.87×10^{4}
		180	1.2×10^{-1}	3.40	-	1.76×10^{4}
		210	1.4×10^{-1}	3.39	-	1.51×10^{4}
		240	1.6×10^{-1}	3.40	-	1.32×10^{4}
		270	1.8×10^{-1}	3.42	-	1.17×10^{4}
		300	2.0×10^{-1}	3.47	-	1.06×10^{4}
		315	2.1×10^{-1}	3.48	-	1.01×10^{4}
		345	2.3×10^{-1}	3.45	-	9.22×10^{3}
		365	2.5×10^{-1}	3.48	-	8.71×10^{3}
		390	2.7×10^{-1}	3.47	-	8.15×10^{3}

1	2	3		4	5	6
		420	2.9×10^{-1}	3.50	-	7.57×10^{3}
		450	3.1×10^{-1}	3.52	-	7.06×10^{3}
		480	3.3×10^{-1}	3.53	-	6.62×10^{3}
		540	3.7×10^{-1}	3.57	-	5.89×10^{3}
		570	3.9×10^{-1}	3.57	-	5.88×10^{3}
		600	4.1×10^{-1}	3.56	-	5.30×10^{3}
		635	4.4×10^{-1}	3.58	-	5.00×10^{3}
		720	4.9×10^{-1}	3.53	-	4.41×10^{3}
		780	5.4×10^{-1}	3.49	-	4.07×10^{3}
		900	6.2×10^{-1}	3.49	-	3.53×10^{3}
						r^2/t'
25.9.64	Pumping stopped on discharging well at 09:00 hrs.	1	6.96×10^{-4}	-	1.25	3.18×10^{6}
		2	1.39×10^{-3}	-	1.55	1.59×10^{6}
		3	2.09×10^{-3}	-	1.73	1.06×10^{6}
		4	2.78×10^{-3}	-	1.83	7.95×10^{5}
		5	3.48×10^{-3}	-	1.91	6.36×10^{5}
		6	4.17×10^{-3}	-	2.00	5.30×10^{5}
		8	5.57×10^{-3}	-	2.08	3.97×10^{5}
		9	6.26×10^{-3}	-	2.15	3.53×10^{5}
		10	6.96×10^{-3}	-	2.19	3.18×10^{5}
		11	7.64×10^{-3}	-	2.25	2.89×10^{5}
		12	8.33×10^{-3}	-	2.28	2.65×10^{5}
		13	9.02×10^{-3}	-	2.31	2.44×10^{5}
		15	1.04×10^{-2}	-	2.37	2.12×10^{5}
		16	1.11×10^{-2}	-	2.40	1.98×10^{5}
		17	1.18×10^{-2}	-	2.43	1.87×10^{5}
		18	1.25×10^{-2}	-	2.45	1.76×10^{5}
		19	1.31×10^{-2}	-	2.49	1.67×10^{5}
		20	1.38×10^{-2}	-	2.50	1.59×10^{5}

SEMI-LOG PLOT (t/t' VERSUS s') OF PUMP TEST DATA FOR MILITARY FIELD WORKS AREA WELL; ROORKEE

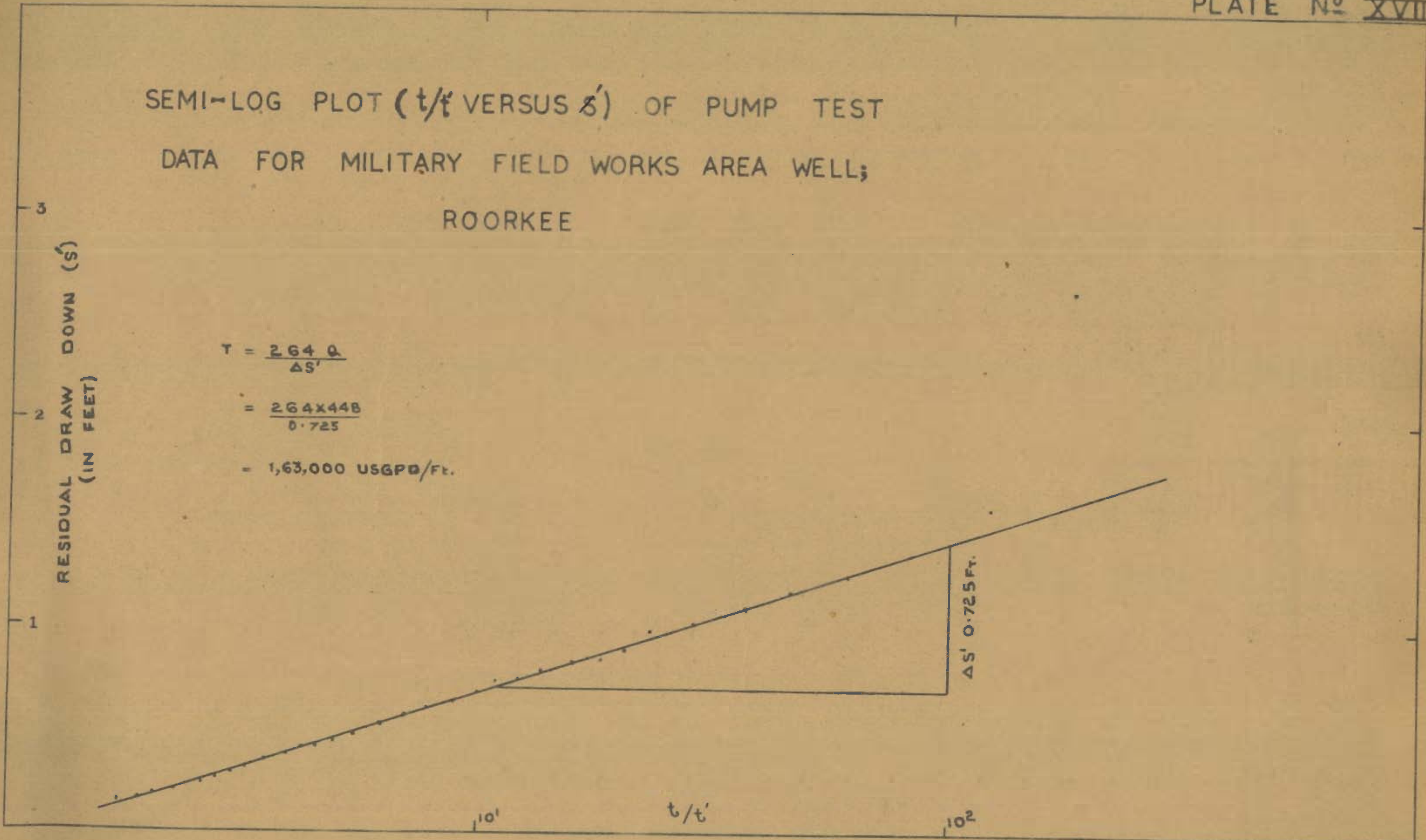


PLATE No XVIII

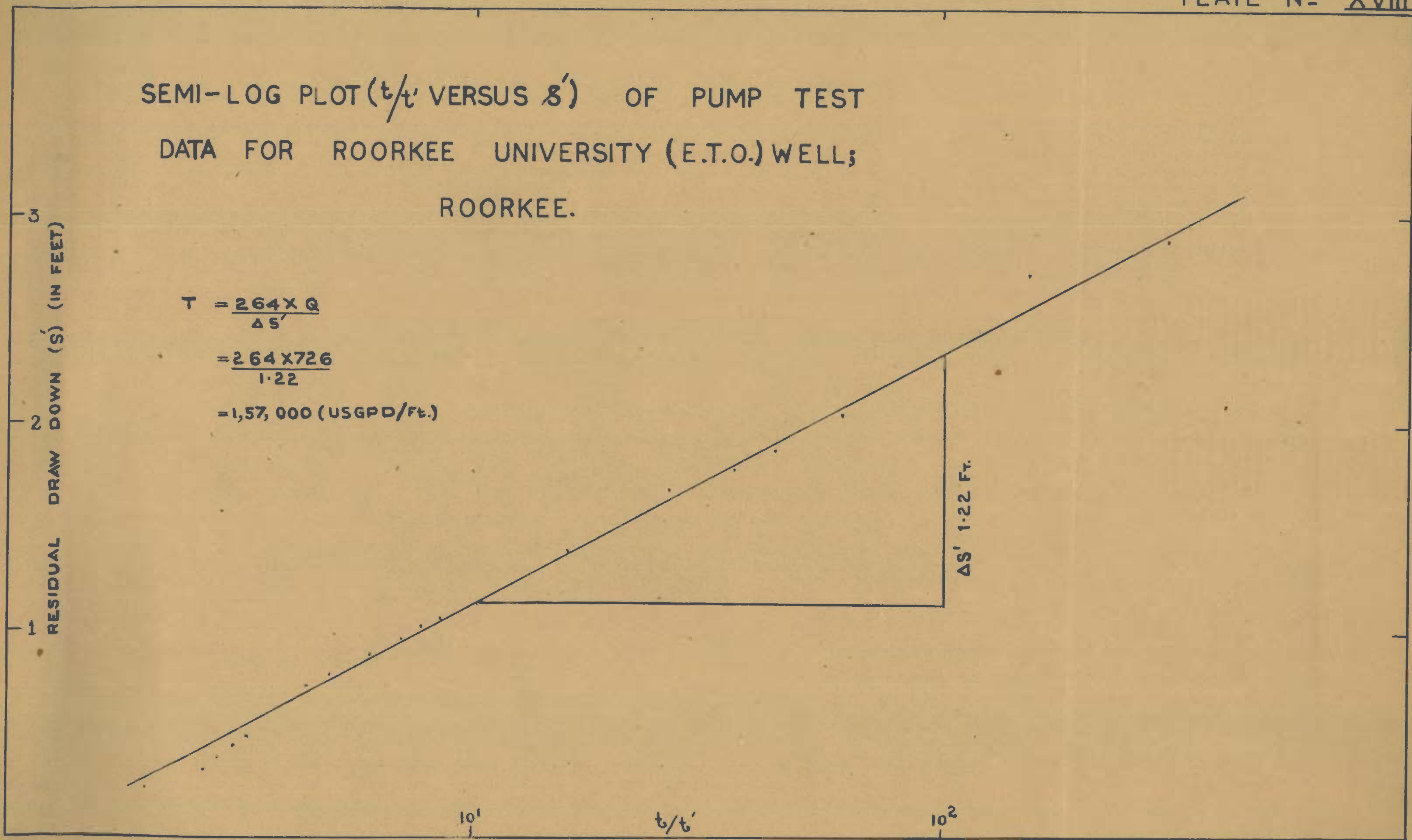


PLATE No XIX

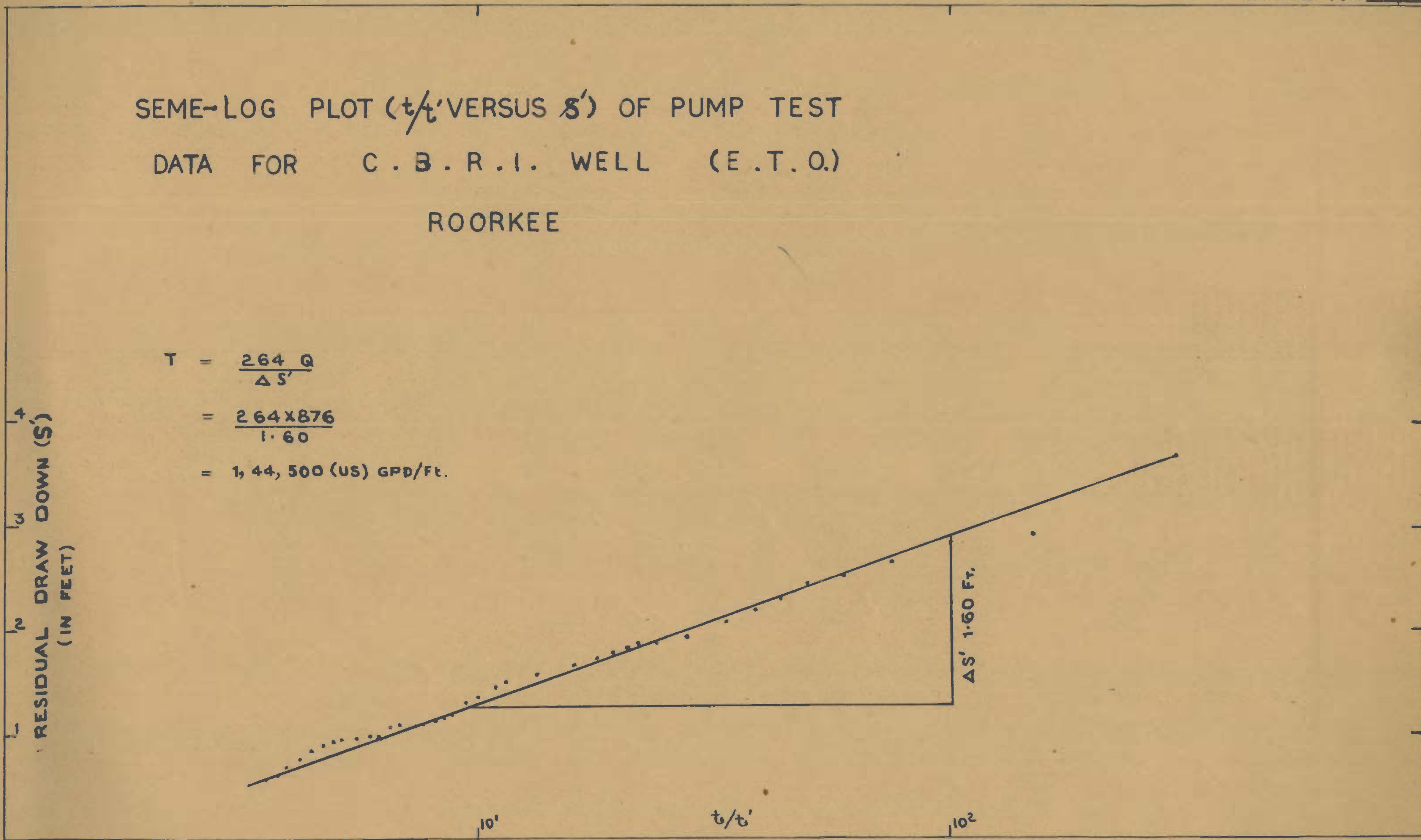
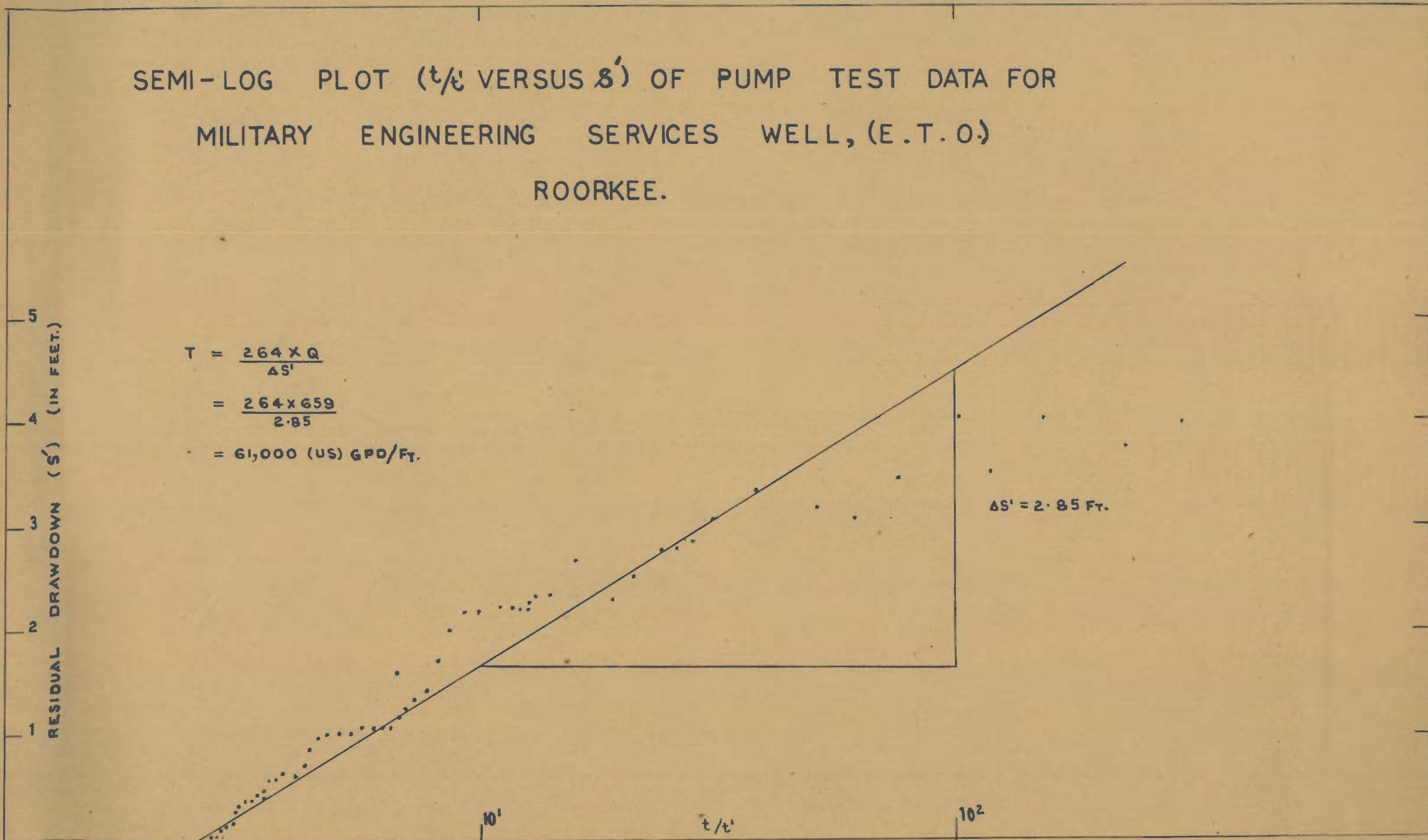

SEME-LOG PLOT (t/t' VERSUS S') OF PUMP TEST
DATA FOR C.B.R.I. WELL (E.T.O.)
ROORKEE
T = 264 Q / ΔS'
= 264X876 / 1·60
= 1, 44, 500 (US) GPD/Ft.
ΔS' 1·60 Ft.
RESIDUAL DRAW DOWN (S')
(IN FEET)
1
2
3
4
10'
t/t'
10²

PLATE № XX



SEMI-LOG PLOT (t/t' VERSUS s') OF PUMP TEST DATA FOR
MILITARY ENGINEERING SERVICES WELL, (E.T.O.)
ROORKEE.
T = 264 X Q / ΔS'
= 264 X 659 / 2.85
= 61,000 (US) GPD/FT.
ΔS' = 2·85 FT.
RESIDUAL DRAWDOWN (S') (IN FEET.)
1
2
3
4
5
10¹
t/t'
10²

SEMI-LOG PLOT (t/t' VERSUS S') OF PUMP TEST DATA FOR STATE TUBEWELL Nº 29, BHAGWANPUR, ROORKEE.

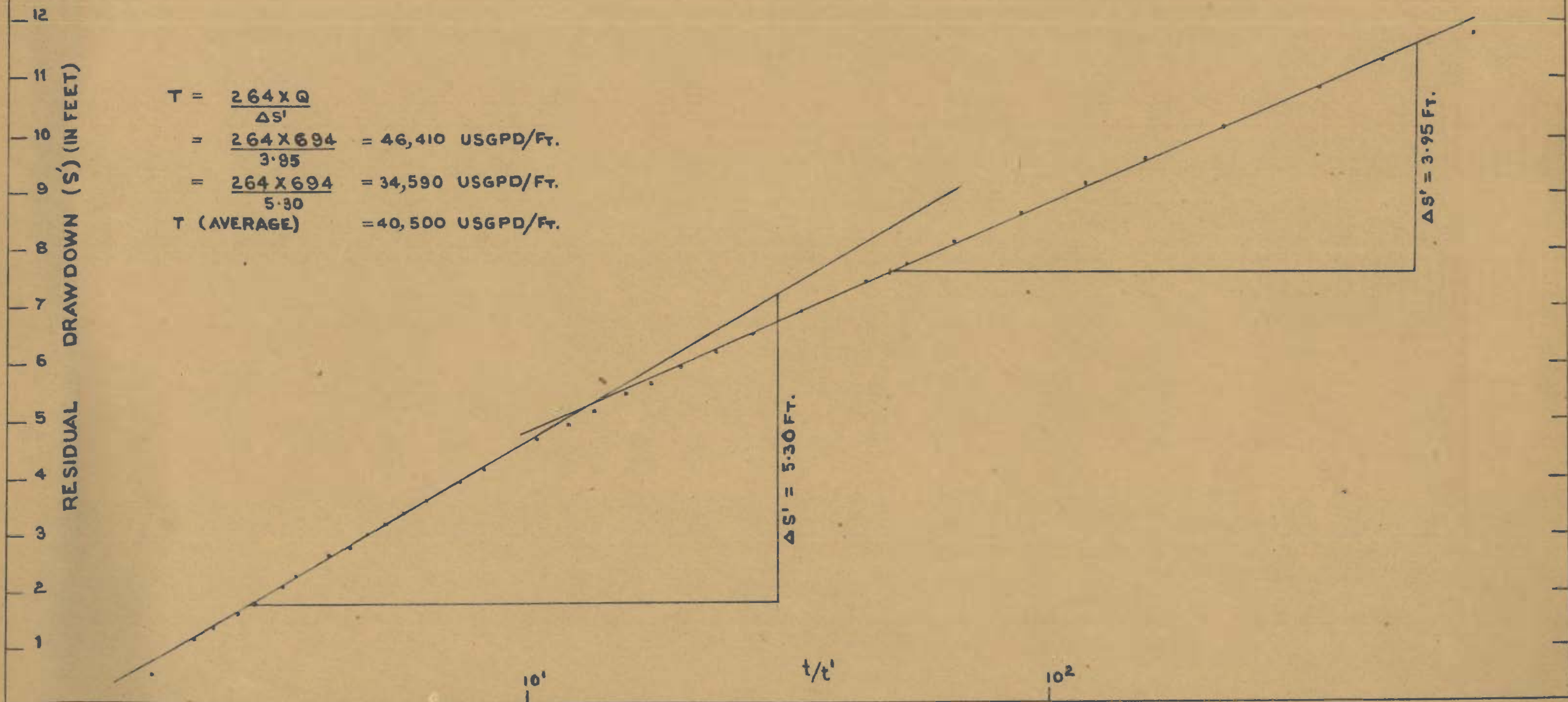


PLATE No. XXII

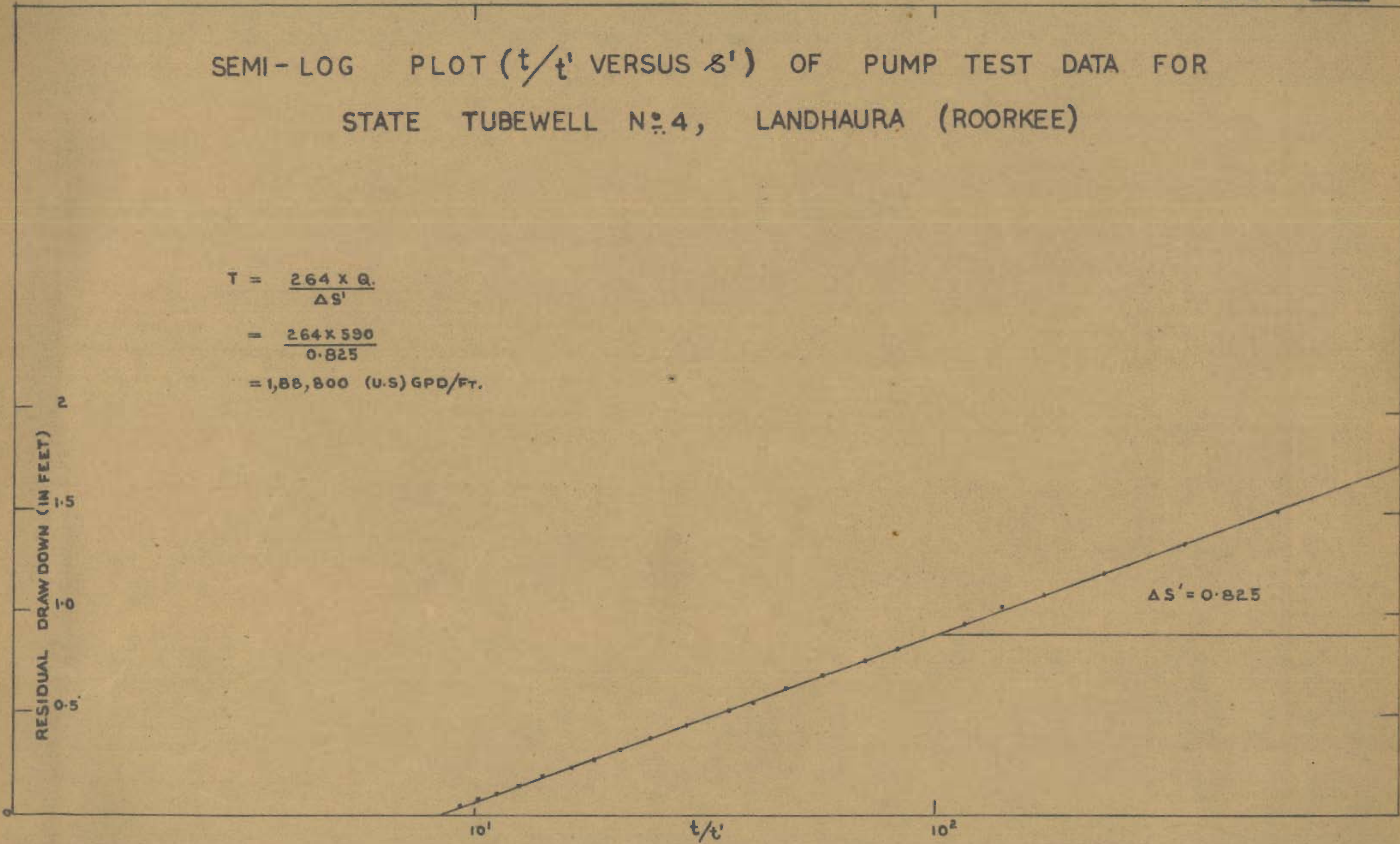
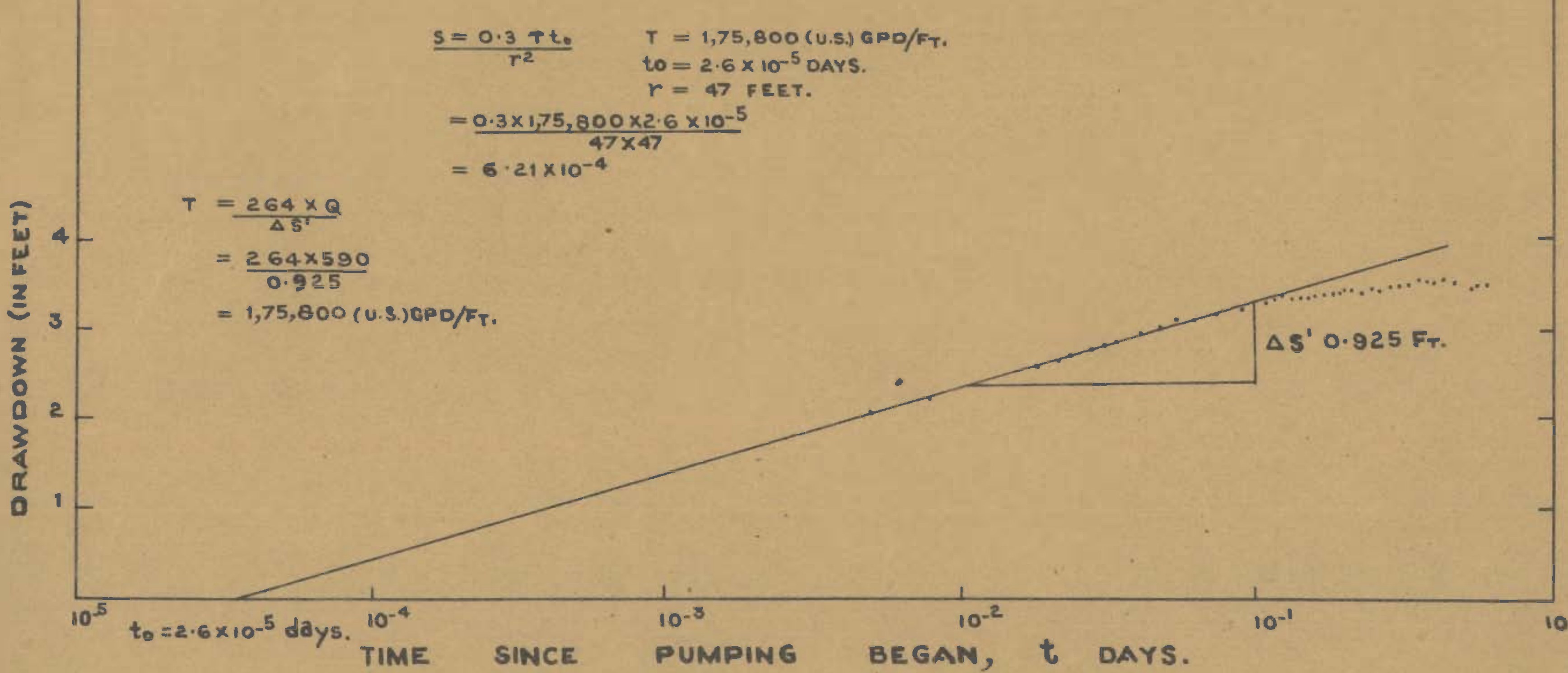


PLATE Nº XXIII

SEMI-LOG PLOT (TIME VERSUS DRAWDOWN) OF PUMP TEST DATA FOR OBSERVATION WELL CLOSE TO STATE TUBEWELL Nº4, LANDHAURA ROORKEE.



1	2	3		4	5	6
		22	1.52×10^{-2}	-	2.54	1.44×10^{5}
		24	1.67×10^{-2}	-	2.57	1.32×10^{5}
		30	2.09×10^{-2}	-	2.68	1.06×10^{5}
		40	2.78×10^{-2}	-	2.79	7.95×10^{4}
		50	3.48×10^{-2}	-	2.88	6.36×10^{4}
		60	4.17×10^{-2}	-	2.95	5.30×10^{4}
		78	5.44×10^{-2}	-	3.04	4.07×10^{4}
		100	6.96×10^{-2}	-	3.13	3.18×10^{4}
		120	8.33×10^{-2}	-	3.19	2.65×10^{4}
		150	1.02×10^{-1}	-	3.27	2.12×10^{4}
		180	1.25×10^{-1}	-	3.33	1.76×10^{4}

Except for the test data of well no.4, Landhaura (Roorkee), the rest of the hydrological data were subjected to analysis by modified Theis recovery method. The formation constants were derived by other methods using the observation well data at Landhaura. The details of calculation are furnished below.

a) The values of transmissibility for the alluvial aquifers as obtained by the application of modified Theis formula are recorded on the semi-log-plots t/t' versus s' (Plates XVII to XXIII). The results are summarised under Table No.11. The implications regarding the disposition of the curves are further discussed in the following pages.

b) The transmissibility and storage coefficients of the alluvial aquifers close to Landhaura Village are computed as follows:

i) Drawdown measured in the observation well was plotted against 't' time since pumping began in days, (duration) on a semi-log graph. Time in days for zero drawdown, 'to', was obtained by extending the straight line graph to cut the time axis (Plate No.XXIII). The transmissibility is computed from equation No.(vii) and the storage coefficient is derived from equation No.(viii) stated earlier.

$$T = \frac{264\ Q}{\Delta s'} = \frac{264 \times 590}{0.925}$$

$$= 1,75,800 \text{ USGPD/ft.}$$

$$S = \frac{0.3\ T\ t_o}{r^2} = \frac{0.3 \times 1,75,800 \times 2.6 \times 10^{-5}}{47 \times 47}$$

$$= 6.21 \times 10^{-4}$$

ii) The observation well data are also plotted against time since pumping began in days on a semi-log paper (Chow's Method - Plate No.XXIV and XXV). The data in table No.9 are utilised to bring out the graph. A tangent is drawn to the curve at an arbitrary point 'A' to determine Δh, in feet per log cycle of time. F(u) was computed using equation No.(ix) stated earlier. From the plot $t = 4.4 \times 10^{-2}$ day, s = 3.00 ft. and $\Delta h = 0.925$ ft.

$$F(u) = \frac{ho - h}{\Delta h} = \frac{3.00}{0.925} = 3.24$$

From Chow's type curve (Plate No.XXIV):

$$u = 0.0002$$

$$W(u) = 7.80$$

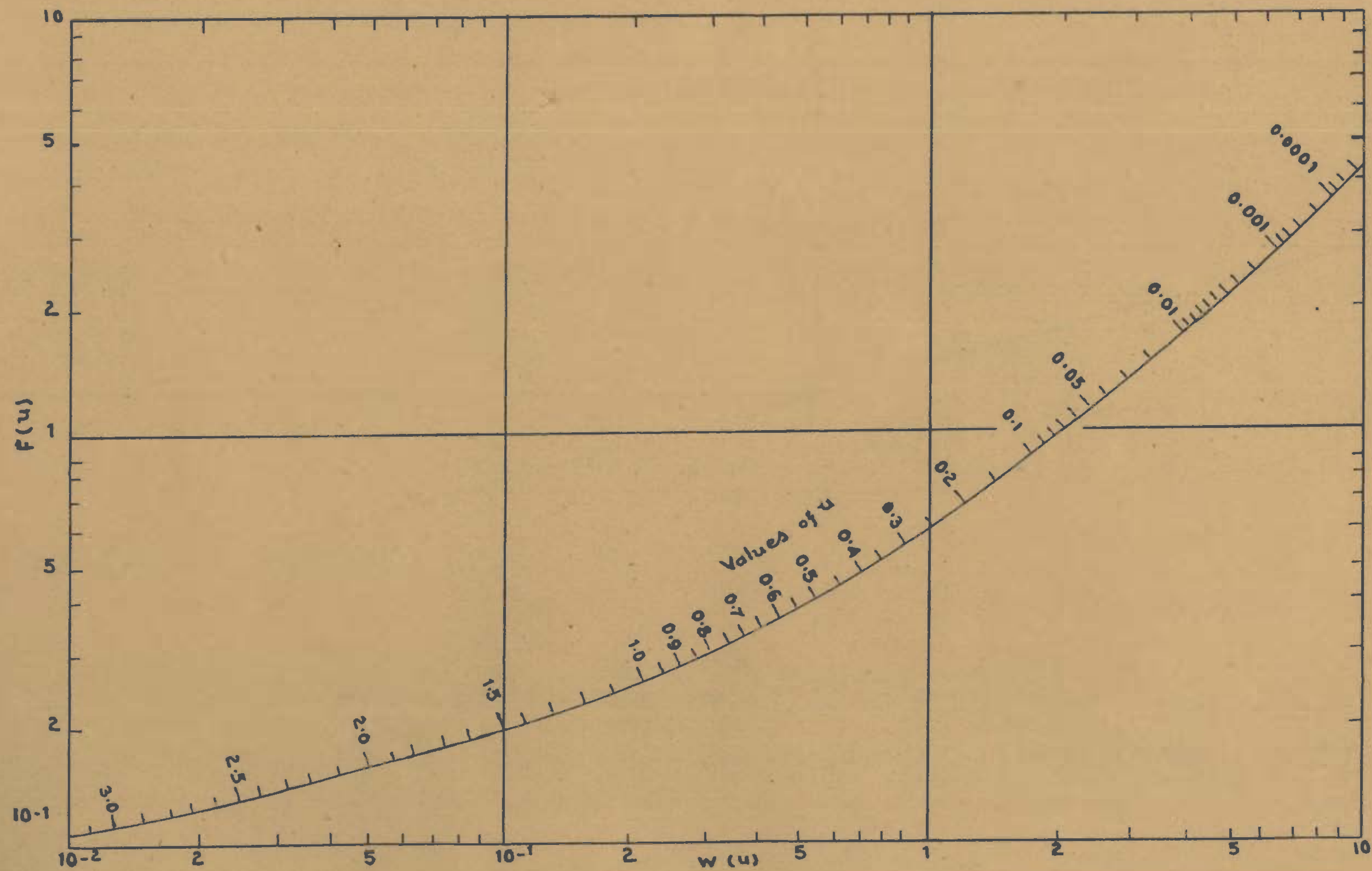
$$T = \frac{114.6\ Q}{ho - h} W(u)$$

$$= \frac{114.6 \times 590 \times 7.80}{3.00}$$

$$= 1,75,800 \text{ (US) GPD/ft.}$$

LOGORITHMIC GRAPH INDICATING RELATION OF F(U), W(U) AND (U)

(AFTER CHOW)



$$S = \frac{ut\,T}{1.87\, r^2}$$

$$= \frac{0.0002 \times 1,75,800 \times 4.4 \times 10^{-2}}{1.87 \times 47 \times 47}$$

$$= 0.000374$$

$$= 3.74 \times 10^{-4}$$

iii) By utilising the hydrological test data of Table No.9, the Theis method of superposition for the formation constants was resorted to by plotting the values of 's' versus 'r^2/t ' on the logarithmic paper both for the recovery and the drawdown observations (Plate Nos.XXVII and XXVIII). The recovery and drawdown plots are superposed on the type curve (Plate No.XXVI) and on each coincident segment match points A and A' are selected. Outside the coincident segment also ~~are~~ one match point is taken on each curve (B and B') to average out the computed value of 'S'. The values for match points A and B (draw down) are $s = 3.30$, $r^2/t = 3 \times 10^4$

$u = 3.35 \times 10^{-5}$, $W(u) = 9.80$ and $s = 1.05$,

$r^2/t = 4 \times 10^4$, $u = 6 \times 10^{-5}$, $w(u) = 3.0$

respectively.

Thus from the equation (v) and (vi).

<u>For Point A:</u>

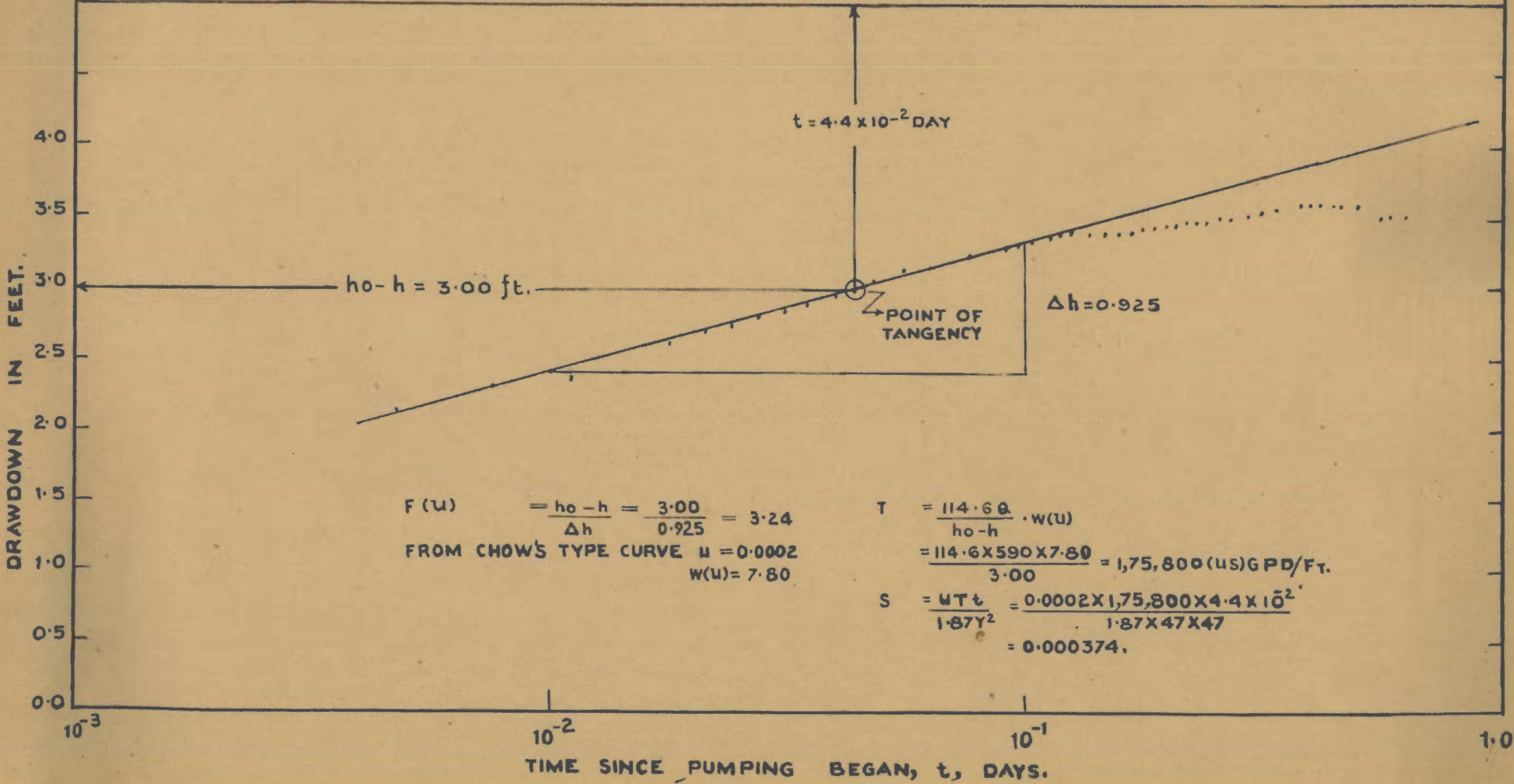
$$T = \frac{114.6\,Q}{s}\, w(u)$$

$$= \frac{114.6 \times 590}{3.30} \times 9.80$$

$$= 2,00,800 \text{ (US)GPD/ft.}$$

$$S = \frac{u\,t\,T}{1.87\, r^2} = \frac{uT}{1.87\,(r^2/t)}$$

SEMI-LOG PLOT (TIME VERSUS DRAWDOWN) FOR SOLUTION OF NON-EQUILIBRIUM EQUATION BY CHOW'S METHOD; OBSERVATION WELL, LANDHAURA (ROORKEE)



LOGARITHIMIC PLOT OF u VERSUS W(u) THEIS TYPE CURVE

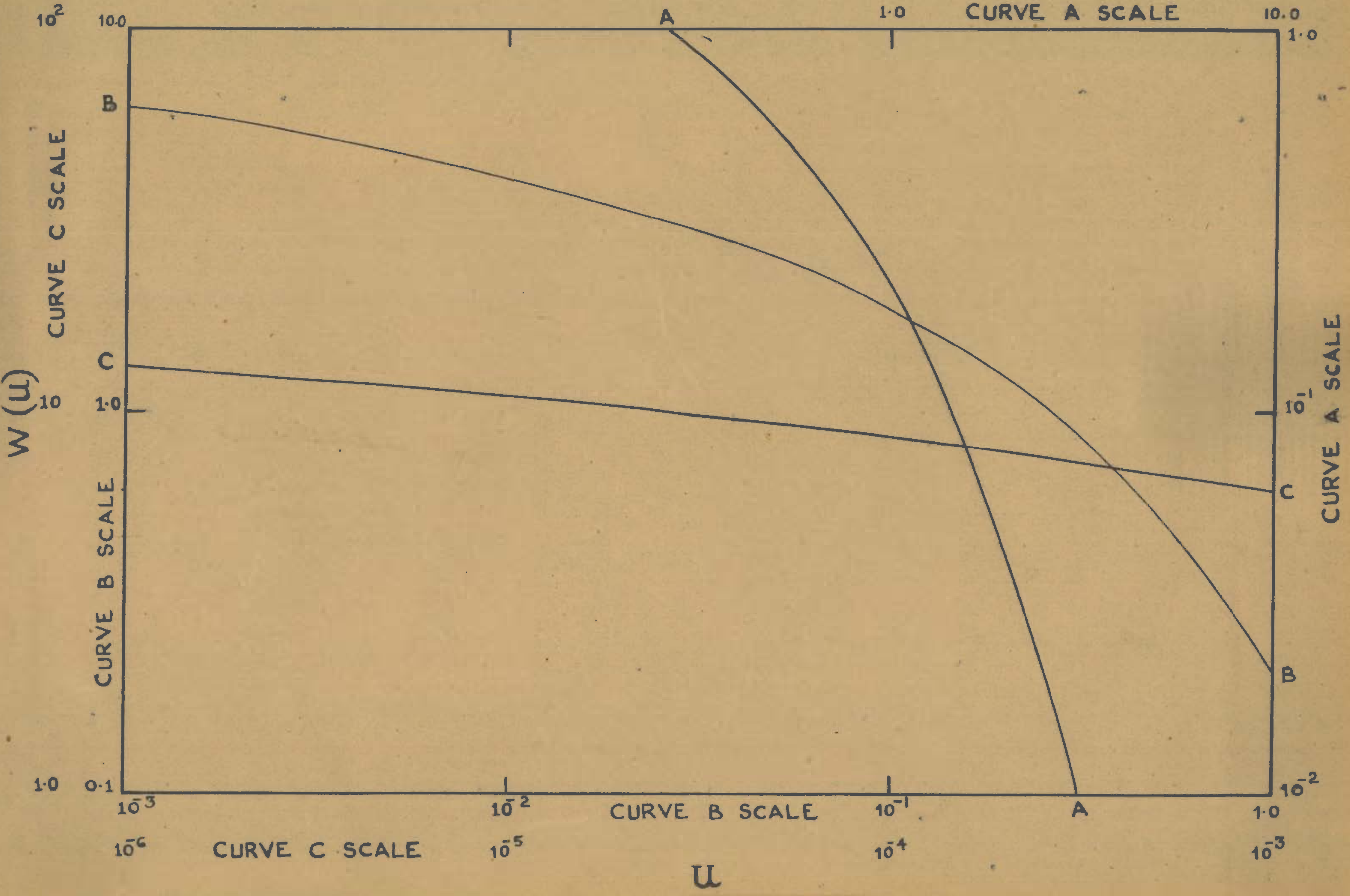
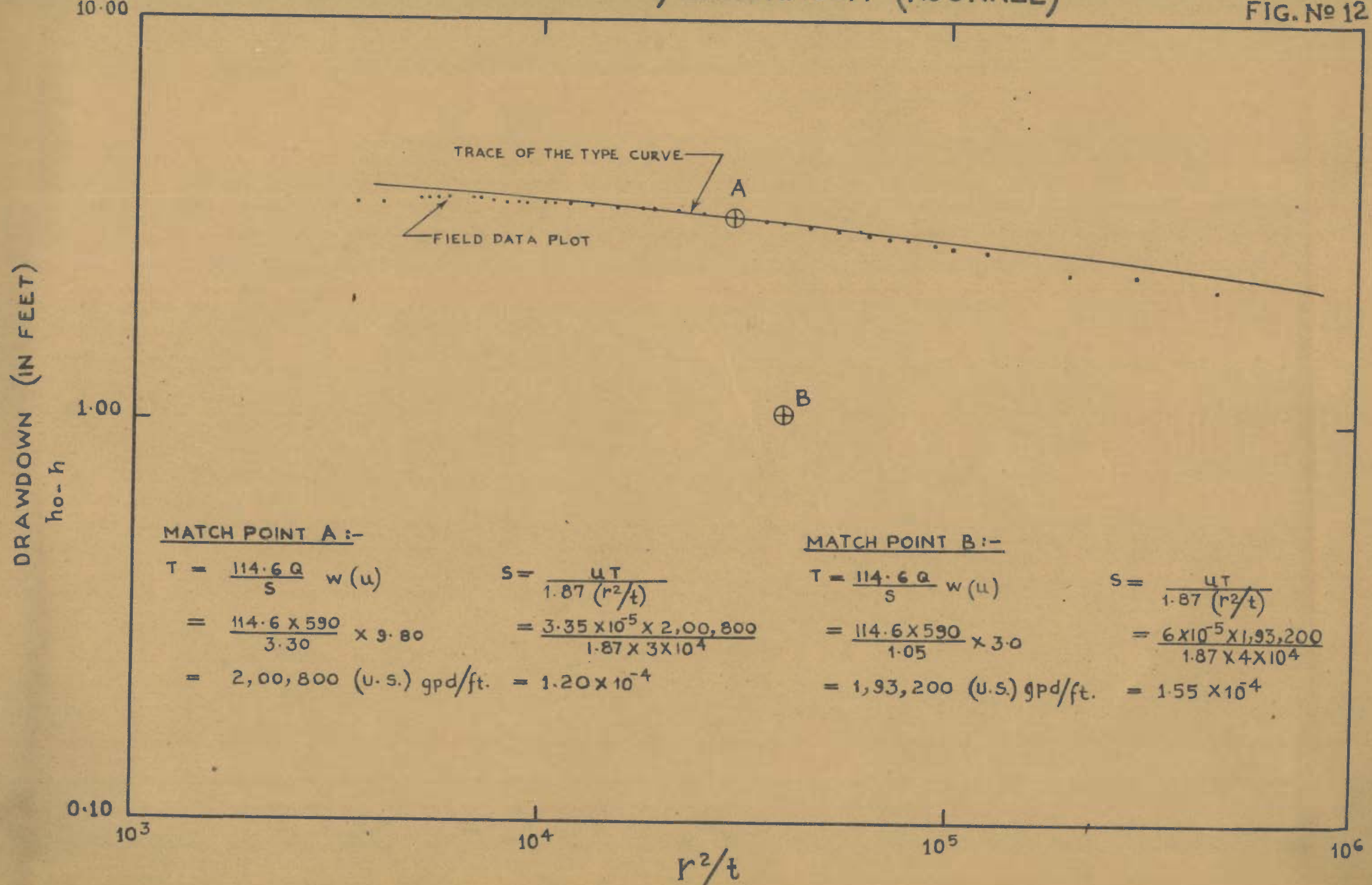


PLATE Nº XXVII

LOGARITHIMIC GRAPH OF DRAWDOWN OF WATERLEVEL IN WELL Nº 4, LANDHAURA (ROORKEE)

FIG. Nº 12



MATCH POINT A :-

$T = \frac{114 \cdot 6\, Q}{S} w(u)$

$= \frac{114 \cdot 6 \times 590}{3 \cdot 30} \times 9 \cdot 80$

$= 2,00,800$ (U.S.) gpd/ft.

$S = \frac{uT}{1.87\,(r^2/t)}$

$= \frac{3 \cdot 35 \times 10^{-5} \times 2,00,800}{1 \cdot 87 \times 3 \times 10^4}$

$= 1 \cdot 20 \times 10^{-4}$

MATCH POINT B :-

$T = \frac{114 \cdot 6\, Q}{S} w(u)$

$= \frac{114 \cdot 6 \times 590}{1 \cdot 05} \times 3 \cdot 0$

$= 1,93,200$ (U.S.) gpd/ft.

$S = \frac{uT}{1 \cdot 87\,(r^2/t)}$

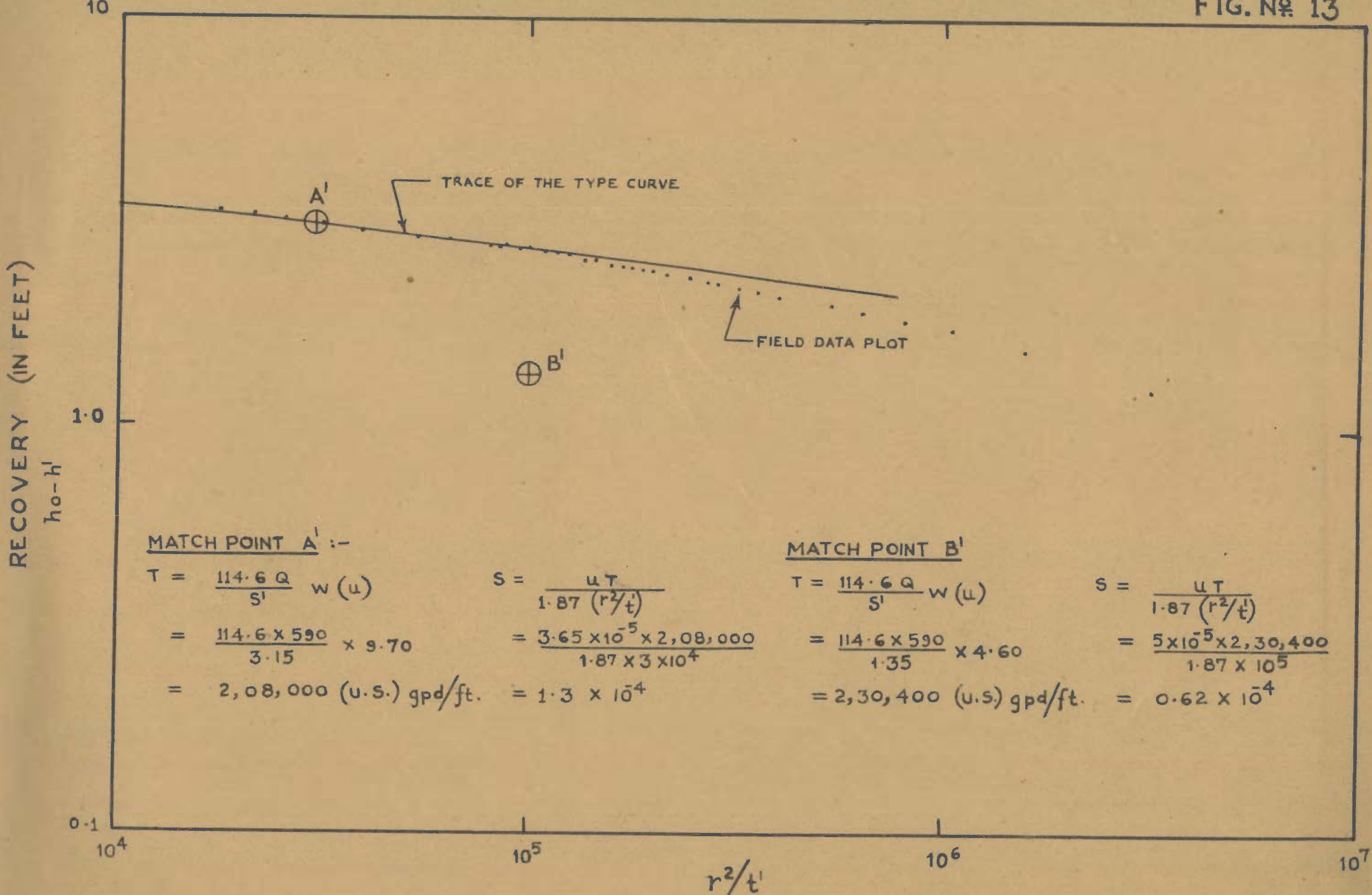
$= \frac{6 \times 10^{-5} \times 1,93,200}{1 \cdot 87 \times 4 \times 10^4}$

$= 1 \cdot 55 \times 10^{-4}$

PLATE No. XXVIII

LOGARITHMIC GRAPH OF RECOVERY OF WATERLEVEL IN WELL No. 4, LANDHAURA (ROORKEE)

FIG. No. 13



$$= \frac{3.35 \times 10^{-5} \times 2,00,800}{1.87 \times 3 \times 10^{4}}$$

$$= 0.0001190$$

$$\text{or} \quad 1.20 \times 10^{-4}$$

<u>For Point B:</u>

$$T = \frac{114.6\ Q}{s}\ w(u)$$

$$= \frac{114.6 \times 590}{1.05} \times 3.0$$

$$= 1,93,200 \text{ (US) GPD/ft.}$$

$$S = \frac{u\ T\ t}{1.87\ r^{2}}$$

$$= \frac{6 \times 10^{-5} \times 1,93,200}{1.87 \times 4 \times 10^{4}}$$

$$= 1.55 \times 10^{-4}$$

The values for match points A' and B' (recovery) are $s' = 3.15$, $r^2/t' = 3 \times 10^4$, $u = 3.65 \times 10^{-5}$, $w(u) = 9.70$ and $s' = 1.35$, $r^2/t' = 1 \times 10^5$, $u = 5 \times 10^{-5}$, $w(u) = 4.60$ respectively.

<u>For Point A':</u>

$$T = \frac{114.6\ Q}{s'}\ w(u)$$

$$= \frac{114.6 \times 590}{3.15} \times 9.70$$

$$= 2,08,000 \text{ (US) GPD/ft.}$$

$$S = \frac{u\ T\ t}{1.87\ r^2}$$

$$= \frac{3.65 \times 10^{-5} \times 2,08,000}{1.87 \times 3 \times 10^{4}}$$

$$= 0.000135$$

$$\text{or} \quad 1.3 \times 10^{-4}$$

<u>For Point B':</u>

$$T = \frac{114.6\,Q}{s'} \; w(u)$$

$$= \frac{114.6 \times 590}{1.35} \times 4.60$$

$$= 2,30,400 \text{ (US)GPD/ft.}$$

$$S = \frac{u\,T\,t'}{1.87\,r^2}$$

$$= \frac{5 \times 10^{-5} \times 2,30,400}{1.87 \times 10^{5}}$$

$$= 0.62 \times 10^{-4}$$

The average of the above values (A, A', B and B' match points) give the T and S values for the alluvial formations around Landhaura by Theis method.

$$T = 2,08,200 \text{ (US)GPD/ft.}$$

$$S = 1.16 \times 10^{-4}$$

iv) The field permeabilities of the alluvial formations in the area have been determined by the application of the simple relationship between transmissibility, thickness of the aquifer and the field permeability (P_f). This relationship is expressed as

P_f = T/m. ('m' is the thickness of the aquifer in feet and T is the transmissibility of the aquifer in gpd/ft.).

Since the transmissibilities of the alluvial aquifers as obtained from pump test analysis represent essentially the values for the aquifers screened in the wells, in a cumulative manner the field permeability values are computed by applying the above formula where 'm' is the screened thickness of the aquifers in the wells. The permeability values at the six sites tested in the region are given below:

TABLE NO.10.

FIELD PERMEABILITY OF THE ALLUVIAL AQUIFERS IN ROORKEE AREA:

Sl. No.	Well Location	Transmissibility USGPD/ft. (as computed from the pumped well data	Thickness of the aquifer screened (in ft.)	Field Permeability of the aquifers (US gpd/sq.ft.)
1	2	3	4	5
1.	Roorkee Military Field Works Area Site	1,63,000	110	1,480
2.	Roorkee University Site	1,57,000	150	1,040
3.	Military Cantonement (MES)Site, Roorkee	61,000	100	610
4.	C.B.R.I. Premises, Well Roorkee	1,45,000	110	1,310
5.	State Tubewell No.4, Landhaura,Roorkee.)	1,83,000	100	1,830
6.	State Tubewell No.29, Bhagwanpur (Roorkee)	40,500	80	510

The field permeabilities of the aquifers in general vary from 500 to 1850 (US) GPD/Sq.ft.

A summary of the results of pump tests is given in the following Table No.11.

TABLE NO.11.

Sl. No.	Test Well	Date and time of Test (in hrs)	Duration of Test (in hrs.)	Number of observation wells used	Rate of pumping (USGPM)
1	2	3	4	5	6
1.	Military Field Works Area Well, Roorkee	6-9-62 (11:00 to 14:00)	3	Nil	448
2.	Roorkee University Tubewell (ETO), Roorkee.	6-11-62 (10:00 to 15:00)	5	Nil	726
3.	CBRI Tubewell (ETO), Roorkee	17-10-63 (10:00 to 15:00)	5	Nil	876
4.	Military Cantonement Well (ETO), Roorkee	18-12-63 (10:00 to 15:00)	5	Nil	659
5.	State Tubewell No.4, Landhaura (Roorkee Group)	24/25-9-64 (10:00 on 24.9.64 to 09:00 on 25.9.64)	23	One (Tubewell, 47 ft. away N 195°; simulating the pumped well)	590
6.	State Tubewell No.29, Bhagwanpur (Roorkee Group)	28/29-12-64 (12 Noon on 28.12.64 to 10:00 on 29-12-64)	22	One (Shallow open well 300 ft. away due East; not reacted).	694

Thickness of the aquifer screened (feet)	Method of computation	Transmissibility (USgpd/ft.) T	Storage coefficient. S	Field Permeability (US gpd/sq.f) Pf
7	8	9	10	11
110	t/t' versus RDD Plot	1,63,000	-	1,480
150	-do-	1,57,000	-	1,040
110	-do-	1,45,000	-	1,310
100	-do-	61,000	-	610
100	a) t/t' versus RDD plot	1,83,000	-	1,830
	b) to intercept method (time versus drawdown semi-log plot)	1,75,000	6.21×10^{-4}	1,750
	c) Theis non-equilibrium method.			*
	i) Drawdown(average)	1,97,00	1.37×10^{-4}	1,970

7	8	9	10	11
	ii) Recovery (average)	2,19,200	0.96×10^{-4}	2,192 *
	d) Chow's Method	1,75,800	3.74×10^{-4}	1,758 *
80	t/t' versus RDD plot	40,500	-	510

* Average:

T = 1,84,600 USGPD/ft.

S = 3.70×10^{-4}

P_f = 1,900 USGPD/Sq.ft.

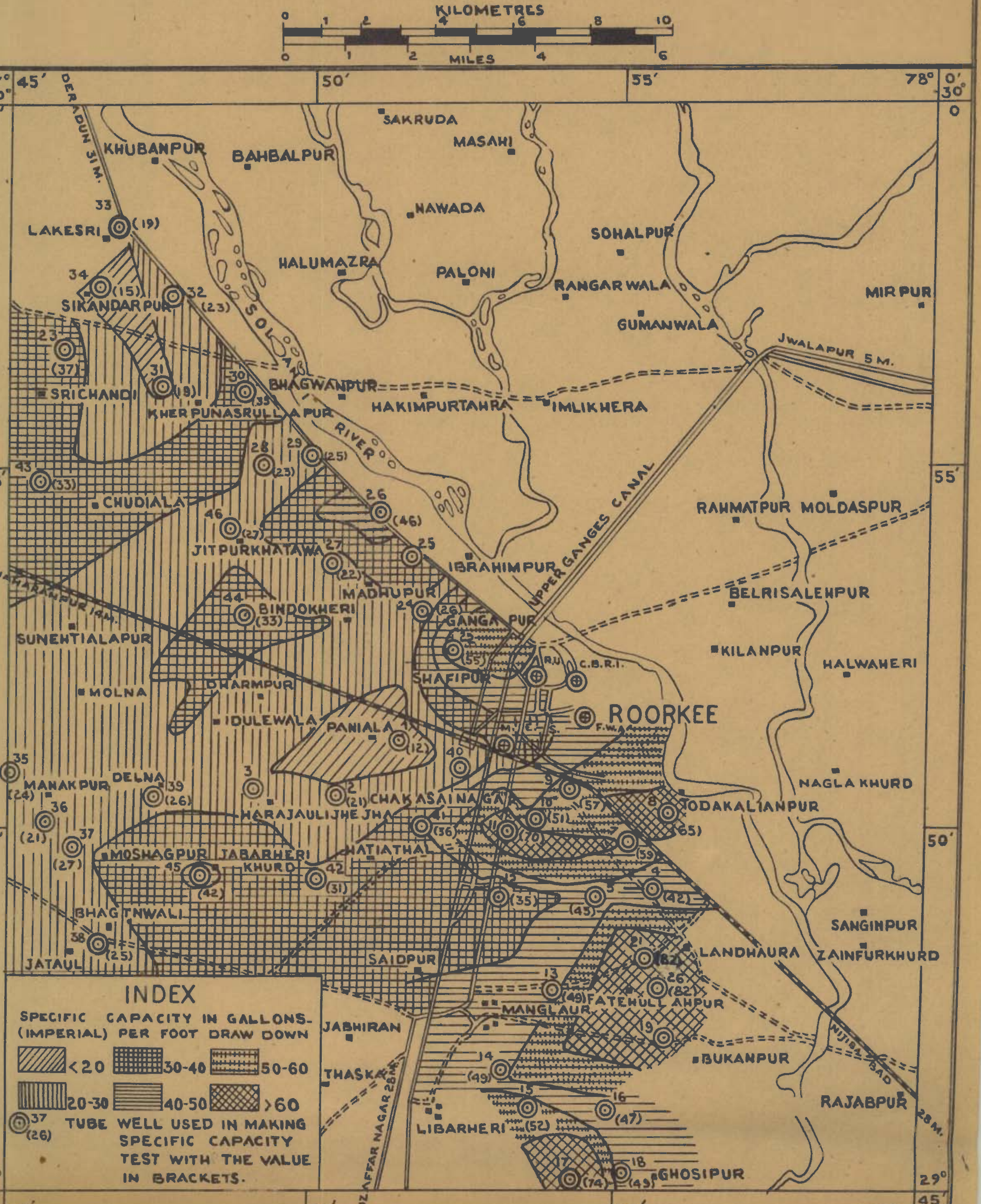
MAPPING SPECIFIC CAPACITIES OF WELLS IN ALLUVIUM:

The specific capacity of a well is computed from the yield and drawdown, measured with reference to a known time of pumping or after equilibrium conditions are attained and is expressed in gallons per minute per foot of drawdown. For wells of equal diameter and efficiency, the specific capacity is directly proportional to the transmissibility of the aquifer. Even if the latter is variable, the specific capacity affords a reasonably good chance to assess the transmissibility of the aquifers.(46)

Specific capacity computations are made as indicated below from nearly 44 tubewells especially located west of Solani river in Roorkee area. Areal differences in specific capacity of the alluvial aquifers in this region have been mapped (Plate No.XXIV). This is almost a new attempt and can be applied in many other areas of the Gangetic alluvium where control on such data exists.

Quite a number of State owned tubewells have been sunk west of Solani river. These tubewells are designed and developed roughly in the same pattern (i.e. using reverse rotary method of drilling, gravel packing the wells with slotted pipe assembly

MAP SHOWING THE AREAL DISTRIBUTION OF SPECIFIC CAPACITIES OF THE ALLUVIAL AQUIFERS IN, ROORKEE AREA



etc.). Following the development operation at each well a yield test was run for nearly 72 hours when the rated capacity of the tubewell and its drawdown performance were recorded. This data helped in the computations of the specific capacity at each well site. This data has been further supplemented with the specific capacity data obtained for the wells constructed and tested by the Exploratory Tubewells Organisation in and around Roorkee town (Table No.IX; Serial Nos. 41 - 44).

TABLE NO.12.

SPECIFIC CAPACITY VALUES FOR TUBEWELLS CONSTRUCTED IN AND AROUND ROORKEE TOWN:

Sl. No.	Roorkee Group State Tubewell Number	Location (Village)	Specific capacity gpm/ft. D.D. as arrived from yield-discharge test of the well after completion
1	2	3	4
1.	1	Paniala	12
2.	2	Latherdeva Shekh	21
3.	5	Landhaura	45
4.	13	-do-	49
5.	20	-do-	82
6.	16	-do-	47
7.	18	-do-	49
8.	21	-do-	82
9.	8	-do-	64
10.	9	-do-	57
11.	7	-do-	59
12.	17	-do-	74
13.	12	-do-	35
14.	10	-do-	51

1	2	3	4
15.	11	Landhaura	70
16.	14	-do-	49
17.	15	-do-	52
18.	4	Nagla	42
19.	36	Jaberhera	21
20.	37	-do-	27
21.	41	-do-	36
22.	39	-do-	26
23.	46	Nauhera	27
24.	40	Jaberhera	25
25.	24	Salempur	26
26.	32	Bhagwanpur	23
27.	22	-do-	55
28.	38	Jaberhera	25
29.	26	Bhagwanpur	46
30.	44	Iqbalpur	33
31.	28	Roorkee (Group)	23
32.	31	-do-	19
33.	35	-do-	24
34.	23	-do-	37
35.	42	Jaberhera	31
36.	43	Chudiala	33
37.	27	Bhagwanpur	22
38.	29	-do-	25
39.	30	Maudawan	35
40.	45	Jaberhera Kalan	23
41.	CBRI Well Roorkee(ETO)	Roorkee	48
42.	University [illegible]	-do-	49

1	2	3	4
43.	Military Cantonement Well (ETO)	Roorkee	32
44.	Military Field Works Well (ETO)	-do-	44

The specific capacity values of the last four wells (Serial Nos. 41-44) are based on the aquifer performance test data (Table No.8). The values represent the specific capacity for three to five hours of pumping. Similar values for various discharges of the well have been computed from the Step-drawdown tests and discussed at a later stage.

WELL CHARACTERISTICS:

Well characteristics such as well losses, formation or aquifer losses and entrance velocities are arrived at from the analysis of the Step-drawdown tests. Well losses usually represent the loss in head which occurs in the immediate vicinity of a well. It is caused by the flow through well screens and also by flow inside the well casing to the pump intake.[(34)] The formation losses are related to the loss of head from that great distance where the draw-down is negligible upto the face of the well.[(29a)] The former is closely associated with turbulent flow and the latter to the laminar flow. The entrance velocities are treated under this chapter as a ratio between the rate of flow through the pumped well to that of the working area of the screen.

The Step-tests (or yield-drawdown tests) were conducted in the field on four productive wells (CBRI, University, MES and Military Field Works area tubewells). During these tests, the various drawdowns against noted discharge and RPM were recorded. Each step was normally run for an hour and four to five similar steps were conducted to complete the test. These data were further utilised for computing the specific capacities of the wells at various rates of pumping. The data on the step-drawdown tests are recorded below:

TABLE NO.13.

STEP DRAWDOWN TEST DATA OF PUMPED WELL IN ROORKEE AREA:

Pump tested well	Date	Duration on individual step	Discharge (US)GPM	Maximum drawdown for the step (in ft.)	Specific capacity (in GPM/ft. DD.	Remarks
1	2	3	4	5	6	7
1. Military Field Works Area Tubewell Roorkee	5-9-62	10:30 to 11:00 hrs	320	5.45	58.71	Specific Capacity for 30 mts of pumping.
		11:00 to 11:45 hrs.	340	6.14	55.39	Specific Capacity for 45 mts of pumping.
		11:45 to 12:15 hrs.	390	7.15	54.54	Specific Capacity for 30 mts of pumping.
		12:15 to 12:45 hrs	446	8.30	53.72	-do-
		12:45 to 13:15 hrs	474	9.06	52.32	-do-
2. Roorkee University Tubewell (ETO) Roorkee	5.11.62	11:45 to 12:45 hrs	508	7.65	66.40	Specific Capacity for 60 mts of pumping.
		12:45 to 13:45 hrs	578	8.91	64.87	-do-
		13:45 to 14:45 hrs	726	11.48	63.24	-do-
		14:45 to 15:45 hrs	791	13.13	60.24	-do-

1	2	3	4	5	6	7
		15:45 to 16:45 hrs	895	15.81	56.61	Specific Capacity for 60 minutes of pumping.
		16:45 to 17:15 hrs	1001	18.23	54.91	Specific Capacity for 30 minutes of pumping.
3. CBRI Tube well (ETO), Roorkee	15-10-63	09:20 to 10:20 hrs	699	10.54	66.31	Specific Capacity for 60 mts of pumping.
		10:20 to 11:20 hrs	744	11.40	65.24	-do-
		11:20 to 12:20 hrs	825	13.32	61.94	-do-
		12:20 to 13:20 hrs	876	14.46	60.57	-do-
		13:20 to 14:00 hrs	919	15.59	56.30	Specific Capacity for 40 mts of pumping.
4. Military Cantonement Tube well(ETO), Roorkee.	17-12-63	14:05 to 15:05 hrs	423	9.37	45.14	Specific Capacity for 60 mts of pumping.
		15:05 to 16:05 hrs	530	12.91	41.06	-do-
		16:05 to 17:05 hrs	620	15.58	39.80	-do-
		17:05 to 18:00 hrs	692	18.21	38.89	Specific Capacity for 55 mts of pumping.
		18:00 to 18:30 hrs	703	18.69	37.61	Specific Capacity for 30 mts of pumping.

Under this study, well losses have been computed by the derivation of the well loss coefficient or constant by the application of both graphical and empirical methods. The procedure adopted on the empirical basis is given in the following equations. The Rorabaugh method (33) of well loss evaluation was not attempted in view of the elaborate procedure and absence of large range of pumping rates. An equation representing the approximate well loss was given by Jacob (29b) as follows:

$$sw = CQ^2 \quad \ldots (x)$$

Where sw = Well loss in ft.

C = Well loss constant, in $sec^2/ft.^5$ (empirical).

Q = Discharge, in cubic feet per second (Cfs).

The value of C in the above equation may be computed by using the step-test data in the following equation.

$$C = \frac{(\Delta si/\Delta Qi) - (\Delta si\text{-}1/\Delta Qi\text{-}1)}{\Delta Qi - 1 + \Delta Qi} \quad \ldots (xi)$$

The Δs and ΔQ terms are the incremental drawdown and discharges in the rate of pumping. The same equation may be re-written as follows for any step-drawdown test. (35)

$$C = \frac{(\Delta s2/\Delta Q2) - (\Delta s1/\Delta Q1)}{\Delta Q1 + \Delta Q2} \quad \ldots (xii)$$

The equation speaks for the 1 and 2 steps. Similarly, the same can be written for further steps. The commonly used dimensions of Δs and ΔQ are feet and cubic feet per second respectively. When the well loss constant is known, well loss can be computed for any particular pumping rate from equation No.(x).

The step-drawdown test data (Table No.13) for the wells tested close to Roorkee town are further subjected to above analysis. The results pertaining to the constants (C) and well losses (sw) are given below (Table No.14). Care has also been taken to see that steps of same duration of time are used for the computation of the constants.

TABLE NO.14.

WELL LOSS DATA FOR TESTED (STEP-TEST) WELLS CLOSE TO ROORKEE BASED ON THE APPLICATION OF EMPIRICAL FORMULA:

Sl. No.	Pump tested well	C Values $Sec^2/ft.^5$ C1	C2	C_3	C_4	Average C Value Sec^2/ft^5	C Value * taken for calculation of sw	Disch. against 'C' value taken for calculation (in cusecs)	sw ($C.Q^2$ in ft.)	Draw-down against 'C' value taken for calculation (in ft.)	Well loss expre sed i perce -tage (% sW
1	2	3	4	5	6	7	8	9	10	11	12
1.	Military Field Area Tubewell, Roorkee.	5.00	Negative value	17.05	-	11.02	5.00	1.04	5.40	7.15	75%
2.	Roorkee University Tubewell (ETO), Roorkee.	1.27	-do-	8.53	Negative value	4.90	1.27	1.28	2.08	8.91	23%
3.	CBRI Tubewell (ETO), Roorkee.	1.64	3.82	Negative value	-	2.73	1.64	1.65	4.46	11.40	39%
4.	Military Cantonement Tubewell (ETO, Roorkee.	4.73	Negative value	8.55	-	6.64	4.73	1.19	6.65	12.91	51%

* Note:- Since the values of C beyond the first two steps have indications regarding lack of stability and full development of the well, it is necessary to restrict the calculations of 'sw' to values obtained at low pumping rates (i.e. C_1).

The relationship between the well loss and formation loss is obvious as the total drawdown inside a pumping or flowing well is mainly made up of these two components. The same is explained further through equations in the following pages. The values of the pump tested (step-test) data were plotted graphically and the results obtained therefrom have been inserted in the formulae.

The drawdown at a distance 'r' and time 't' since the start of a discharging well at a constant rate is given by Jacob (29a) as

$$s = (2.30Q/4\pi T) \log (2.25\, Tt/Sr^2) \quad \ldots \quad (xiii)$$

where 'S' and 'T' are the storage and transmissibility coefficients of the aquifer, respectively, and 'Q' is the discharge rate of the well.

The formation loss can be expressed as an equation utilising the effective radius (rw) in place of (r) in the above equation. The well loss being CQ^2 (Cf: equation No.X) the drawdown in a pumping well may be expressed as

$$sW = (2.30\, Q/4\pi T) \log (2.25\, Tt/Sr^2W) + CQ^2 \quad \ldots \quad (xiv)$$

This equation may be abbreviated as follows:-

$$sW = A(t)\, Q + CQ^2$$

where A(t) is the formation loss coefficient and can also be expressed as 'B'

$$\text{i.e.} \quad sW = BQ + CQ^2 \quad \ldots \quad (xv).$$

By dividing the drawdown by the discharge of the well, the above equation changes as

$$\frac{sW}{Q} = A(t) + CQ$$

$$\frac{sW}{Q} = B + CQ \quad \ldots \quad (xvi)$$

The ratio sW/Q is the <u>specific drawdown of the well.</u>

Plotting of specific drawdown of the well against discharge for several steps (step tests) was attempted (Plates Nos. XXX A, B, C, D) and the well loss and formation loss coefficients were determined from the slope and intercepts of the straight line plots.

The results obtained through graphical representation of the data are tabulated below in Table No. 15.

(For Table No.15; see overleaf)

PLATE No XXX A

SPECIFIC DRAWDOWN GRAPH FOR UNIVERSITY OF ROORKEE WELL (E. T. O.) ROORKEE.

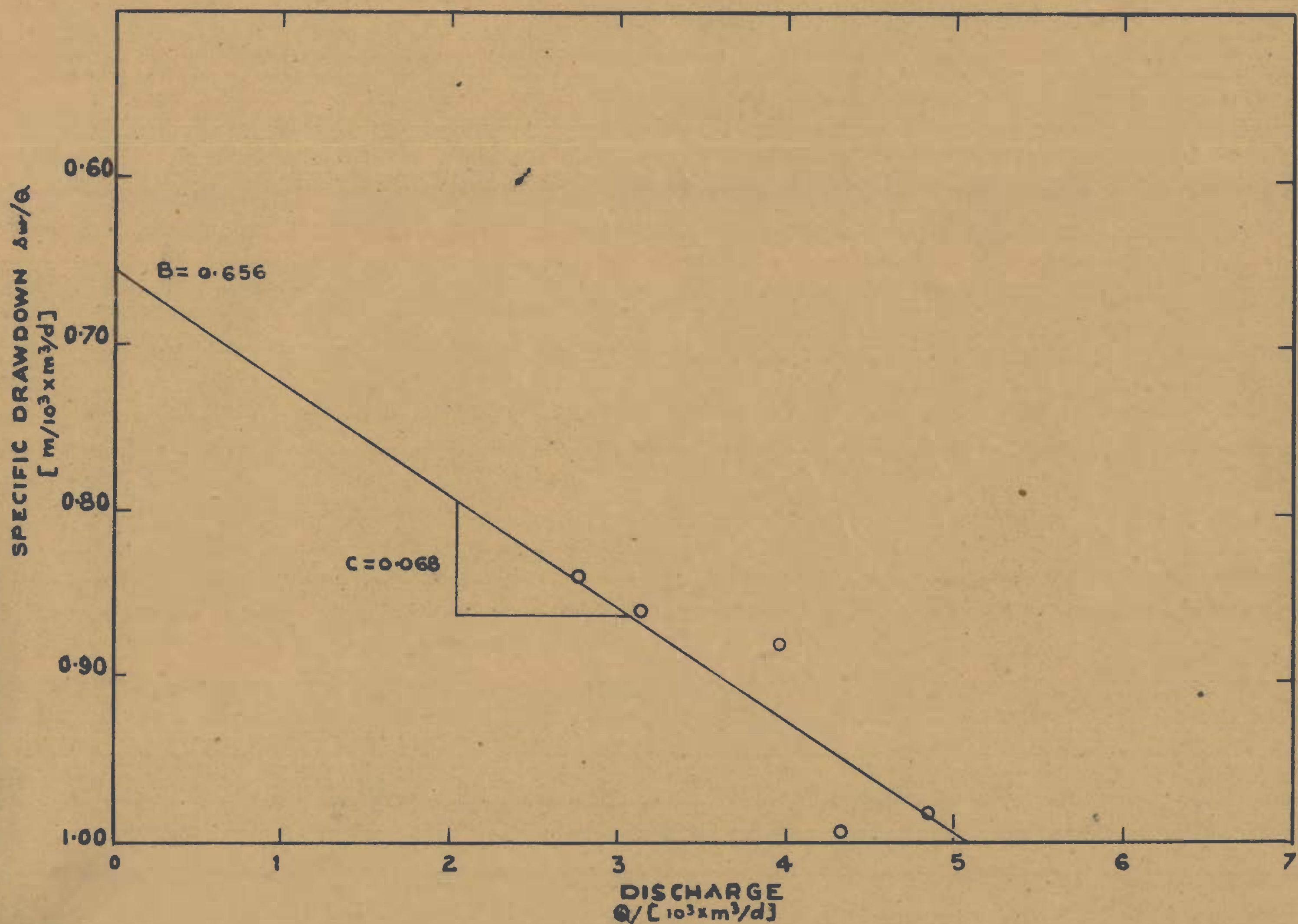


PLATE Nº XXX B

SPECIFIC DRAWDOWN GRAPH FOR C.B.R.I. WELL (E.T.O.) ROORKEE

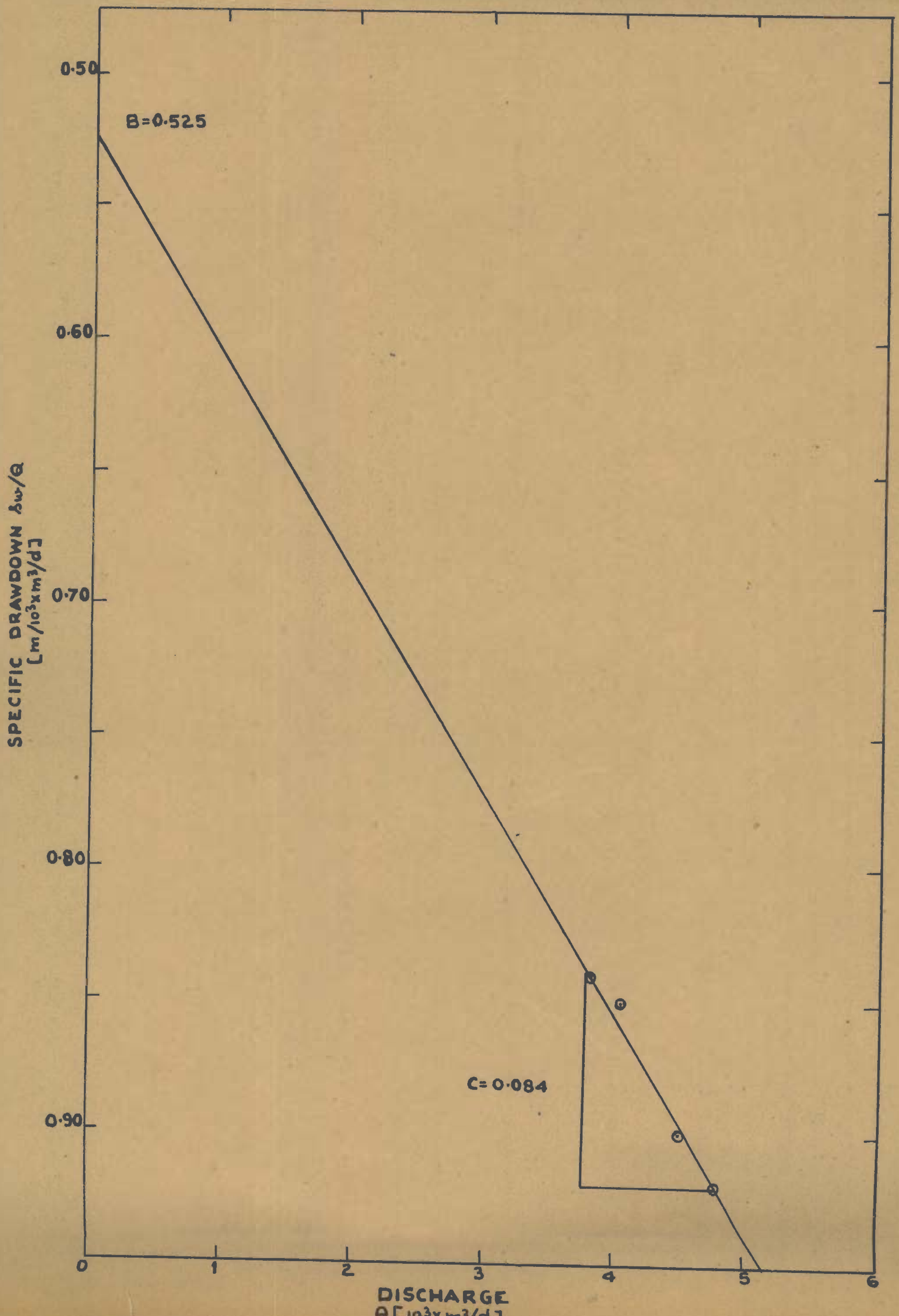


PLATE № XXX C

SPECIFIC DRAWDOWN GRAPH FOR MILITARY CANTONEMENT WELL (E. T. O.) ROORKEE

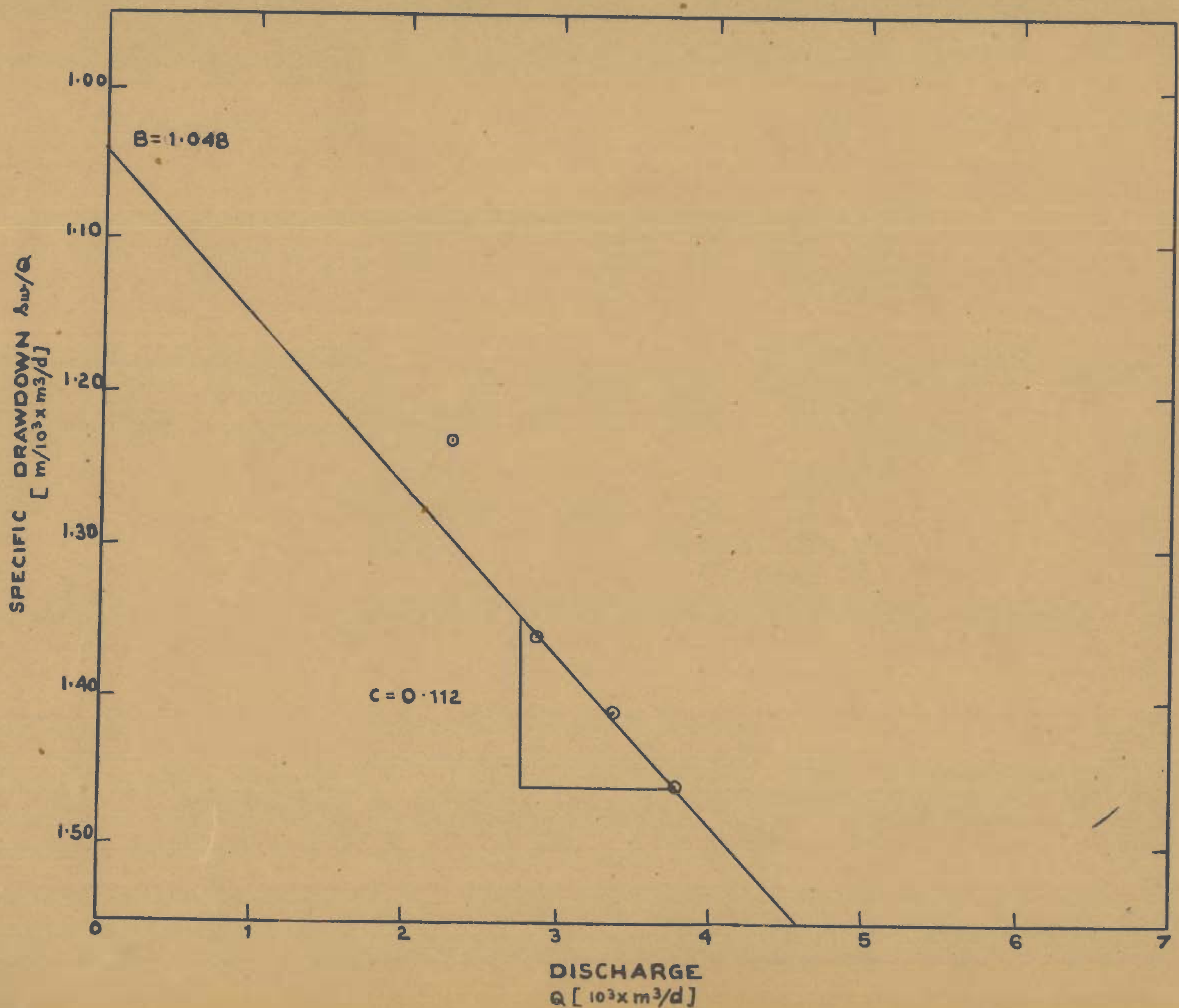


PLATE Nº XXX D

SPECIFIC DRAWDOWN GRAPH FOR MILITARY FIELD WORKS WELL (E. T. O.) ROORKEE.

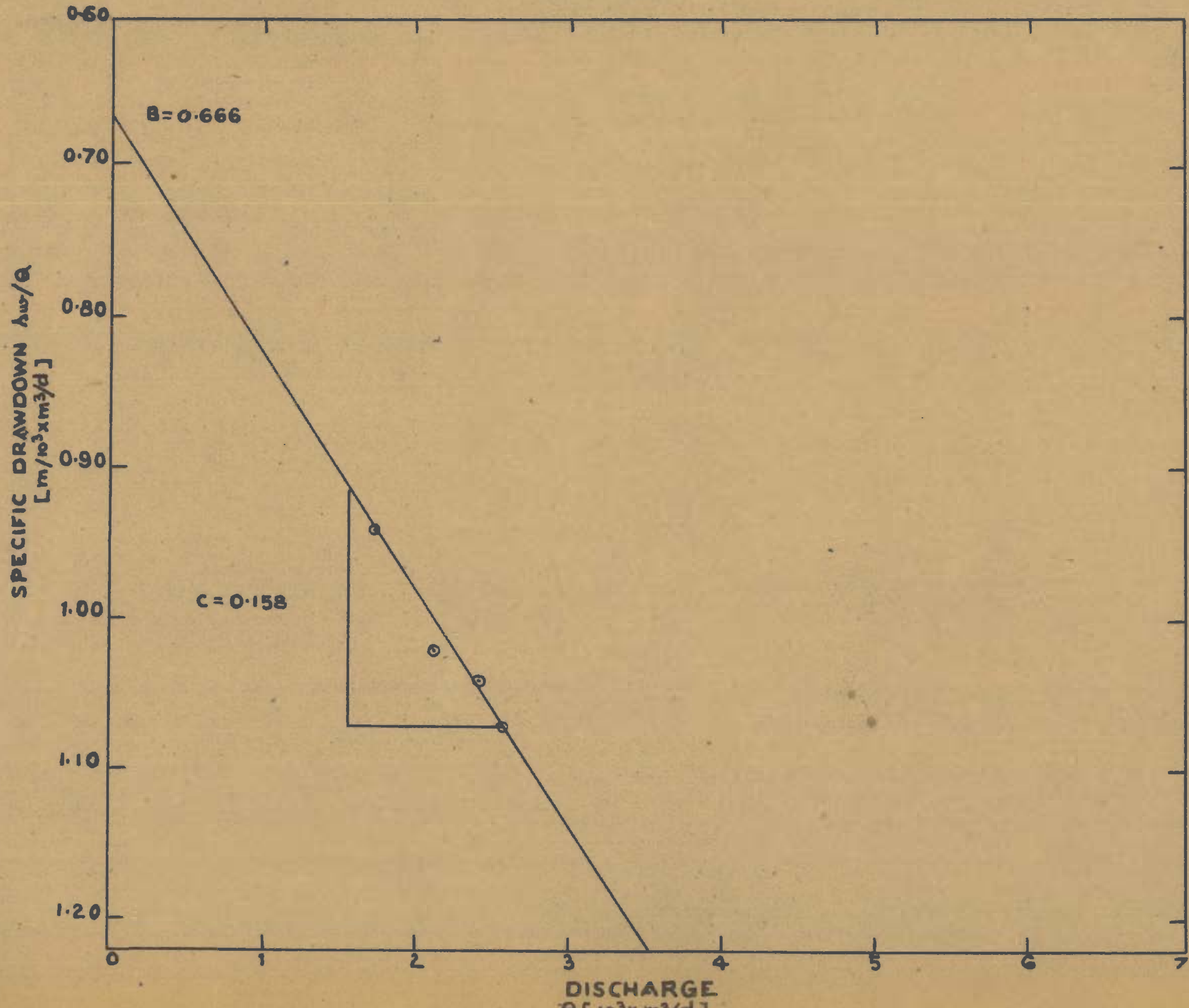


TABLE NO.15.

WELL CHARACTERISTICS OBTAINED THROUGH GRAPHICAL METHOD FOR WELLS TESTED CLOSE TO ROORKEE:

Sl. No.	Well Location	Step used	Discharge in USGPM	Drawdown (in mtrs)	Discharge Q in metric units ($10^3 x m^3/d$)	Specific Drawdown SW/Q $m/10^3 x m^3/d$	Well loss coefficient C	Formation loss coefficient B	Well loss calculated as $sw=CQ^2$@ (in metres) for the first step	Total drawdown calculated as $sw=BQ + CQ^2$ for the first step (in metres)
1	2	3	4	5	6	7	8	9	10	11
1.	Roorkee	I	508	2.32	2.76	0.84				
	University	II	578	2.70	3.13	0.86				
	Tubewell	III	726	3.49	3.96	0.88	0.068	0.656	0.51	2.32
	(ETO)	IV	791	3.99	4.32	0.92			(1.67 ft.)	(7.60 ft.)
	Roorkee	V	895	4.81	4.86	0.98				
2.	CBRI Tube	I	699	3.20	3.80	0.84				
	well (ETO)	II	744	3.47	4.04	0.85	0.084	0.525	1.21	3.20
	Roorkee.	III	825	4.05	4.49	0.90			(3.9 ft.)	(10.49 ft.)
		IV	876	4.40	4.76	0.92				
3.	Military	I	423	2.85	2.30	1.23				
	Cantonement Tube-	II	530	3.92	2.88	1.36	0.112	1.048	0.59	3.00
	well (ETO)	III	620	4.74	3.36	1.41			(1.93 ft)	(9.84 ft.)
	Roorkee.	IV	692	5.54	3.77	1.46				

1	2	3	4	5	6	7	8	9	10	11
4.	Military Field Works Area Tubewell, Roorkee	I	320	1.65	1.74	0.94	0.158	0.666	0.47 (1.54 ft.)	1.62 (5.31 ft.)
		III*	390	2.17	2.11	1.02				
		IV	446	2.52	2.41	1.04				
		V	474	2.75	2.57	1.07				

Note:- @ The well losses were calculated with reference tò the first step as it would facilitate comparison with the empirical formula data (Table No.14).

* Second Step has been omitted as it does not conform to 30 minutes duration of pumping; In all other wells the duration of the step is 60 minutes.

The C and B values on the plots indicate that the formation loss, or loss of head from a distance at which the water in the formation is beginning to expand upto the face of the well, is equal to about 0.656 metres in case of University well, 0.525 metres in case of CBRI well and 1.048 metres in case of Military Cantonement well for every 1000 cubic metres per day of flow. Similarly, the well loss, the loss of head from the face of the well through the perforations and up the casing to the point of intake, varying with the square of the discharge, amounts to 0.068, 0.084 and 0.112 metres for Roorkee University, C.B.R.I. and Military Cantonement wells respectively for each 1000 cubic metres per day, squared.

The entrance velocity in a water well is defined as the ratio between the rate of flow through the pumped well to that of the working or open area of the screen. It is usually expressed as an equation given below.

$$V_n = \frac{Q}{Ar} \qquad \ldots \text{(xvii)}$$

Where V_n = entering velocity of water (metres per second or feet per second).

Q = pumping rate of flow, (cubic metres per second or cubic feet per second).

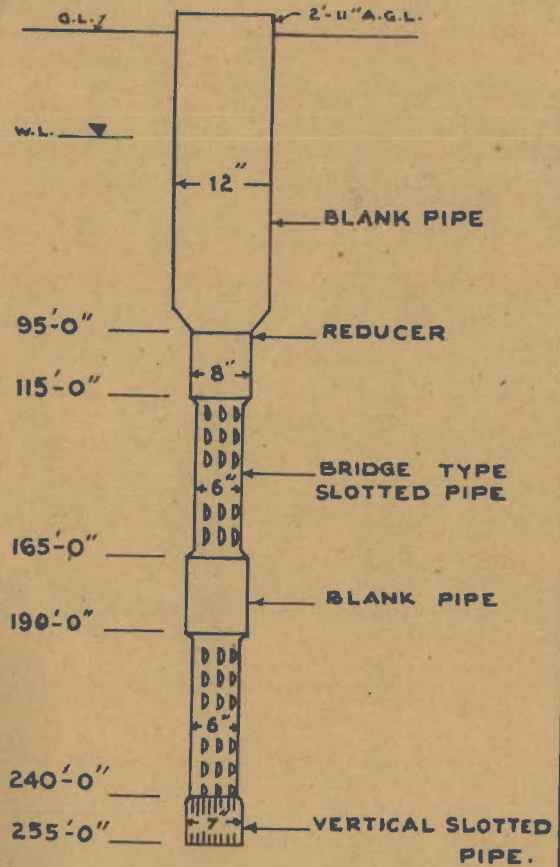
Ar = working area of the screen (square metres or square feet).

The step-test data of the four wells have been utilised to compute specially the various rates of entrance velocities for different discharges. The well in the Military Field Work area could not be covered as the record showing area of the screen is not available. The design of water wells constructed by the Exploratory Tubewells Organisation

DESIGN OF WATER-WELLS CONSTRUCTED BY THE E.T.O. IN ROORKEE.

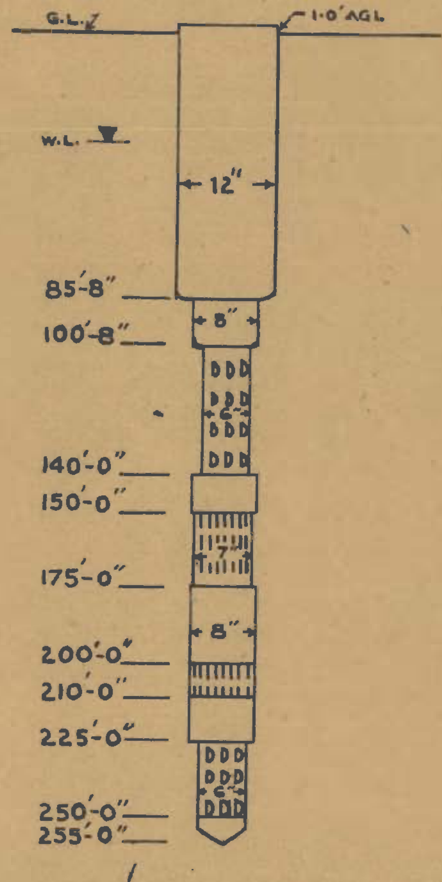
SCALE: HORZ: 1 INCH = 24 INCHES. VERT: 1 INCH = 60 FT.

ROORKEE UNIVERSITY WELL



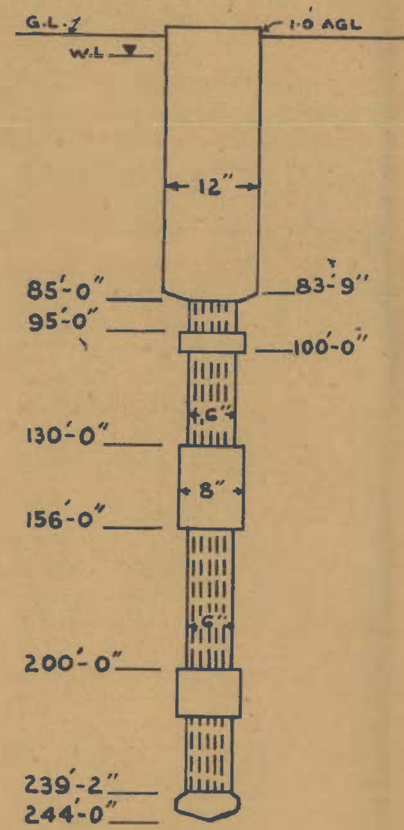
GRAVEL PACKED WELL
AVERAGE WORKING AREA OF SCREEN, IN SQ. FEET: 20·87

M.E.S. WELL



GRAVEL PACKED WELL
AVERAGE WORKING AREA OF SCREEN IN SQ. FEET: 19·80

C.B.R.I. WELL



GRAVEL PACKED WELL
AVERAGE WORKING AREA OF SCREEN IN SQ. FEET: 21·41

in Roorkee is given in Plate No.XXXI. The rest of the data are tabulated below in Table No.16.

TABLE NO.16.

DATA ON ENTRANCE VELOCITIES FOR WELLS TESTED CLOSE TO ROORKEE:

Sl.No.	Well Site	Discharge in Cubic feet per second 'Q'	Average working area of the screen in sq. ft.	Entrance velocity in ft./sec.
1	2	3	4	5
1.	Roorkee University Tubewell (ETO) Roorkee.	1.130 1.271 1.730 1.907	20.87	0.0524 0.0590 0.0820 0.0885
2.	CBRI Tubewell (ETO), Roorkee	1.518 1.659 → 1.801 1.871 1.977	21.41	0.0688 0.0754 → 0.0820 0.0853 0.0918
3.	Military Cantonement Tubewell (ETO), Roorkee.	0.9181 1.165 1.342 1.553	19.80	0.0459 0.0557 0.0656 0.0754

DISCUSSIONS OF THE RESULTS:

It would be worthwhile to recall the statement of Schoellar in his book on 'Arid Zone Hydrology' where he emphasised the importance of the aquifer tests as a means for the evaluation of the hydrogeological parameters in various regions.(36) According to him " the calculation of groundwater discharge is one of the essential tasks of hydrogeology, but is impossible to execute unless the permeability, or preferably the transmissibility, of the aquifers has previously been ascertained .... however, to measure the permeability of a whole horizon and not simply of samples, there is no substitute for pumping tests on wells or borings". In view of this, the text of the material presented under this chapter deals essentially with the analysis of the hydrological tests conducted on the water wells and their interpretation towards the evaluation of the hydrological characteristics.

The objective of such tests is (i) to determine the formation constants (ii) to determine the characteristics of the pumping wells and (iii) to enable predictions of the future performance of the wells.

a) <u>Confined Nature of the Alluvial Aquifers:</u>

It has been said in the previous chapters that based on the sub-surface lithological correlation charts, the existence of confined aquifer beds in Roorkee area is not ruled out. Hydrological tests, especially the parameter on the Storativity (coefficient of storage) reveals the nature of the beds from the hydrological point of view -- confined or free water table conditions. It has been stated earlier that the value for the coefficient of storage for confined aquifers usually ranges from 10^{-3} to 10^{-5}. The hydrological tests in the region reveal that the average 'S' value (coefficient of storage) is of the order of 3.70×10^{-4} which substantiates the earlier presumption that confined aquifers do exist in the area at deeper depths apart from the free water table aquifers close to the land surface. Apart from this, it has been stated earlier (page 89) that while conducting the hydrological test on State Tubewell No.29, a close-by shallow open well (water table 17 feet: depth of the well 47 feet below land surface) situated at a distance of 100 yards from the discharging well did not react to pumping in the main well for a period of nearly 22 hours. This also supports the view that pumping has been done exclusively on the confined aquifers in the area and probably the presence of a non-leaky acquiclude or acquicludes in depth prevented the shallow water table zone to react to pumping. Since most of the hydrological tests were run on wells screening aquifers below 100 feet depth, it may be stated that the water bearing formations encountered below this depth in this region conform to the elastic conditions normally met within the confined aquifers. (5)

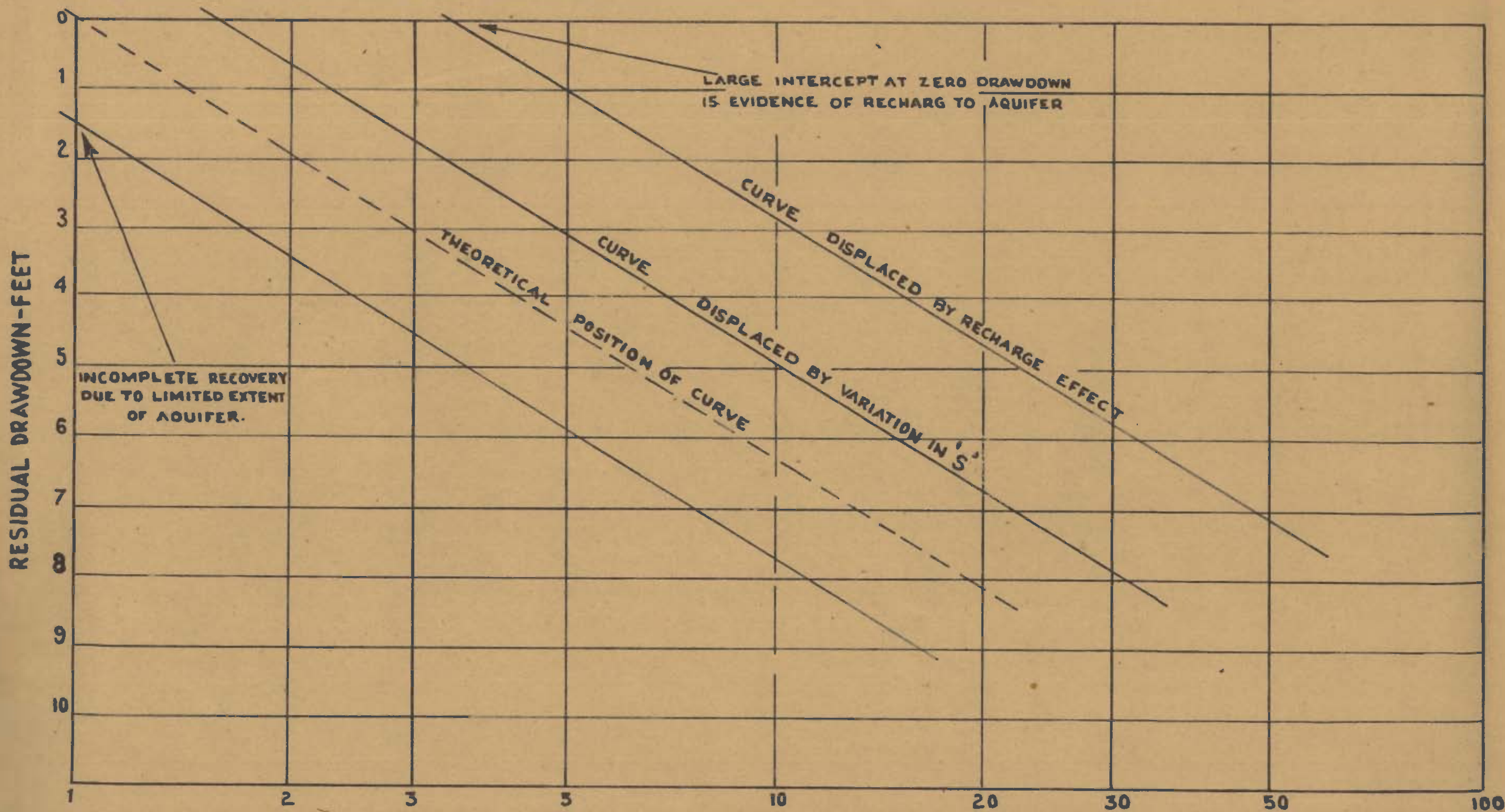
From earlier experience, it has been realised that most aquifers in nature are not uniform in character and do not conform to the theoritical assumptions. To judge this, the curves showing the residual drawdown against t/t' and the charting performance (time-drawdown) curves help us to interpret the aquifer conditions in regions where the wells have been tested. When the curve conforms to the theoritical assumptions, the residual drawdown curve when extended should pass through the zero drawdown or origin of the diagram (Plate No.XXXII). Based on this, the following three situations arise and show a departure from the theoretical considerations. (39)

i) If the graph indicates zero drawdown at a value of t/t' equal to or greater than 2, it can be concluded that some recharge water reached the aquifer during pumping period,

ii) when the graph indicates residual drawdown of several inches or more as t/t' approaches unity, the situation is related to the case of an aquifer of limited extent with no immediate recharge, and

iii) a little displacement of the residual draw down curve results from a variation in the value of the storage coefficient 'S' (in practice 'S' varies, though in theory it is assumed to

DIAGRAM SHOWING THE AQUIFER CONDITIONS WHICH DIFFER FROM THEORETICAL CONDITIONS BASED ON THE RESIDUAL DRAWDOWN CURVE.



WHEN THE AQUIFER CONDITIONS DIFFER FROM THEORETICAL CONDITIONS, THE RESIDUAL-DRAWDOWN-CURVE MAY BE DISPLACED IN ANY ONE OF THE THREE WAYS SHOWN IN THIS DIAGRAM

(THE JOHNSON NATIONAL DRILLER'S JOURNAL JULY-AUG 1961) be constant).

An application of the above concepts to the data plots (Plates Nos.XVII to XXII) indicate as shown in Table No.17.

TABLE NO.17.

DATA ON t/t' VERSUS R.D.D. PLOTS:

Sl.No.	Well Location	t/t' intercept at zero drawdown	REMARKS
1	2	3	4
1.	Military Field Works Area Tubewell, Roorkee.	1.17	Value indicates probable change in storage.
2.	Roorkee University Tubewell (ETO) Roorkee.	1.15	-do-
3.	CBRI Tubewell (ETO), Roorkee	1.45	-do-
4.	Military Cantonement Tubewell (ETO), Roorkee	2.50	Value greater than 2; indicates slight recharge to the well during pumping.
5.	State Tubewell No.29, Roorkee Group.	1.35	Value indicates, probable change in storage.
6.	State Tubewell No.4, Roorkee Group.	8.40	Value much higher than 2; large amount of recharge to the aquifer; time-drawdown plot (Fig.No.8) for the observation well also confirms this.

From the above inferences it may further be noted that confined ground water conditions exist in the area. Writing in one of his contributions to ground water studies in western Uttar Pradesh Chaturvedi (41) stated "Pump out tests on a number of tubewells reveal that the planning of irrigation tubewells, or feeder wells, should be on entirely different lines for the southern areas of Bulandshahr-Aligarh as compared to Meerut-Muzaffarnagar areas. The reservoir concept for Meerut-Muzaffarnagar areas is now fully confirmed on a more rational approach". The 'reservoir concept' referred to here speaks for the presence of ground water under water table conditions. From a perusal of the Plate No.II, it is evident that the Ganges valley in these parts of Uttar Pradesh can be divided into three distinct regions (i) the Roorkee area (ii) the Muzaffarnagar - Meerut area and (iii) the Bullandshahr-Aligarh-Hathras region. The author earlier recorded (13) the existence of distinct large scale water table conditions along with confined and leaky confined conditions at close distances and within 400 feet in the third region of the Ganges Valley. The present study in the Roorkee area also points out that confined conditions at reasonable depths are common in Ganges Valley. Data collected since 1960 as given in Table No.18, show that diverse hydrogeological settings exist and govern the occurrence of ground water in the Ganges Valley.

TABLE NO.18.

COMPARATIVE STATEMENT OF THE FORMATION CONSTANTS OF ALLUVIAL DEPOSITS IN WESTERN UTTAR PRADESH:

Sl. No.	Area	Depth of aquifers tested (in ft.)	Formation Constants: Range of Transmissibility 'T' (USgpd/ft.)	Formation Constants: Range of Field Permeability 'Pf' (USgpd/sq.ft)	Formation Constants: Storage Coefficient 'S'	Hydrological Situation	Remarks.
1	2	3	4	5	6	7	8
1.	Roorkee Area	400	40,500 to 1,85,000	500 to 1,900	3.70×10^{-4}	Confined conditions below 100 feet depth.	Results as per present study.
2.	Muzaffarnagar -Meerut Area	200	1,72,000 to 3,74,000	2,000 to 3,500	0.093 to 0.20	Water table conditions down to 200 ft. depth.	Results as worked out by Chaturvedi and Pathak (41)
3.	Atrauli Area	300	50,000 to 3,75,000	500 to 3,500	0.017 to 0.140	Water table conditions down to 300 ft. depth	Results as given in ETO Technical Bulletin (13) (in press).
4.	Aligarh-Hathras Area	300	45,000 to 1,60,000	400 to 1,300	1.4×10^{-4} to 0.025	Leaky confined down to 200 ft. depth and confined below 200 ft. depth.	-do-

1	2	3	4	5	6	7	8
5.	Jalesar Area	250	30,000 to 1,00,000	400 to 1,400	6×10^{-4} to 0.009	Confined conditions	Results as given in E.T.O. Technical Bulletin (13) (in press).
6.	Agra Area	450	35,000 to 95,000	350 to 800	-	Confined conditions	Results based on the E.T.O. Reports on Exploratory sites (un-published)

b) Geohydrological Boundaries:

The two definite straight line trends observed in Plate No.XXI (State Tubewell No.29) clearly show the boundary effect. Theoritically, it would be reasonable that in such cases the computation of transmissibility should be attempted based on the latter half of the curve slope as it tends to pass through the origin. For conservative purposes an average transmissibility figure could also be worked out by averaging the 'T' values obtained by analysing both the straight line slopes. The figure given for 'T' in table No.11 for State Tubewell No.29, represents an average transmissibility value.

Similarly, the time-drawdown plot (Plate No.XXIII) for the observation well close to State Tubewell No.4 at Landhaura for the test conducted on the well, indicated a marked change in the slope of the curve after 2½ hours of pumping. As can be seen, the curve flattens compared to its earlier disposition and maintains the same trend till the end of the pumping period. In the normal analysis of hydrological test data, this phenomenon reflects a recharge boundary condition to the aquifer during pumping. Singhal[(42)] in his review on the application of pumping test methods to field conditions observed that "on a time versus drawdown plot, the effects due to non-uniform thickness of the aquifer, partial penetrating well, leaky aquifers and recharge image well will be the same. Hence, the drawdown data can be interpreted in several ways, if sufficient information on the hydraulic system from other sources is not known .....". But the data plot representing r^2/t against ~~against~~ drawdown (Plate No.XXVII) also indicates a departure of the end points of the plotted curve with respect to the typed curve. This departure of field data supports the effects of boundaries on the drawdown. Here also the points fall below the trace of the type curve after an elapse of time 210 minutes of pumping and substantiates the earlier expressed view that the boundary is transmitting more water to the aquifer (recharge boundary).

However, the above analyses indicate that boundary conditions do prevail in the alluvial formations of the Ganges Valley and influence the analysis of the hydrological parameters even within short periods of straining the aquifers through pumping.

e) <u>Evaluation of Storage Coefficient:</u>

Various methods are in vogue to analyse the pump test data. In recent years, the trend is to determine the effects of natural conditions on the pumping test data and also examine the limitations of the individual methods in the correct evaluation of the hydrological parameters. The pump test data collected under the present study facilitated to gather an idea on the variation in the transmissibility from place to place. Though the pump tests have been carried out on six wells, the storage coefficient could only be computed for the aquifers around Landhaura. For this purpose, three methods of analysis of data were considered -- (i) t_0 intercept method (ii) recovery and drawdown non-equilibrium method and (iii) Chow's method. As can be made out from the Table No.19 below, each one of these three methods gave a different value for the storage coefficient.

Intercepts often occur at points where the values of time are very small and minor deviations in extrapolating the straight line will result in large variations in computed values of the coefficient of storage".

Since the observation well at Landhaura is close to the pumping well (State Tubewell No.4) and confined conditions prevail in the area, the present semi-log plot (Plate No.XXIII) indicates that the straight line disposition in the plot has been achieved after 7 minutes of starting the pumped well. In view of this and also as the 'u' value is less than 0.01, application of this method to the test data is justified.

While adopting the non-equilibrium method of computing the storage coefficient, it would also be of importance to take cognisance of the following observations based on field experience.

i) Ubell [43] while analysing the drawdown conditions of the water table near pumped wells stated "with increasing distance from the well, drawdown is not only delayed but it takes place at a gradually decreasing rate. The coefficient of permeability increases with increasing distance from the well, while the coefficient of storage shows a diminishing rate. It is remarkable that a low value of the coefficient of storage results from the formula of the non-equilibrium type".

ii) While referring to the application of Theis non-equilibrium formula to water table aquifers, Ferris [27] writes " for water table aquifers, experience indicates that the Theis equation should not be used for tests of less than 2 days duration, assuming that the observation wells are within a few hundred feet of the pumped well".

TABLE NO.19.

VALUE OF 'S' BY DIFFERENT METHODS OF ANALYSIS:

Sl.No.	Method adopted to derive the coefficient.	Coefficient of storage value	
1	2	3	
1.	Semi-log time versus drawdown plot to-intercept method	6.21×10^{-4}	
2A.	Non-equilibrium Theis method (drawdown) r2/t versus s	1.20×10^{-4}	(Match point on the curve)
		1.55×10^{-4}	(Match point out side the curve)
B.	Non-equilibrium Theis method (Recovery), r2/t versus s'	1.30×10^{-4}	(Match point on the curve).
		0.62×10^{-4}	(Match point out side the curve)
3.	Chow's method	3.74×10^{-4}	
	Average: 'S' Value	2.70×10^{-4}	

From the above it is evident that the time versus drawdown semi-log plot gives fairly a high value for the storativity of the confined aquifers. On the contrary the values obtained through the non-equilibrium type curve method exhibit a low range.

It is well known that the semi-log time drawdown plot is an approximate method and should be used with caution by restricting it to values of 'u' less than 0.01. Writing on this Walton (25a) has pointed out that " the determination of the storage coefficient by the straight line method may involve appreciable error. The zero-drawdown interceipt is poorly defined where the slope of the semi-log plot is small.

iii) Walton[25a] has demonstrated that even in water table aquifers, the coefficient of storage computed from the early time-drawdown data prior to the establishment of the gravity drainage in the sands and gravels, falls sometimes in the artesian range. The same, computed from the late time-drawdown relationship gives the water table range. He further concluded that the coefficient of storage is not constant but depends largely on the time of pumping and distance from the pumped well. The coefficient of storage appears to increase with time and decrease with distance.

iv) According to Boulton[44] the non-equilibrium formula describes the drawdown in wells (under water table conditions) with sufficient accuracy for practical purposes when the time factor expressed in days is greater than 5 and 'r' is between 0.2 m and 6 m ('m' being the saturated thickness of aquifer).

The above practical difficulties are more oriented towards the application of the Theis non-equilibrium formula for water table conditions. However, in the present case of analysis, this methodology has been resorted to as it has been assumed (and later established) that mainly confined conditions existed in the area and a reasonably long duration test (23 hours) has been conducted on the confined aquifers. As such, the above quoted limitations do not play a significant role in the analysis of the data by this method. It may be seen from Table No.19, that the average value of 'S' for the 'Drawdown Method' of Theis, works out to be 1.37×10^{-4} and the same by 'Recovery Method' of Theis works to be 0.96×10^{-4}. An appreciable difference is noted in the value of 'S' computed from both these methods. Such a situation has been explained by Santing[45] as a case of release of water from partially non-elastic storage in confined aquifers or to entrapment of air in case of rising phreatic groundwater. Release of water from partially non-elastic storage can be achieved in two ways in confined aquifers associated with alluvial formations.

i) When the confined conditions reach a stage of gravity or drainage during pumping.

ii) When some of the confined aquifers screened in a pumped well merge with the water table aquifers at reasonable distances away from the well.

The latter case is not uncommon in the unconsolidated alluvial formations. If these conditions are met with, based on the above reasoning, at Landhaura pump test well then it would be worth recalling the observation recorded by Mr. Ubell [250] -- 'it is remarkable what a low value of the coefficient of storage results from the formula of the non-equilibrium type'. In view of this, the low values of 'S' obtained through this method may be agreed upon.

The overriding advantage of Chow's method of analysis for the formation coefficients is that it helps in finding out the apparent values of such constants at any instant as the pumping goes on and avoids matching of curves. Further in the analysis described a tolerable error of five percent is assumed. It may be seen from table No.19, that the value of 'S' (3.74×10^{-4}) derived according to Chow's method comes very close to the average value of 'S' (3.70×10^{-4}) obtained through various other methods. It has been observed that each method has its own drawback when used alone and as such an average value of 'S' computed by various methods gives enough reliability for the theoretical prediction of the future yield of ground water in storage. This may also be adopted towards the solution of practical problems.

d) Relationship Between Geomorphic History and Anomalous Hydrological Conditions:

It may be noted from the summarised results of the pumping tests in Roorkee area (Table No.11) that the water transmitting capacities of the alluvial aquifers vary markedly in the regions North-West and South-East of Roorkee town. The latter area is more promising. Similarly, wells within a radius of one mile around Roorkee proper, though designed practically on the same pattern (Plate No.XXXI), indicate through pump tests marked variation in the permeabilities of the alluvial formations. The Military Cantonement Well (ETO) has given values on transmissibility and permeability almost half to that of the values recorded at CBRI, Military Field Works area and the University wells. The specific capacity value for the former is 32 and for the rest the value lies between 44 to 49 (see Table No.12). A careful examination of the former drainage trend map (Plate No.X) drawn from aerial photographs, indicates that the Military Cantonement well (ETO) lies at the tip of the oval shaped land form recognised south-east of Roorkee town and extending upto Landhaura village. This zone, being on the border of a recognisable landform of a fluvial origin may exhibit considerable variation in depth especially in the stratification and lithology of the sediments constituting the alluvium. The sub-surface lithological correlation charts (Plate No.XI A, B, C) also reflect this phenomenon. The other three wells are situated almost in the beds of the earlier drainage channels recognised close to villages Bangheri, Malakpur and Roorkee University campus. This observation is further supported when well performances are studied around Hasan Alipur village. Earlier drainage course has been recorded around this place also. The performance of the State Tubewell No.11 is superior when compared to the Tubewells 10, 9 and 7 situated away from this drainage course and close to villages Mohanpur, Dandhera and Nagla Marti (spread over the earlier stated land-form). Since the wells are constructed more or less to the same design and tested in uniform manner the performance of the wells is judged from their specific capacities. The well at Hasan Alipur bears a specific capacity of 70 and the other wells exhibit a range between 51 - 59.

Based on the above observations it may be stated that marked variations in the formation constants at short distances in the alluvial formations of the Ganges Valley close to Roorkee have a definite bearing to the lithogenetic variations introduced by former drainage pattern in the geomorphic history of the region. This also brings home the fact that the map indicating the areal distribution of the specific capacities reflects indirectly the transmissibilities of the sub-surface water formations and acts as a useful tool for the interpretation of the hydrogeological features of the region. Such a map introduced in the text may be taken as suitable for the general understanding of the regional productive nature of the wells and aquifers despite a few discrepancies noticed in the values obtained by testing the wells immediately after their construction and at the close of the observations in 1964. The values plotted on the map (25 and 42 GPM/ft. D.D. for three days pumping) refer to 1953 and 1950 for the State Tubewells Nos. 29 and 4 respectively. The same for 1964 is 20 and 54 GPM/ft. D.D. respectively for about a day's pumping. The difference in the specific capacity at the former well can be attributed to the fact that the same varies with time also, even though the discharge is kept constant. In the latter case the specific capacity figure of 54 GPM/ft.D.D. refers to the newly constructed well (1964) only 50 feet away from the old one constructed and tested in 1950. The difference in the performance of the wells may be attributed to the minor lithogenetic variations within short distances and also due to the mode of construction and development of the well. A noteworthy feature of the map is that in the north-west and western parts of the Roorkee area fairly low values for specific capacities were recorded and they reflect on low transmissibility values for the formations also. They pass through a transition zone just south of Roorkee and Liberheri village before these merge into highly productive wells located in the South-Eastern portion of the area close to the Solani river channel.

It may be noted that just north and north-west of Roorkee town, intensive meandering courses have been recognised in the former drainage patterns. Such conditions of meandering are also recognised in the western part of the area. In such regions, the fluvial landforms and sediments are bound to be interpenetrative and complex to decipher, though small in extent. They become more complex with depth. Such complex sub-surface lithological changes or intermingling of sediments are not to be expected in the area south-east of Roorkee town, since this part does not seem to have been part of any meander belt but only a uniform landmass. This is found to be the case from the study of the sub-surface correlation chart (Plate No.XIB). In view of this, it is, therefore, possible that the sediments constituting the alluvium on the north and north-western part of Roorkee town bear frequent changes in lithology and texture (Plate No.XI A & C). These beds in a cumulative way act as less permeable water carriers compared to the sediments encountered south-east of Roorkee town and close to the present river bed of Solani. This geomorphological history explains in general the ground water situation depicted on specific capacity map.

e) Evaluation of Well Characteristics:

The well loss constant expressed in the empirical approach (equation No.xii) has the implication that the tested well is stable and that the constant 'C' does not change during the step-test. However, in practice it changes depending on the stabilisation achieved by the well. Based on experience, the following ranges were given to the 'C' value to infer the effectiveness of development on the well [25]. 'C' is generally recorded as $Sec^2/ft.^5$

i) The value of 'C' for a properly developed and designed well is generally less than 5.

ii) Values of 'C' between 5 and 10 indicate mild deterioration.

iii) It is difficult and sometimes impossible to restore the original capacity if 'C' is greater than 40.

From the step-tests conducted on the wells close to Roorkee, it may be said that all the wells are stable and satisfactorily developed for low rates of pumping but showed signs of development or slight instability at higher rates of pumping. The analysis on this situation has been discussed further below.

Before we analyse the well characteristic data presented in Tables Nos.14 and 15, it may be noted that in equation (x) 'sw' represents only the well loss (loss of head through the perforations of the screen to the point of intake of the pump) and in equation No.(xv), the same (sw) represents the well loss as defined earlier and the formation or aquifer loss (loss of head from a distance at which the water in the formation is beginning to expand upto the face of the well) and other components effecting the drawdown. These additional components are (i) drawdown due to partial penetration (ii) drawdown due to dewatering of an aquifer (iii) drawdown due to barrier boundaries of the aquifers and (iv) the build-up due to recharge boundaries. The last component does not add to the total drawdown but certainly plays a part as a negative factor.

It may be seen from well characteristics data (Table No.15, columns 10 and 11 and columns 3 and 5 of Table No.13) that values of total drawdown actually measured in the wells (for the first step) during the step-test compare very closely with the computed values using $s_w = BQ + CQ^2$ equation except in the case of the Military Cantonement Well (ETO) where slightly higher computed value is recorded. This is attributed to the recharge conditions in the aquifer during pumping which fact has been established earlier (Cf. Table No.17). This is indicative of the fact that in the area the major components influencing the total drawdown in a well are the formation loss and well loss. Other factors or components are of negligible magnitude.

According to Rorabaugh[(33)] equation No.(xv) should be $s_w = BQ + CQ^n$ and 'n' may deviate from 2 and should be computed from step drawdown tests. Jacob[(29b)] suggested that a value of 2 for 'n' could be reasonably assumed.

The closeness of the computed values with those of the actually measured ones indicates that in the analysis of the well characteristics for the region under study, the well loss may be indicated as being proportional to the square of the discharge (i.e. 'n' is almost equal to 2).

Besides the above, the well characteristic data (Cols. 8 to 11; Table No.15) also indicate that the formation losses contribute in a way more towards the total drawdown than the well losses. This may be attributed to two factors.

i) The frequent 'cut outs' or pinching out of beds at short distances and their effects on the hydraulics of flow towards the discharging or pumping wells.

ii) A safe or desired entrance velocity which minimises the well losses.

The first one has been partly discussed earlier (Page 29). The second aspect can be visualised from the computed entrance velocities into the wells for various rates of pumping (Table No.16). Bennison[(47)] states that a minimum velocity of 0.14 ft./sec. to 0.024 ft./sec. through the individual screen openings will keep sand movement and head losses to a minimum. The minimum entrance velocity recorded on the wells in Roorkee area is 0.046 ft/sec. and the maximum is 0.092 ft./sec. These results further indicate that the design and development of the tested wells in Roorkee area are to the normal requirements and as such contribute towards low well losses compared to the formation losses.

It has been observed that the well losses computed exclusively from the empirical formula (equation x and Table No.14) differ from those obtained through the graphical method. Much higher values are recorded for the well in Military Field Works area, and the Cantonement Wells (5.40 ft. and 6.65 ft.) compared to the values obtained through the second method (graphical). Since the actual draw-downs observed in the wells during the test and computed through equation No.(xv), agree very closely, the latter method may be relied upon. The two wells mentioned above also indicate less stabilisation even at low rates of pumping (C value being 5 and 4.73) compared to the rest of the wells and this might have been reflected in the high well loss values when computed exclusively based on equation $s_w = cQ^2$.

In other parts of the Ganges Valley in Uttar Pradesh (Aligarh - Atrauli area), it has been observed through the analysis of step-tests on fifty newly constructed and developed wells that the well loss constant 'C' is mostly a negative value or a value higher than 10 (usually ranging from 6 to 22*) indicating non-stabilisation of the wells during the test periods -- especially during higher rates of pumping. It is not unlikely that the wells may get stabilised in due course of running them. Based on this experience and also on the present study the writer is of the opinion that rapid changes in lithology and frequent 'cut outs' govern to a large measure the hydrological factors especially the movement of water towards the pumped wells. As such, the application of the empirical procedures for determination of well characteristics should be carried out with caution for water wells located in unconsolidated alluvial formations.

CONCLUSIONS:

On the basis of the descriptions, the data and the discussions regarding the hydraulic properties of aquifers, the influence of the geohydrologic boundaries on the well performance, analyses of aquifer test data, specific capacity data and well characteristics the conclusions arrived at are as follows:

i) Based on the storativity parameter which is of the order

---

* Data not yet published.

of 3.70×10^{-4} in the main well field area of Roorkee, it has been concluded that the water bearing formations below hundred feet depth in this area conform to elastic conditions normally met within the confined aquifers. This substantiates the inferences drawn on similar lines based on the study of sub-surface lithological correlations.

ii) The present study in Roorkee area along with the results of an earlier study in Aligarh - Bulandshahr districts of Uttar Pradesh indicate that data collected since 1960 show the existence of diverse hydrogeological settings which govern the occurrence of ground water in the Ganges Valley.

iii) It has been established through hydrological tests that boundary conditions do prevail in the alluvial formations of the Ganges Valley and they influence the analysis of hydrological parameters even within short periods of straining the aquifers by pumping. In view of this and also due to the facts stated under conclusion (ii), ultimate ground water development in the Ganges Valley is hinged to careful evaluation of the geohydrologic parameters including the vertical drainage or permeability and thickness of the confining layers (aquicludes).

iv) The formation constants have been derived by the application of various methods and the limitations of each method when used alone to determine the effects of natural conditions on pumping are reviewed. It has been observed that in such cases the average values for the coefficients give enough reliability for the prediction of the future yield of ground water in storage and adopt the same to the solution of practical problems.

(The computed transmissibility values for the alluvial aquifers in the region vary from 41,000 gpd/ft. to 1,85,000 gpd/ft. The field permeability coefficients range almost from 500 gpd/sq. ft. to 1,900 gpd/sq.ft. The coefficient of storage is of the order of 3.70×10^{-4}.)

v) (It has been further proved that marked variations in the formation constants at short distances in the alluvial formations of the Ganges Valley close to Roorkee, have a definite bearing to the lithogenetic variations introduced by former drainage patterns.) The geomorphic history of the region explains many of the apparently anomalous ground water situations.

vi) A hydrogeological map showing the areal differences in the specific capacities of the alluvial aquifers has been brought out for the Roorkee area and it has been shown that such maps act as useful tools for the interpretation of groundwater situations as they reflect indirectly the transmissibility distribution of the water bearing formations.

(vii) From a study of the well characteristics it has been established that in the area, the important components influencing total drawdown in a pumped well are the formation and well losses. The former contributes more towards the drawdown. The other components are of negligible magnitude. The predominence of formation losses over the well losses are due to frequent 'cut outs' in the alluvial formations and their effects on the hydraulics of flow towards the discharging wells. It has also been shown that the safe range of entrance velocities in the pump tested wells also contribute on a large measure towards the low range of well losses. These are of the order of 0.046 ft./sec to 0.092 ft./sec. in the area.)

viii) It has been pointed out that the application of empirical procedures in the determination of well characteristics should be carried out with caution for water wells located in unconsolidated alluvial formations. The graphical method is preferred. The latter method should be used to supplement analysis of data by the empirical method.

— ••• —

CHAPTER V:

STATISTICAL ANALYSIS OF THE WATER LEVEL DATA:

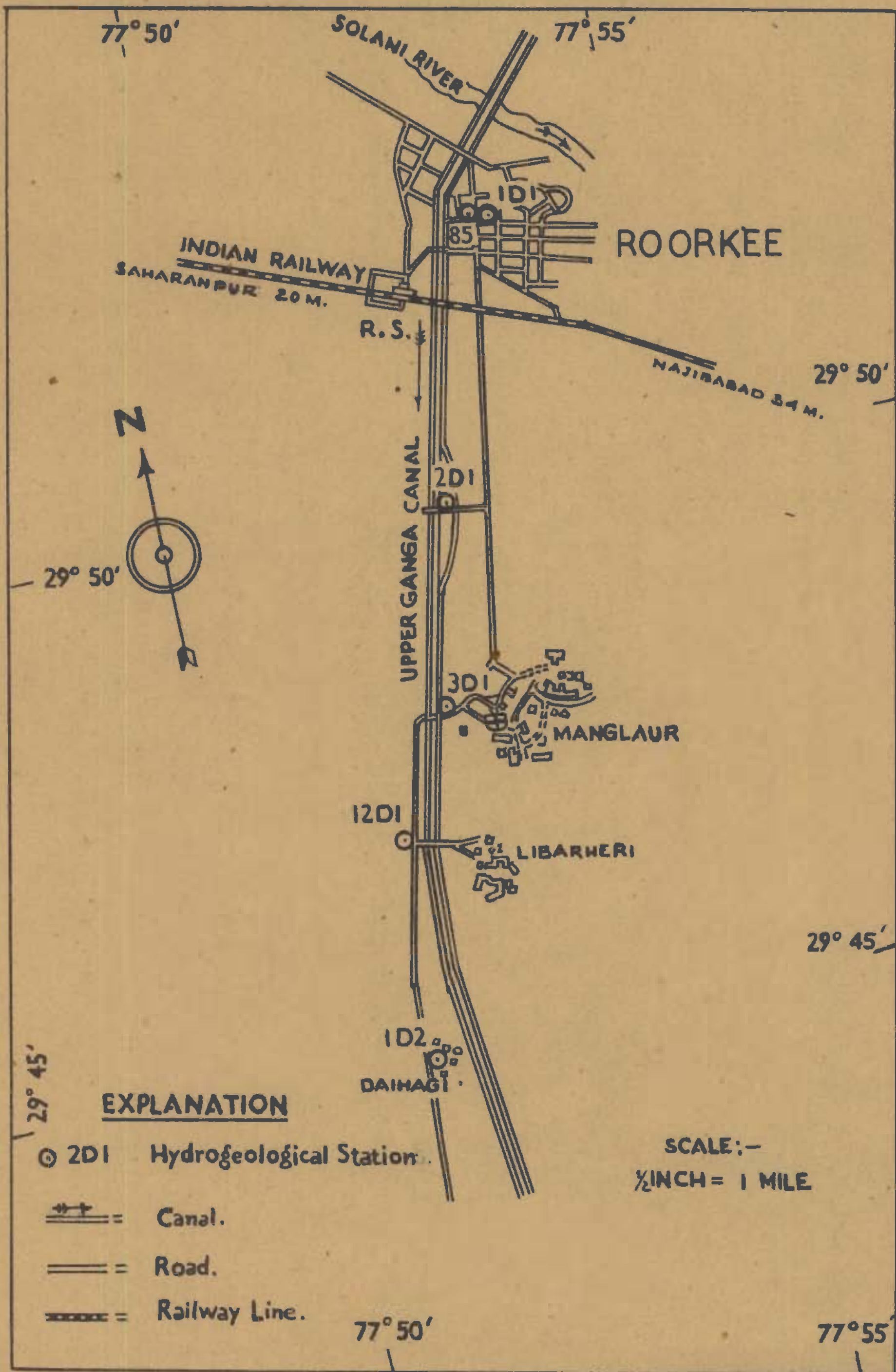
As a prelude to the statistical analysis of the water level data, the effects of meteorological and artificial factors (surface water bodies) on ground water levels are studied by establishingh hydrogeological stations in the non-masonry part of the Upper Ganges Canal in Roorkee area. The relationship between the flow of water in the canal and its effects on water table has been established. The water level data are interpreted in the light of the statistical methods which are in vogue to establish the relationship between the various factors governing the overall ground water regime. As demonstrated in the following pages, these studies are of importance in their future application to other alluvial areas and the second statistical method elaborated in the text has been applied to ground water data for the first time in the country.

LOCATION OF THE HYDROGEOLOGICAL STATIONS:

The canal area, stretching about eleven miles south of Roorkee town has been considered suitable for this study. In the absence of any provision for construction of shallow and small diameter slotted tubewells as observation stations around Roorkee, some of the already existing open wells in the area are chosen for the study of the water level fluctuations. In all six stations have been selected close to the canal and south of the Roorkee town (Plate No.XXXIII). The chosen stations lie almost at perpendicular distance from the canal varying from a few yards to nearly half a mile and are so spaced that these are considered capable of furnishing data regarding the effects of the canal flow on the near surface ground waters. In the area under

PLATE No XXXIII

LOCATION MAP OF THE HYDROGEOLOGICAL STATIONS ALONG THE UPPER GANGES CANAL, USED IN STATISTICAL STUDIES ON GROUND-WATER FLUCTUATIONS; ROORKEE AREA



consideration three stations (1D1, 85 and 3D1) fall to the east and two (12D1 and 1D2) to the west of the canal. The station 2D1 is located between the main canal and a diversion channel joining the main canal again at about one mile south of the observation station.

METHODS OF COLLECTION OF DATA:

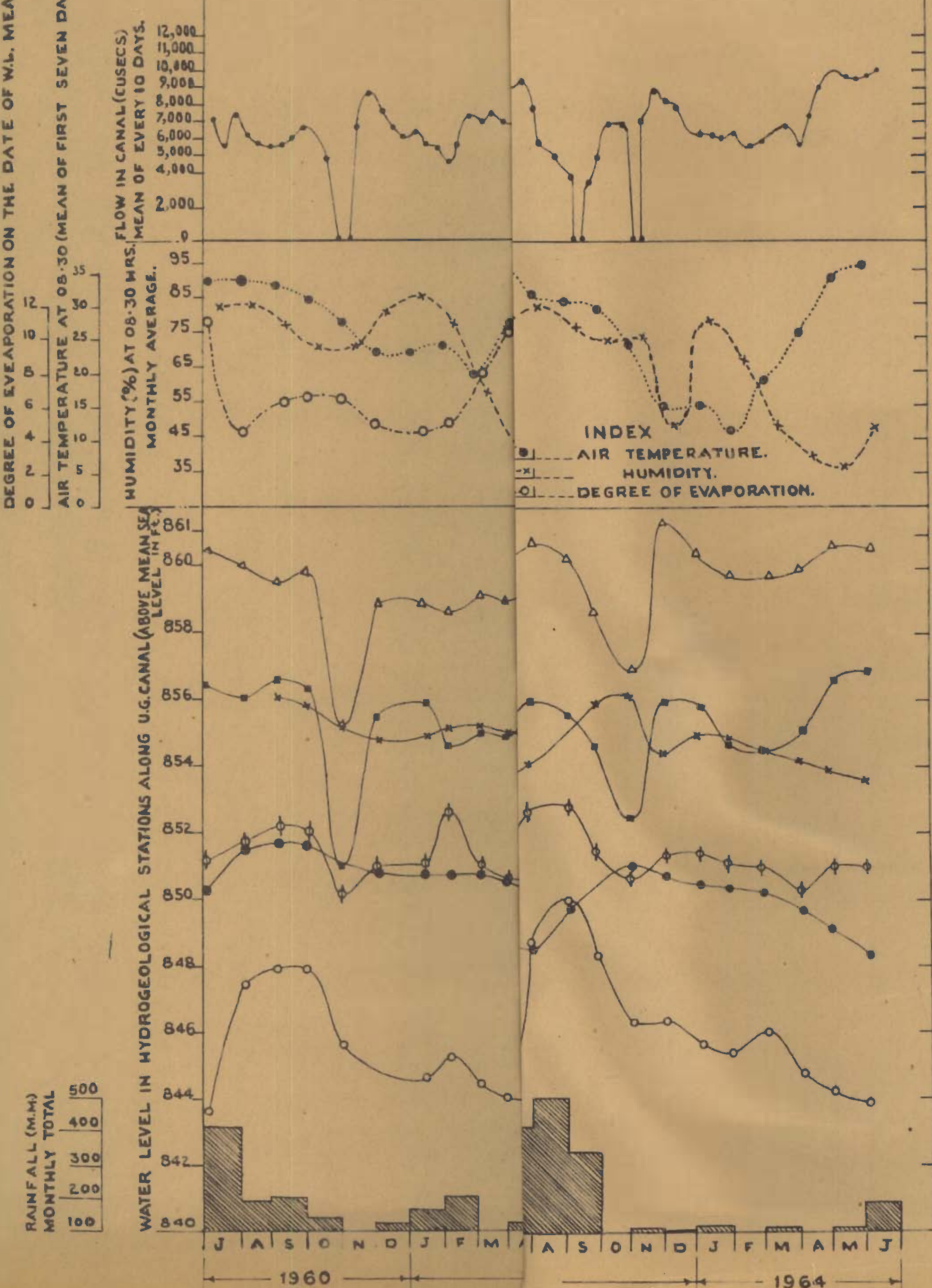
The water level measurements on the observation stations were carried out in the first week of every month and on the same day in the forenoon at all the stations. Water levels are recorded with graduated Lufkin Steel tapes correct upto the second decimal place. The meteorological data has also been collected for the same day from the meteorological station attached to the physics section of the Central Buildings Research Institute, Roorkee where the humidity and air temperature data are recorded daily at 08:30 and 17:30 hours. The evaporation data are furnished by the Soils Section of the C.B.R.I., Roorkee and the Daily Canal flow data for the period under study are obtained from the Northern Ganga Canal Division Office, Roorkee. The area under study being close to Roorkee Meteorological Station, it is justified to utilise the same for the interpretation of the hydrological conditions.

GROUNDWATER LEVELS IN RELATION TO METEOROLOGICAL AND ARTIFICIAL FACTORS:

The hydrographs for the different hydrogeological stations are brought out (Plate No.XXXIV) for the period July, 1960 to June 1964 alongwith the humidity, air temperature, rainfall and evaporation on the same (graph). Artificial factors, like the quantity of flow in the canal, are also indicated in this figure. The temperatures are plotted as the mean of the first seven days' temperature in a month, recorded at 08:30 hours, as

PLATE No XXXIV

FLUCTUATIONS O[F] METEOROLOGICAL AND ARTIFICIAL F[...] UPPER GANGES



most of the water level measurements are confined to the early part of the first week of a month and to the forenoon of the day. Monthly average of humidity recorded at 08:30 hours is plotted on the graph. Monthly rainfall and degree of evaporation are also plotted. Average of every ten days' flow of water in the canal is represented on the same graph.

The data for the four year period are given below (Table Nos. 20 to 23).

TABLE NO.20.

DETAILS OF HYDROGEOLOGICAL STATIONS USED FOR STATISTICAL ANALYSIS OF WATER LEVELS IN ROORKEE AREA:

Station	Location	Distance from canal.	Depth of the well below land surface (in ft)	Diameter (in ft.)	Use	Approx. depth to water below canal bund (in ft.)	Remark
1	2	3	4	5	6	7	8
1D1	In the compound of Sri Kedar's building on the High-way Delhi-Dehra Dun at M/s 104	618 Yds.	32.75	6.45	Gardening	14	Not in very heavy use.
2D1(i)	In the compound of the Inspection Bunglow (Canals)	48 Yds. (east point)	22.15	5.00	Not in use	2 ft. from east point & one foot from west point.	Station set between the main canal and diversion channel.
(ii)	2 furlongs east of M/S 101 on Delhi-Dehra Dun Road.	205 Yds. (west point).					

1	2	3	4	5	6	7	8
3D1	100 ft. in N60°E direction from western end of Manglaur (29°48'30"; 77°52'30") across U.G. Canal.	25 Yds.	15.00	3.00	Not in use.	13	Station set very close to the canal.
12D1 *	NW quadrant of the road junction at M/S 97 on Delhi-Dehra Dun Road.	393 Yds.	8.52	4.90	Domestic.	7	Station set close to Irrigation field, not in heavy use.
85	In the compound of British Insulated Co., Roorkee.	310 Yds.	25.00	9.00	Gardening	14	Not in very heavy use.
* 1D2	150ft.NE of road Mile 95/2 on Delhi-Dehra Dun Road	712 Yds.	21.78	4.45	Domestic	6	Stn.close t a pool of water durin rainy seasc only.

TABLE No.21.

WATER LEVEL DATA OF THE HYDROGEOLOGICAL STATIONS ALONG U.G. CANAL: ROORKEE:

Reduced Levels of the land-surface, at the Hydrogeological stations in feet above mean sea level.

1D1-53G	:	878.24	12D1-53G	:	853.05
2D1-53G	:	867.30	85-53G	:	873.93
3D1-53G	:	865	1D2-53G	:	850.41

Station Month & date	Depth to Water Level below land surface in feet 1D1-53G	2D1-53G	3D1-53G	12D1-53G	85-53G/13	1D2-53G	145-53G/13
1	2	3	4	5	6	7	8
July '60 (1.7.60)	27.87	6.65	8.83	1.78	--	6.82	--
Aug. '60 (4.8.60)	26.70	7.15	9.30	1.35	--	2.85	--
Sept. '60 (4.9.60)	26.50	7.65	9.75	0.85	17.78	2.60	--
Oct. '60 (1.10.60)	26.63	7.40	9.00	1.00	18.02	2.54	--
Nov. '60 (3.11.60)	27.20	12.15	14.42	2.90	18.70	4.88	--

1	2	3	4	5	6	7	8
Dec.'60 (3.12.60)	27.40	8.35	9.90	2.10	19.14	--	--
Jan.'61 (16.1.61)	27.50	8.40	10.45	1.95	18.94	5.90	--
Feb.'61 (8.2.61)	27.49	8.59	10.62	0.41	18.77	4.23	--
March'61 (6.3.61)	27.60	8.16	10.37	2.04	18.77	6.10	--
April'61 (1.4.61)	27.77	8.38	10.54	2.40	18.94	6.51	--
May'61 (4.5.61)	28.20	7.35	9.18	2.42	19.11	6.53	--
June'61 (1.6.61)	28.54	6.24	8.80	2.10	19.30	6.50	--
July'61 (6.7.61)	28.77	6.65	9.05	1.10	19.30	5.40	--
Aug.'61 (5.8.61)	27.94	5.49	8.77	0.19	18.33	0.99	--
Sept.'61 (5.9.61)	26.43	7.64	10.24	1.04	17.38	1.84	--
Oct.'61 (7.10.61)	26.50	8.10	9.65	1.90	18.15	2.95	--
Nov.'61 (6.11.61)	26.80	12.10	13.30	2.84	18.88	4.40	--
Dec.'61 (5.12.61)	27.10	8.33	9.50	1.93	18.79	5.53	11.47
Jan.'62 (3.1.62)	27.03	7.74	9.45	1.69	18.25	5.38	10.80
Feb.'62 (6.2.62)	26.85	8.25	10.17	1.16	18.10	4.05	11.37
March'62 (1.3.62)	26.90	8.59	10.83	1.87	18.24	5.64	11.47
April'62 (3.4.62)	27.26	7.53	9.36	2.52	18.38	6.71	10.63
May'62 (8.5.62)	27.75	6.44	8.90	3.46	18.95	7.04	10.42
June'62 (12.6.62)	28.33	6.30	8.75	2.06	19.10	5.74	10.55

1	2	3	4	5	6	7	8
July'62 (16.7.62)	28.55	5.85	8.25	0.19	18.00	3.90	10.55
Aug.'62 (13.8.62)	28.08	7.00	8.84	0.25	18.04	2.45	10.84
Sept.'62 (6.9.62)	27.96	8.06	9.60	1.25	18.96	2.15	11.67
Oct.'62 (4.10.62)	27.75	8.84	10.69	1.54	18.96	3.89	12.56
Nov.'62 (13.11.62)	28.22	8.71	10.06	2.08	19.45	5.04	12.29
Dec.'62 (10.12.62)	28.22	7.33	9.22	1.54	19.00	4.53	11.07
Jan.'63 (3.1.63)	28.13	8.08	9.85	1.75	18.95	5.15	11.35
Feb.'63 (6.2.63)	28.39	8.60	10.89	1.95	19.80	5.51	--
March'63 (13.3.63)	28.62	7.80	9.99	2.43	19.63	6.13	11.58
April'63 (4.4.63)	28.83	8.28	10.58	2.82	19.80	6.30	11.95
May'63 (2.5.63)	29.28	7.70	9.80	2.48	20.12	6.30	--
June'63 (3.6.63)	29.70	6.83	9.46	2.55	20.33	7.20	--
July'63 (3.7.63)	29.47	7.13	10.00	1.65	20.30	6.15	--
Aug.'63 (1.8.63)	29.70	6.39	8.19	0.43	19.75	1.79	--
Sept.'63 (4.9.63)	28.50	6.85	9.70	0.20	18.55	0.47	--
Oct.'63 (1.10.63)	26.76	8.53	10.60	1.58	17.99	2.10	--
Nov.'63 (2.11.63)	27.20	10.39	12.95	2.33	17.72	4.16	--
Dec.'63 (2.12.63)	27.63	7.03	9.24	1.85	19.64	5.20	--
Jan.'64 (3.1.64)	27.84	6.90	9.45	1.65	18.98	4.85	--

1	2	3	4	5	6	7	8
Feb.'64 (1.2.64)	27.90	7.54	10.65	1.90	19.05	5.13	--
March'64 (2.3.64)	28.13	7.70	10.80	2.10	19.45	4.53	--
April'64 (6.4.64)	28.70	7.45	10.35	2.85	19.73	5.80	--
May'64 (2.5.64)	29.24	6.68	8.85	2.16	20.05	6.30	--
June'64 (5.6.64)	30.01	6.80	8.61	2.18	20.46	6.69	--

TABLE NO.22.

METEOROLOGICAL DATA COLLECTED FROM THE CENTRAL BUILDING RESEARCH INSTITUTE: ROORKEE FOR GROUNDWATER REGIME STUDIES CLOSE TO UPPER GANGES CANAL:

Month and year	Rainfall in mm (monthly total)	Humidity % at 08:30 hrs (monthly average)	Air Temperature °C at 08:30 hrs. (average of first seven days of the month).	Degree of Evaporation (on the dat of water level measu ment.
1	2	3	4	5
July'60	312.3	86.0	84.5	9.3 (1.7.60)
August'60	80.2	86.5	84.8	2.8 (4.8.60)
Sept.'60	82.9	80.5	83.0	4.3 (4.9.60)
Oct.'60	27.1	73.7	79.5	4.7 (1.10.60)
Nov.'60	0.0	73.3	73.5	4.6 (3.11.60)
Dec.'60	0.6	83.5	65.5	3.0 (3.12.60)
Jan.'61	51.2	88.4	65.6	2.4 (16.1.61)
Feb.'61	95.4	80.7	67.5	3.0 (8.2.61)

1	2	3	4	5
March'61	0.0	59.9	59.1	6.0 (6.3.61)
April'61	5.5	41,8	72.8	8.8 (1.4.61)
May'61	9.6	37.5	83.7	8.9 (4.5.61)
June'61	38.3	58.2	91.5	11.3 (1.6.61)
July'61	388.9	83.7	83.0	3.0 (6.7.61)
Aug.'61	350.8	88.2	81.0	1.6 (5.8.61)
Sept.'61	70.2	81.6	81.3	1.6 (5.9.61)
Oct.'61	92.9	77.9	78.6	2.0 (7.10.61)
Nov.'61	4.1	83.5	62.6	2.7 (6.11.61)
Dec.'61	29.6	88.4	45.6)	(Data not available since Dec.'61 as the instrument at the station is out of order)
Jan.'62	83.9	88.8	42.2)	
Feb.'62	33.7	79.4	40.6)	
March'62	26.1	66.5	57.1)	
April'62	0.2	46.3	71.3)	
May'62	3.0	35.8	81.2)	
June'62	47.9	55.7	87.8	
July'62	377.1	77.4	87.8	
Aug.'62	119.5	78.1	83.0	
Sept.'62	169.3	83.3	82.2	
Oct.'62	0.0	74.5	73.0	
Nov.'62	17.1	76.3	16.1	
Dec.'62	27.6	86.9	10.6	
Jan.'63	15.0	88.2	4.6	

1	2	3	4	5
Feb.'63	13.9	77.5	8.7	(Data not availabl[e] since Dec.'61 as the instrument at the station is out of order).
March'63	21.5	63.8	16.4	
April'63	2.9	42.4	21.9	
May'63	12.5	41.7	29.0	
June'63	67.1	66.6	30.3	
July'63	317.1	79.1	31.4	
Aug.'63	401.3	86.3	27.4	
Sept.'63	230.5	81.4	26.1	
Oct.'63	0.0	76.1	25.1	
Nov.'63	10.1	77.7	19.6	
Dec.'63	4.6	48.0	10.9	
Jan.'64	13.8	81.9	10.4	
Feb.'64	3.0	70.6	6.4	
March'64	5.8	50.4	14.4	
April'64	2.9	39.8	22.6	
May'64	8.6	37.9	29.5	
June'64	70.9	49.6	31.2	

TABLE NO.23(a):

DATA ON THE UPPER GANGES CANAL DISCHARGES IN ROORKEE AREA (TEN DAYS AVERAGE)

Month and year	Amount of flow of water in the canal in cusecs (average for the period indicated).		
	Ist. to 10th of the month	11th to 20th of the month	21st. to end of the month.
1	2	3	4
July'60	7632	5737	7792
Aug.'60	6565	6033	5665
Sept.'60	5803	6038	6937
Oct.'60	6462	4978	No flow in the canal
Nov.'60	No flow in the canal	6931	8925
Dec.'60	7832	7082	6510
Jan.'61	6628	5975	5639
Feb.'61	4722	5632	7688
March'61	7372	7767	7239
April'61	7186	7622	9460
May'61	9664	9797	10471
June'61	10481	10412	9121
July'61	9002	6424	5910
Aug.'61	5403	4648	4494
Sept.'61	4494	5143	7008
Oct.'61	7109	7598	No flow in the canal.
Nov.'61	Ist.to5th No flow in the canal 6th to 10th 4405	5703	7207
Dec.'61	8994	9151	8059
Jan.'62	3289	7595	6469
Feb.'62	5856	6200	6610

1	2	3	4
March'62	6458	6836	8326
April'62	8657	7897	8989
May'62	10416	10386	10395
June'62	10480	10269	10258
July'62	9618	7191	6592
Aug.'62	7071	8536	6678
Sept.'62	6517	4772	4502
Oct.'62	5785	7264	21st.to28th 7264
			29th to 31st. No flow in the canal.
Nov.'62	Ist.to 4th No flow in the canal		
	5th to 10th 6754	9511	10171
Dec.'62	9235	8480	7878
Jan'63	7310	6821	6401
Feb.'63	5910	5706	5358
March'63	5526	6682	6761
April'63	7128	7900	7691
May'63	9508	11279	10251
June'63	10404	10298	10375
July'63	10404	9262	9860
Aug.'63	8037	6043	5392
Sept.'63	4474 11th to 16th	4045	3835
	17th to 20th	No flow in the canal	
Oct.'63	4971	7176	7377
Nov.'63	No flow in the canal		
	11th to 13th	No flow in the canal	
	14th to 20th	7249	9282

1	2	3	4
Dec.'63	8678	8275	7041
Jan.'64	6619	6728	6225
Feb.'64	6720	5981	5941
March'64	5664	6765	6911
April'64	5811	7769	9383
May'64	10211	9836	9630
June'64	9905	10345	10415

TABLE NO.23(b):

DATA ON THE UPPER GANGES CANAL DISCHARGES IN ROORKEE AREA (ON THE DAY OF WATER LEVEL MEASUREMENT):

Date	Amount of flow of water in the canal in cusecs on the date of water level measurement.	Date	Amount of flow of water in the canal in cusecs on the date of water level measurement.
1	2	3	4
1.7.60	9798	13.11.62	8504
4.8.60	7181	10.12.62	9035
4.9.60	5528	3. 1.63	7413
1.10.60	8205	6.2. 63	5880
3.11.60	No flow in the canal.	13. 3.63	8275
3.12.60	8441	4. 4.63	7265
16.1.61	5933	2. 5.63	8605
8. 2.61	4504	3. 6.63	10404
6. 3.61	7160	3. 7.63	10404
1. 4.61	7265	1. 8.63	10206
4. 5.61	9477	4. 9.63	4750
1. 6.61	10479	1. 10.63	3500

1	2	3	4
6. 7.61	9393	2.11.63	No flow in the canal
5. 8.61	5606	2.12.63	9063
5. 9.61	4494	3. 1.64	6560
7.10.61	7109	1. 2.64	6040
6.11.61	No flow in the canal.	2. 3.64	5790
5.12.61	9000	6. 4.64	7160
3. 1.62	8608	2. 5.64	10340
6. 2.62	6008	5. 6.64	10898
1. 3.62	5880		
3. 4.62	8902		
8. 5.62	10479		
12.6.62	10133		
16.7.62	7508		
13.8.62	8700		
6. 9.62	7004		
4.10.62	6206		

The hydrographs at each station, clearly reflect the rising trend of water level in response to heavy precipitation. Keeping this in view, the above relationship has been studied further by plotting the rainfall in the preceeding month versus water levels (Plate No.XXXV). The plots for the stations 12D1, 1D2, 85 and 1D1 though indicate some relationship between these two dependencies (rainfall in the preceding month and water levels), the scattering of points do not permit derivation of a coefficient factor for the above said two dependencies through the method of drawing a line of best fit and obtaining the slope of the same.

As such, other methods (statistical) have been adopted in the later part of this chapter to arrive at the correct coefficient factor amongst these two dependencies.

Similarly, a graph showing the relationship between the flow of water in canal and water levels at the hydrogeological stations 3D1 and 2D1 is prepared as the hydrographs of these two stations reveal pronounced effects of variation in the water levels when compared to the canal discharges (Plate No.XXXVI). The slope of the line of best fit gives the coefficient factor as 0.30. This means that for every thousand cusecs increase of water in the canal the water levels in the wells close to the canal would rise by 0.3 ft.

LITHOLOGY AND GROUND WATER LEVELS:

Lithological variations are also a criteria to study the fluctuations of ground water in an area. In view of this, the section across the canal and longitudinal section parallel to the canal are prepared for the area with the help of the log data of the state tubewells. Since the maximum recorded depth at the geohydrological stations fall to 33 feet, the borehole logs have been studied to the first hundred feet depth.

Taking into consideration the reduced levels at the tubewell sites and also the lithological logs prepared by the drillers (Plate No.XXXVII), a panel diagram for the area is also constructed. This diagram indicates an increase of sand percentage in the strata south of Roorkee town and decrease of the same north of it in the first hundred feet depth. The importance of this diagram when studied with other available hydrological data is discussed subsequently (page 150).

TABLE № 24

STATISTICAL CORRELATION TABLE ; ROORKEE AREA

Y ↓ \ X →	0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	24-26	26-28	28-30	I ny	II y_1	III $ny \cdot y_1$	IV $y_1(ny \cdot y_1)$	V Σy_1	VI $y_1(\Sigma y_1)$
30-28														5	15	20	+7	+140	980	+135	945
28-26														23	4	27	+6	+162	972	+166	996
26-24																0	+5	0	0	0	0
24-22																0	+4	0	0	0	0
22-20										2	3					5	+3	+15	45	+13	39
20-18									4	31	1					36	+2	+72	144	+69	138
18-16									1	3						4	+1	+4	4	+7	7
16-14					1											1	0	0	0	-3	0
14-12				1	2	1										4	-1	-4	4	-12	12
12-10					9	7										16	-2	-32	64	-41	82
10-8				6	27	7	4	1								45	-3	-135	405	-123	369
8-6			6	26	6	1										39	-4	-156	624	-154	616
6-4		4	25	4												23	-5	-115	575	-115	575
4-2	10	17	1	1												29	-6	-174	1044	-181	1086
2-0	22	7	1	1												31	-7	-217	1519	-205	1435
I nx	32	28	23	39	45	16	4	1	5	36	4	0	0	28	19	280	—	-440	6380		6300
II x_1	-7	-6	-5	-4	-3	-2	-1	0	+1	+2	+3	+4	+5	+6	+7	—					
III $nx \cdot x_1$	-224	-168	-115	-156	-135	-32	-4	0	+5	+72	+12	0	0	+168	+133	-444					
IV $x_1(nx \cdot x_1)$	1568	1008	575	624	405	64	4	0	5	144	36	0	0	1008	931	6372					
V Σx_1	-214	-171	-112	-156	-125	-40	-12	-3	+9	+71	+11	0	0	+173	+129	—					
VI $x_1(\Sigma x_1)$	1498	1026	560	624	375	80	12	0	9	142	33	0	0	1038	903	6300					

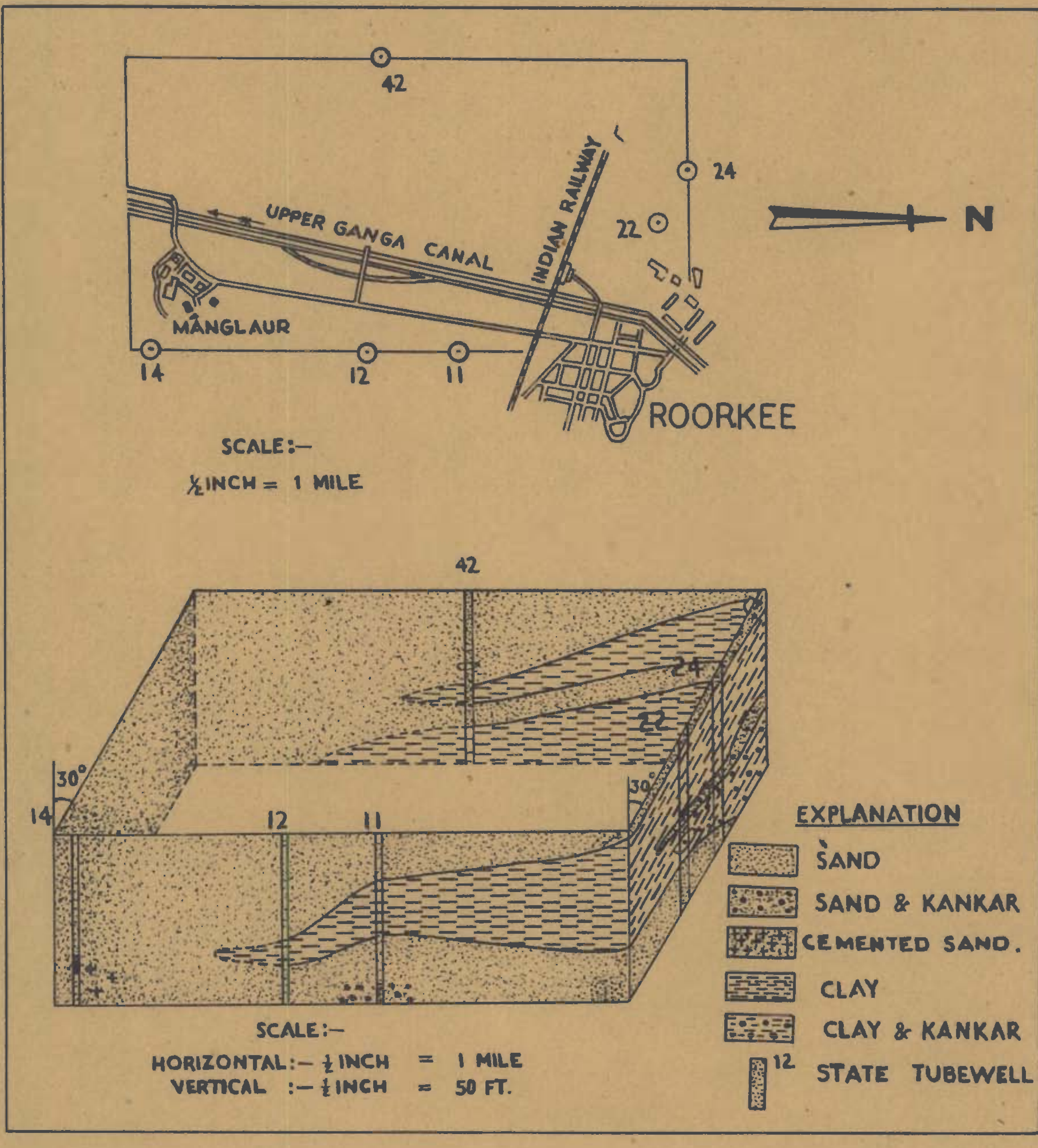
EXPLANATION

X —; WATER LEVEL IN PRECEDING MONTH

Y —; WATER LEVEL IN FOLLOWING MONTH

PLATE No XXXVII

PANEL DIAGRAM SHOWING THE LITHOLOGICAL UNITS IN THE AREA CLOSE TO UPPER GANGES CANAL AND SOUTH OF ROORKEE.



STATISTICAL METHODS FOR THE DERIVATION OF CORRELATION COEFFICIENT AND PREDICTION OF WATER LEVELS:

Correlated dependencies may be found between the level of underground waters and any other natural or artificial factors. In the area under consideration graphical representations of (i) water levels in the preceding month versus water levels in the following month (ii) rise or fall of water level versus rain fall and (iii) rise or fall of water level versus canal flow indicate in general a linear relationship between the stated variables.

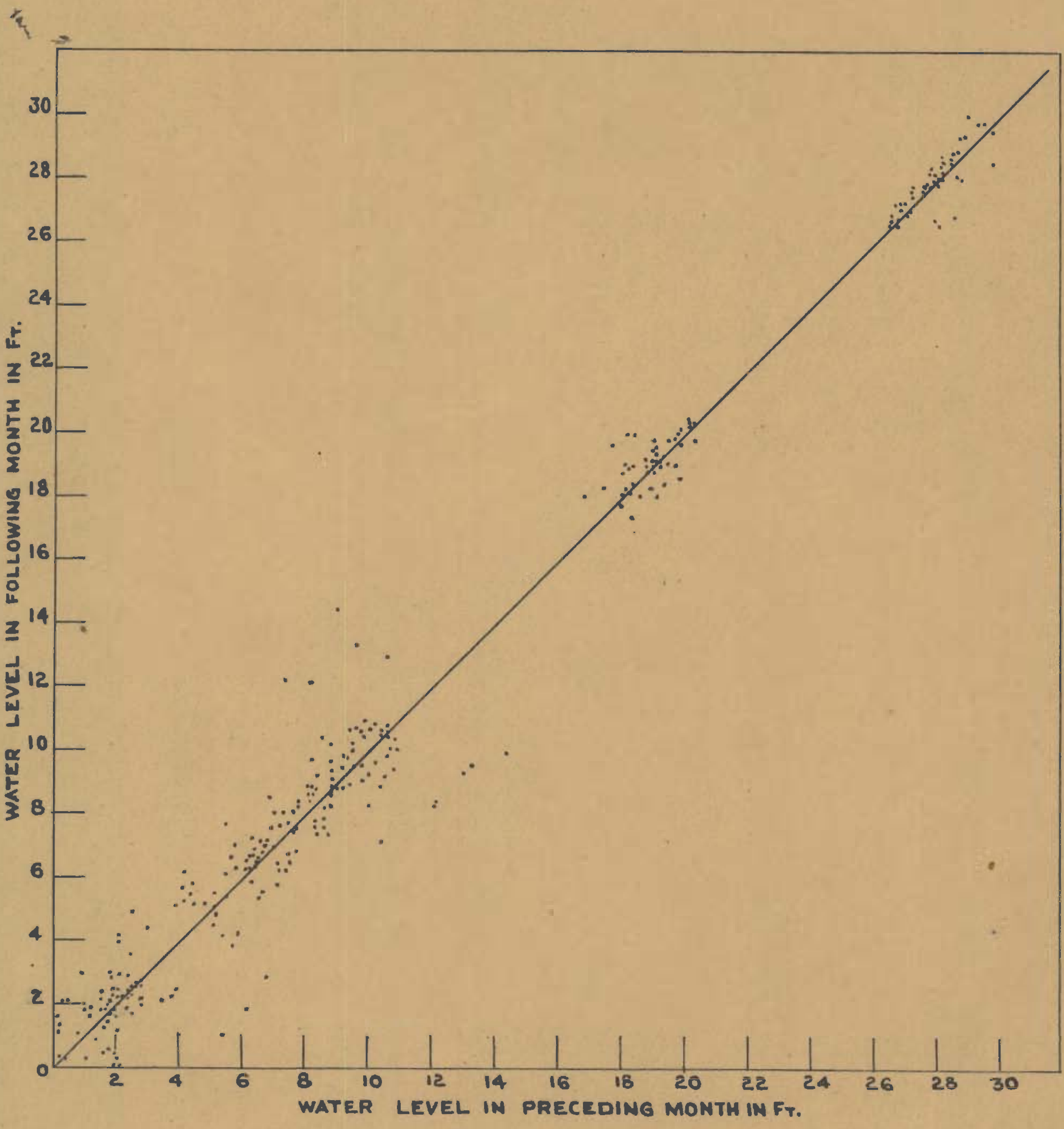
Scatter diagrams showing the relationship of water levels versus rainfall or canal flow (Plate Nos. XXXIV and XXXV) though indicate that there is some relationship between the two, they do not indicate to what extent the relationship is reliable or holds good. The statistical correlation coefficient obtained as a numerical gives an exact idea on the extent to which the relationship is reliable or dependable. Its value extends from -1 through zero to +1. If the correlation coefficient is equal to +1, it indicates that there is a direct and perfect relationship between the two variables. These statistical methods also help to establish the major factors affecting the near surface ground waters in the area. Using these coefficients, it would also be possible to predict the future water levels at various observation stations as discussed in the following pages.

i) LINEAR CORRELATION METHOD I:

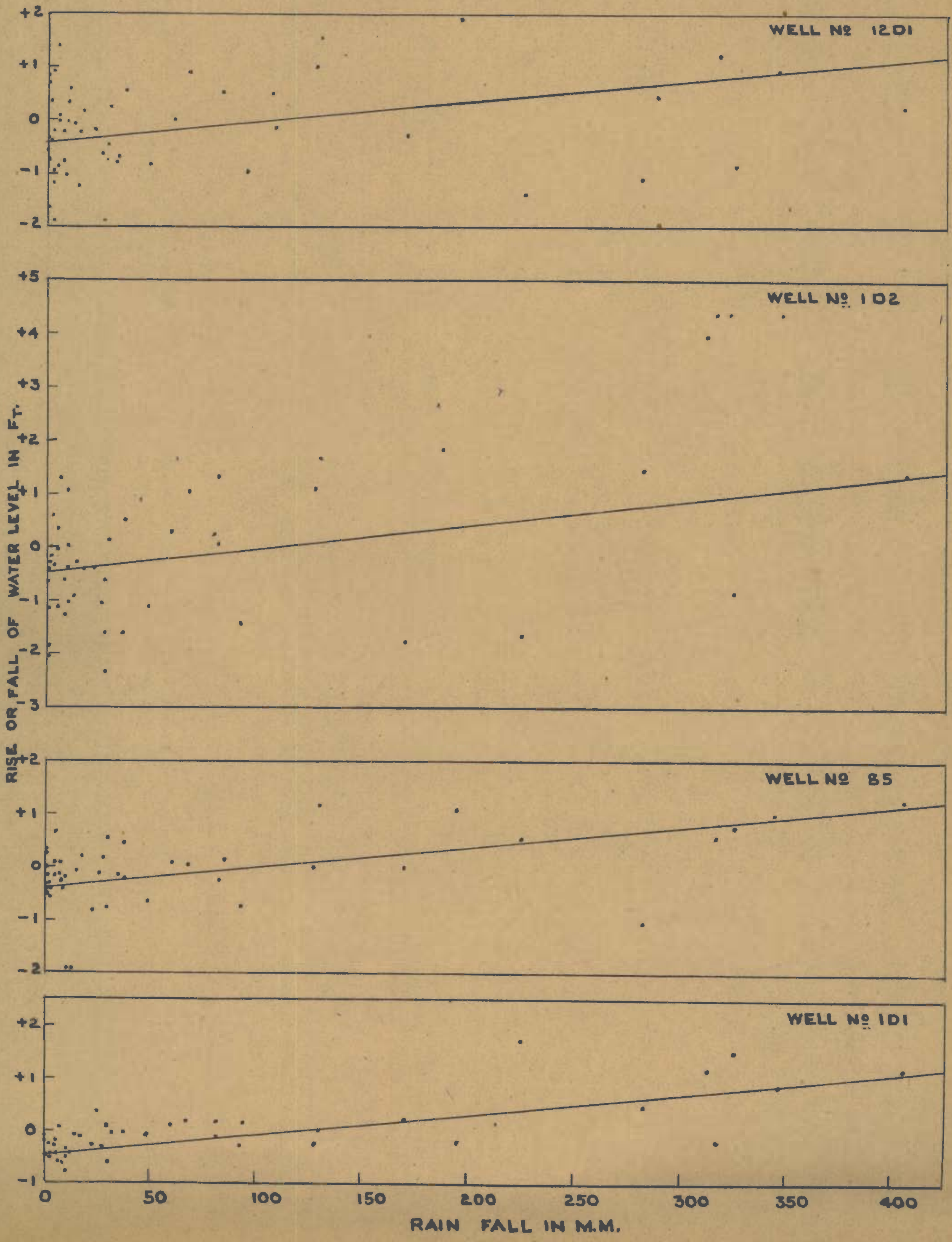
In this method the correlation coefficient has been derived by grouping the data (given in table No.21, page 129) in a manner adopted by Altovsky (Table No.24) for the period July 1960 to June 1964.

PLATE No XXXIV A

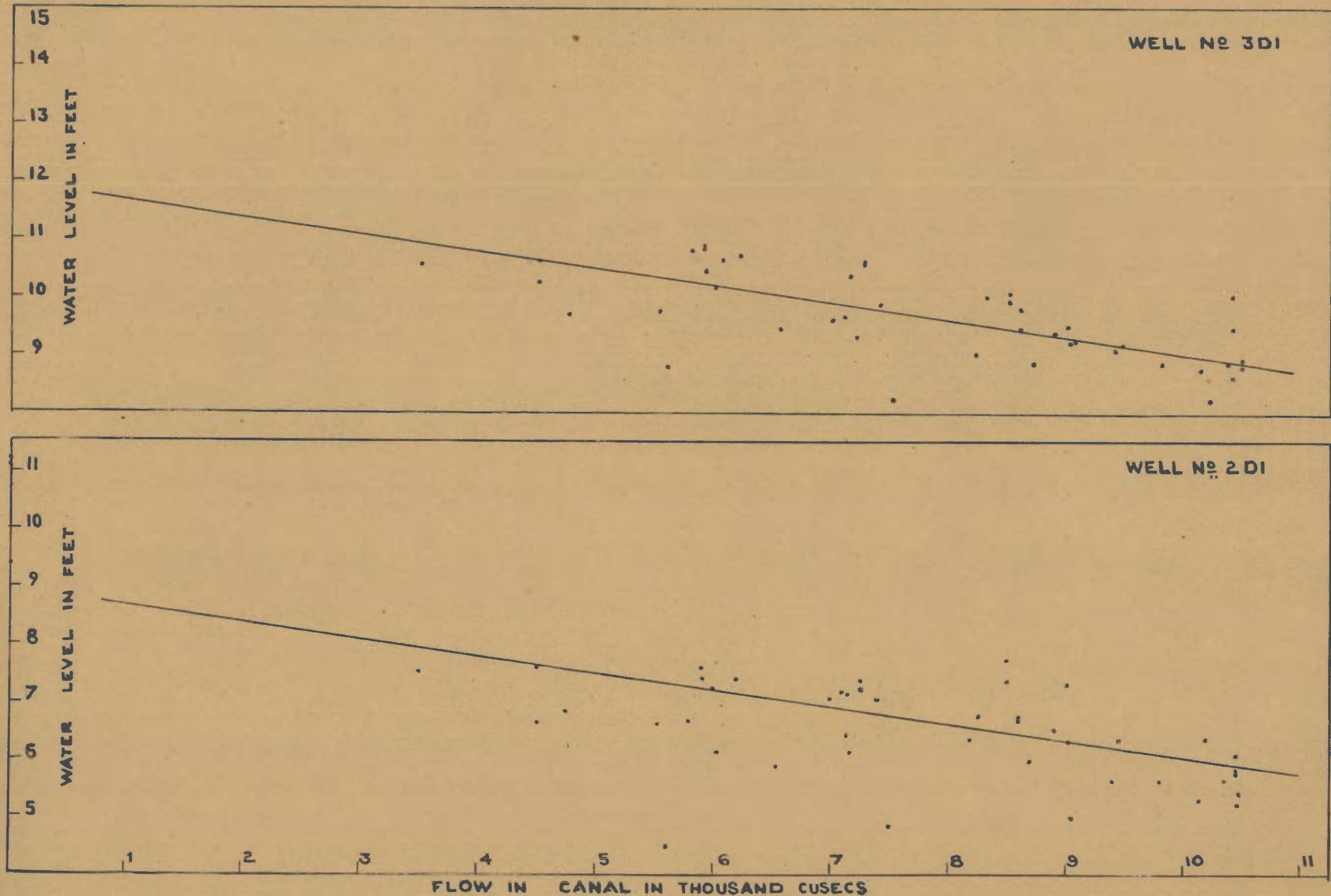
RELATIOINSHIP BETWEEN THE WATER LEVELS IN PRECEDING AND FOLLOWING MONTHS FOR THE STATIONS ALONG UPPER GANGES CANAL, ROORKEE AREA.



RELATIONSHIP BETWEEN WATER LEVELS AND RAINFALL FOR THE HYDROGEOLOGICAL STATIONS ALONG THE UPPER GANGES CANAL, ROORKEE AREA.



RELATIONSHIP BETWEEN THE WATER LEVELS AT THE HYDROGELOGICAL STATIONS AND THE FLOW IN THE UPPER GANGES CANAL, ROORKEE AREA.



The correlation coefficient 'r' is calculated as follows:

The sum of col. I line I denoted by Σn = 280

The sum of Col. III line III by

$\Sigma ny.y_1$ and $\Sigma nx.x_1$ = -440 and -444

The sum of Col. IV line IV by

$\Sigma y_1(ny.y_1)$ and $\Sigma x_1(nx.x_1)$ = 6380 and 6372

The sum of col. VI line VI by Σxy = 6300

$$r = \frac{\frac{\Sigma xy}{\Sigma n} - v_1 v_2}{\delta y . \delta x}$$

where $v_1 = \frac{\Sigma nx.x_1}{\Sigma n}$ $= \frac{-444}{280} - 1.58$

$v_2 = \frac{\Sigma ny.y_1}{\Sigma n}$ $= \frac{-440}{280} = -1.5$

$$\delta y = \sqrt{\frac{\Sigma y_1(ny.y_1)}{\Sigma n} - (v_2)^2}$$

$$= \sqrt{\frac{6380}{280} - (-1.571)^2} = \pm 4.503$$

$$\delta x = \sqrt{\frac{\Sigma x_1(nx.x_1)}{\Sigma n} - (v_1)^2}$$

$$= \sqrt{\frac{6372}{280} - (-1.586)^2}$$

$$r = \frac{\frac{6300}{280} - (-1.571 \times -1.586)}{4.503 \times 4.499}$$

$= (+)\ 0.9877.$

An attempt has also been made to predict the water levels by computing the linear correlated dependencies. Since the prediction of water levels in the following month depending on the preceding month is desirable, the linear correlated dependency for the same is calculated as follows:

For a dependency of the mean value $\bar{y}$ upon x

$$y - \bar{y} = b_y (x - \bar{x}) \qquad \text{... (xviii)}$$

'by' represents angular coefficient of a straight line drawn to the axis of co-ordinates and is computed according to the following formula.

$$b_y = r \frac{\delta y}{\delta x} \qquad \text{... (xix)}$$

where 'r' = 0.9877.

δx = root mean square deviation of the variable x;

δy = root mean square deviation of the variable .

In computing bx, b_y, δx and δy the values found from the correlation table in conventional limits for $\bar{x}$, $\bar{y}$, δx, δy should be converted so as to acquire their true values. The true value of δx is equal to its conventional value (in this case 4.499) multiplied by the capacity of the interval (k) of values X (in this case k = 2).

$$\delta x = 4.499 \times 2 = 8.998$$

$$\delta y = 4.503 \times 2 = 9.006$$

Similarly, the true mean value of x, represented by ($\bar{x}$) is the sum of zero interval of the values for x, represented by (x_0), plus the product of the capacity of the interval (k) and v_1.

$$\bar{x} = x_0 + k v_1 \qquad \text{... (xx)}$$

$$= 15.0 + (-1.586)$$

$$= 11.828.$$

where (x_0) is the zero interval of values for x represented by column VIII (Table 24) and denoted by the range 14 - 16, the mean value being 15.

Similarly, $\bar{y} = y_0 + K v_2$ ... (xxi)

$= 15 + 2 (-1.571)$

$= 11.858$

Substituting the values in equation (xix)

$$by = \frac{0.9877 \times 9.006}{8.998}$$

$= 0.9883$

Substituting the above values in equation (xviii)

$$y_x - 11.858 = 0.9883 (x - 11.828)$$

$$y_x = 0.9883 x + 0.168$$

During the following month, possible deviations of the calculated mean values from actual deviations of ground water level will be

$\Delta y = \delta y \sqrt{1 - r^2}$ ... (xxii)

$= 9.006 \sqrt{1-0.9877^2}$

$= 43.20$ cms

or 1.412 ft.

Accuracy of calculations based on the correlated dependency will be increased considerably if the forecast will be given for a group of wells according to the formula.

$\Delta n = \frac{\Delta y}{\sqrt{n}}$ ... (xxiii)

$= \pm \frac{1.412}{\sqrt{6}}$

$= \pm 0.5765$ feet.

$\therefore \quad y_x = 0.9883 x + 0.168 \pm 0.5765$ ft.

As such, the levels of predicted ground waters will be found within the limits of $[(0.9883\,x + 0.168) \pm 0.5765)]$ feet. In this connection, it should be noted that a single value of Δn will ensure a 68% probability of the value of 'y' obtained in accordance with the correlated dependency; twice the value of 'Δn' ensures 95% probability and thrice the value will make reliability certain in 99% cases.

ii) LINEAR CORRELATION METHOD II:

The earlier method of statistical analysis is considered useful for determining the correlation coefficients when there is enormous grouped data. As the correlation coefficients for the rise/fall of water levels versus rainfall or canal flow have to be established with a set of limited and ungrouped data for each hydrogeological station, the second linear correlation method as elaborated below is adopted.

The computations are as follows:

X = Values of water levels in the preceding month (in cm).

Y = Values of water levels in the following month (in cm).

Xm = the average obtained from the values of X

Ym = the average obtained from the values of Y

x and y are deviation values.

The data are given under table No.25(a) below:

X Rise or fall of water level (in ft)	Y Rainfall (in cm.)	X-Xm	Y-Ym	X^2	y^2	Xy
1	2	3	4	5	6	7
+3.970	31.23	+3.968	+23.41	15.75	548.0	+92.9
+0.250	8.12	+0.248	+0.30	0.06	0.1	+ 0.1
+0.060	8.19	+0.058	+0.37	0.004	0.1	+ 0.02

1	2	3	4	5	6	7
-2.340	2.71	-2.342	- 5.11	5.48	26.1	+12.0
-0.630	0	-0.632	- 7.82	0.40	61.1	+ 4.9
-0.390	1.73	-0.392	- 6.09	0.15	37.1	+ 2.4
+1.670	13.00	+1.668	+ 5.18	2.78	26.8	+ 8.6
-1.870	0	-1.872	- 7.82	3.50	61.1	+14.6
-0.410	0	-0.412	- 7.82	0.17	61.1	+ 3.3
-0.020	0.55	-0.022	- 7.27	0.0004	52.8	+ 0.2
+0.030	0.96	+0.028	- 6.86	0.0009	46.0	- 0.2
+1.100	12.76	+1.098	+4.94	1.21	24.4	+ 5.4
+4.410	34.64	+4.408	+26.82	19.44	719.1	+118.2
-0.850	32.57	-0.852	+24.75	0.73	612.7	-21.1
-1.110	4.85	-1.112	-2.97	1.24	8.8	+ 3.3
-1.450	9.29	-1.452	+1.47	2.11	2.2	- 2.1
-1.130	0.41	-1.132	-7.41	1.28	54.9	+ 8.4
+0.150	2.96	+0.148	-4.86	0.02	23.6	-0.7
+1.330	8.42	+1.328	+0.60	1.40	0.4	+ 0.8
-1.590	3.34	-1.592	-4.48	2.53	15.9	+ 7.1
-1.070	2.61	-1.072	-5.21	1.15	27.1	+ 5.6
-0.330	0.32	-0.332	-7.50	0.11	56.3	+ 2.5
+1.300	0.65	+1.298	-7.17	1.69	51.4	- 9.3
+1.840	19.43	+1.838	+11.61	3.38	134.8	+21.3
+1.450	28.37	+1.448	+20.55	2.10	422.5	+29.8
+0.300	6.00	+0.298	-1.82	0.09	3.3	- 0.5
-1.740	16.93	-1.742	+9.11	3.03	83.0	-15.9
-1.150	0	-1.152	-7.82	1.33	61.1	+ 9.0
+0.490	3.74	+0.488	-4.08	0.24	16.6	- 2.0
-0.620	0.73	-0.622	-7.09	0.39	34.9	+ 4.4

1	2	3	4	5	6	7
-0.360	2.26	-0.362	-5.56	0.13	30.9	+ 2.0
-0.620	2.78	-0.622	-5.04	0.39	25.4	+ 3.1
-0.170	0.15	-0.172	-7.67	0.03	58.8	+ 1.3
0	0.14	-0.002	-7.68	0	59.0	- 0.02
-0.906	1.25	-0.902	-6.57	0.81	42.2	+ 5.9
+1.050	6.71	+1.048	-1.11	1.10	1.2	- 1.2
+4.360	31.71	+4.358	+23.89	19.00	453.5	+104.1
+1.320	40.66	+1.318	+32.84	1.74	1078.0	+ 43.3
-1.630	22.52	-1.632	+14.70	2.66	216.1	- 24.0
-2.060	0	-2.062	- 7.82	4.25	61.1	+ 16.1
-1.040	1.01	-1.042	- 6.81	1.08	46.3	+ 7.1
+0.350	0.46	+0.348	- 7.36	0.12	54.2	- 2.6
-0.280	1.38	-0.282	- 6.44	0.08	41.5	+ 1.8
+0.600	0.30	+0.598	- 7.52	0.36	56.5	- 4.5
-1.270	0.79	-1.272	- 7.03	1.62	49.4	+ 8.9
-0.500	0.08	-0.502	- 7.74	0.25	59.9	+ 3.9
-0.390	0.86	-0.392	- 6.96	0.15	48.4	+ 2.7

$\Sigma x = +0.110$ $\Sigma Y = 3675.7$ $\Sigma x^2 = 105.53$ $\Sigma y^2 = 5660.7$ $\Sigma xy = +470.$

$x = +0.0023$ $y = 78.2$

Substituting values of $\sigma y = \sqrt{\frac{5660.7}{47}} = \pm 10.97$

$\therefore \frac{P}{\sigma x \cdot \sigma y} = (+) \frac{10.02}{1.498 \times 10.97} = (+) 0.609$

The correlation coefficient is (+) 0.609.

Based on this method the correlation coefficients for establishing the relationship between (i) rainfall and water levels and (ii) canal flow and water levels have been computed for all the hydrogeological stations on similar lines and the summerised results are tabulated below:

TABLE NO.25(b)

SUMMARISED RESULTS OF CORRELATION COEFFICIENTS BASED ON LINEAR CORRELATIONS, ROORKEE AREA:

Well Numbers→ Factors	1D1	35	2D1	3D1	12D1	1D2
1	2	3	4	5	6	7
(i) Rainfall Versus Rise or fall of water level	+0.799	+0.589	-	-	+0.216	+0.609
(ii) Canal Flow Versus water level	-	-	-0.761	-0.845	0.022	-
(iii) Major Influencing Factor ~~fall~~	Rain fall	Rain Fall	Canal Flow	Canal Flow	i) Rainfall ii) Canal Flow iii) Evapo-transpiration	Rain Fall.

The same statistical method, when applied to establish the relationship between (i) humidity and water levels and (ii) evaporation and water levels, did not indicate any definite relationship.

DISCUSSION:

Of late, statistical methods have been used to solve several problems in applied and pure sciences. Although in the knowledge of the writer, the technique has not been used widely for the ground water regime analysis, however, it is evident from the present attempt that this study may prove suitable for this purpose. The accumulated data obtained from the hydrogeological stations over a period of four years would permit the application of statistical correlation methods and help in determining the basic factor/or factors influencing any given element of the water regime.

Discussing these methods as they are applied to ground water hydrology Altovsky writes " work related to the establishment of correlated dependencies should begin chiefly with an investigation of the natural processes themselves, disclosure of general laws characterising their course within natural environments, and finally with the revealing of the principal natural or artificial factors affecting one or the other element of the regime of under ground waters".

The investigations on the natural processes involved in the regime of groundwaters for the Upper Ganges Canal area, Roorkee have been analysed in a graphical manner. The interrelation between various factors governing the ground water regime phenomena are best revealed in a combined diagram (Plate No.XXXIV) especially for long term analysis. In order to arrive at the definite dependencies, the data related to the factors thus established are further subjected to a statistical analysis.

a) Relationship between rainfall and ground water levels:

From the hydrographs (Plate No.XXXIV), it is also inferred that close to stations 1D1, 85, 1D2 the trend of water levels closely follows the precipitation in the area and the station 12D1 also shows fairly similar relationship. A diversity is exhibited by 2D1 and 3D1 stations. The graph showing the relationship between rainfall and ground water levels (Plate No.XXXV) for the above also indicates a fair degree of mutual dependency (i.e. the plot shows a relationship between the two factors). Prediction of water levels for the stations 1D1, 8S, 1D2 and 12D1 based on rainfall in the preceding months is possible if there are no other factors such as lithology, irrigation effects and evapotranspiration influencing the water levels.

b) <u>Relationship between canal flow, distance of canal and groundwater levels:</u>

The hydrographs (Plate No.XXXIV) indicate that the amount of flow of water in the canal is reflected remarkably in the behaviour of water levels at the two stations 2D1 and 3D1. When there was absolutely no flow in the canal (checked for short periods for purposes of repairs to the canal) the water levels recorded a steep fall. Similarly a minor relation-ship of this nature was observed as far as 12D1 station is concerned.

The above facts establish that wells which are within 50 yards distance from the canal embankment are affected to a great extent by the canal waters. From these observations the effects are easily marked upto a perpendicular distance of more than 2 furlongs from the canal bund.

The graph showing the relationship between the flow in the canal and the water levels at the hydrogeological stations (Plate No.XXXVI) also show a fair degree of dependency of one factor on the other. The correlation factor as worked out from the graph is 0.30. This indicates that for every thousand cusecs increase of water in the canal, the water level in the wells close to canal ~~the water levels in the wells~~ would rise by 0.30 feet. This factor to a large measure enables us to predict the fluctuation in the water table close to the canal, if the amount of water to be allowed into the canal is known.

c) Relationship between lithology and ground water levels:

A close study of the panel diagram (Plate No.XXXVII), prepared for the area, indicates a few important salient features of the sub-surface geology:-

i) The east-west sections of the canal close to Roorkee indicate just north of the town considerable clay deposits within a hundred feet depth.

ii) The sand percentage in the strata, down to a hundred feet depth or so, increases south of the Roorkee town and actually dominates (sand) for more than five miles south of Roorkee (north-south section). The lower clay beds do not ramify but pinch out in this direction (south wards).

The above observation on the lithology of the area does not preclude the possibility of seepage of water through the porous sandy media for fairly long distances from the canal bund. This supports the earlier inference (page 149) that the flow in the canal has an effect on the water levels near station 12D1 which is 393 yards away from the canal.

d) Relationship between temperature, humidity and groundwater levels:

The trend of water levels (Plate No.XXXIV) in the various stations, when compared and studied with temperature and evaporation curves, indicates that there existed no definite relationship between these two meteorological factors on the one hand and the water table fluctuations during the period under study. This study is a primary analysis of annual cycle of observations recorded at different hydrogeological stations. As such any information on lack of general relationship between any two factors is also useful for future studies on the regime. To a small degree, at station 12D1, the hydrograph indicates that the water level decreases as the temperature rises and vice versa except for the cycle in 1963.

e) Relationship between irrigation and ground water levels:

Except for station 18D1, all other stations in the area have no bearing directly to the irrigation fields. The water table fluctuations recorded on this station indicate that during heavy crop period (July - August) the effects of precipitation are not predominantly reflected on the water levels. During the non-crop period or for the period of such crops which do not depend much on water (December to February) the behaviour of the water level has a marked bearing on the precipitation. The trend of water level for the period October, November and the first fortnight of December has a bearing on the amount of flow of water in the canal.

f) Correlation coefficients:

In the preceding pages, the probable relationship, that existed between a few of the factors influencing the ground water regime, have been discussed. The application of the correlation method of statistical analysis of the water level data further facilitates the determinations of exact dependencies between the variables. The correlation between the two variables -- water levels in the preceding and water levels in the following months -- has been attempted as a linear correlation and the same gives a value (page No.141) for the correlation coefficient 'r' as (+0.9877). Since the value being close to unity, the relationship between the two variables, is direct and definite.

It may be further noted that though the predicted water levels for the following month depending on the preceding months are within limits by the application of the above (page No.143) derived factors, the deviation factor obtained (+0.5765) is almost half a foot. This limitation has to be attributed to (i) a less number of observation stations and (ii) single water level measurement in a month, instead of an average of a number of measurements.

Altovsky (55) emphasised the importance of subjecting ground water data to statistical analysis for the rise or fall periods of the water table measured at various hydrogeological stations. In this connection it may be noted that the variables (water levels in the preceding and water levels in the following months) are not dependent on the precipation or any single and uniform overall factor, making a gradual rise or fall to the water levels. Other man made factors such as the control of canal discharge and allied factors also play a role in governing the trends of water level at these stations through out the cycle of observations. As such, it is felt necessary in this case to subject the complete data to the analysis of linear correlation method and establish the positive dependencies.

The magnitude of a dependency amongst the individual factors can be judged from the proximity of the correlation coefficient value to unity. With limited data, (as in this case) two or more dependencies governing the ground water regime at each station can be best evaluated by the application of the second Statistical Correlation Method (Page No.144). From table No.25, it is evident that at stations 1D1, 85, 1D2 the rise/fall of water level is 60 to 80 percent dependent on the rainfall. At stations 2D1 and 3D1, 75 to 85 percent of this rise/fall is dependent on the discharge in the Upper Ganges Canal. Station 12D1 uniquely embraces a good number of factors such as rainfall, canal flow and other meteorological factors. The water table being very shallow at this station and the well being close to an irrigation field, the factor of evapo-transpiration might be having considerable influence on the water levels of the well. In view of this, it would be difficult to evolve a dominant correlation factor for this station. However, the value of 'r' in all the cases mentioned above also indicates that rainfall is not the only factor controlling the water levels. It has established that there are also other factors governing the fluctuations in the water table. The factors besides rainfall influencing the water table near station 1D2 could not be ascertained fully, though it may be reasonable to assume an influence of some seepage from the near by pond (surface water) to the ground water body based on the lithology (sandy horizon).

CONCLUSIONS:

As part of ground water regime studies close to the non-masonry part of the Upper Ganges Canal, South of Roorkee town, six hydrogeological stations have been established. The results of such an analysis are recorded below.

i) The factors - both artificial and meteorological - affecting the ground water table in the area have been discussed individually.

ii) The correlation coefficients for the variables (a) water levels in the preceding and following months (b) Rise/fall of water level versus rainfall and (c) water levels versus canal flow or discharge in the canal, have been derived by applying two statistical methods of linear correlation successfully to ground water data. The method of correlation not only helps in deriving the correlated dependency, but also the basic factor influencing any given element of the ground water regime.

iii) The sub-surface geology of the area has been worked out with the help of the borehole data and represented by a panel diagram. Its role as one of the factors influencing ground water fluctuations has also been discussed.

— ... —

CHAPTER VI:

STUDIES ON THERMOGRAPHS:

THERMOGRAPHS:

Studies on thermographs of ground water and surface water bodies (Canals, Lakes, and Streams) have come into vogue for the last one decade. These studies act as useful tools in the interpretation of selective hydrogeologic regime situations such as recharge conditions close to streams, groundwater velocities, analysis of reverse water level fluctuations and relation between different aquifers.

In the preceding chapter relationship between the ground water fluctuations and meteorological factors and also the effects of artificial factors such as canal flow on the near surface groundwaters have been brought out. Here a further attempt has been made to study the effects of Canal Water temperatures and air temperature on the near surface ground water and relationship of thermal regime to depth of water table and depth of observation stations.

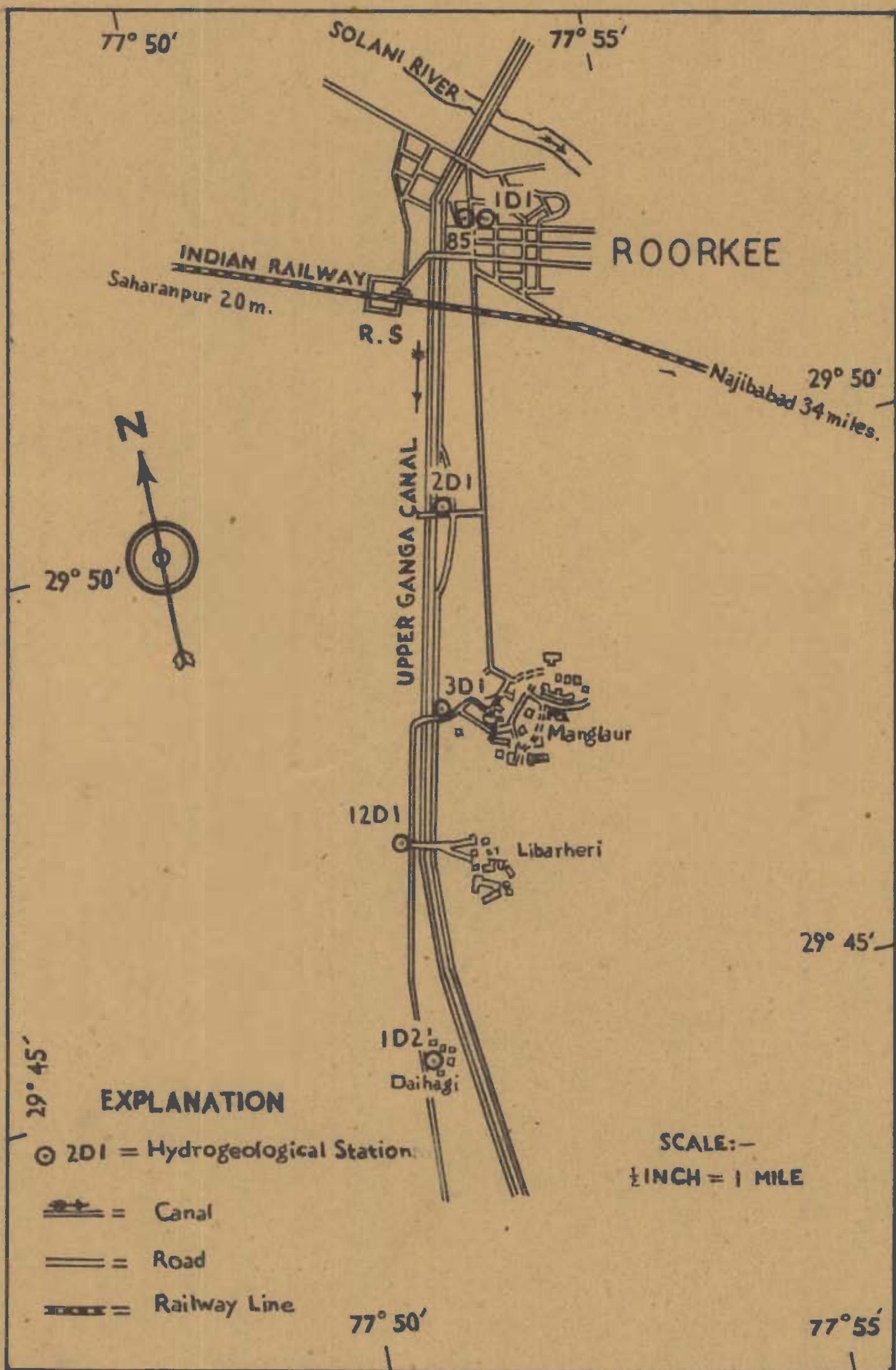
METHODS OF COLLECTION OF DATA:

The canal area falling under the non-masonry part of the Upper Ganges Canal and stretching for about eleven miles south of Roorkee town was chosen for the study (Plate No.XXXVIII). The notation of the stations (1D1, 85, 2D1, 3D1, 12D1 and 1D2) was adopted during the systematic inventory for shallow wells in the area (refer page No.13).

The temperature measurements of canal waters and groundwaters have been noted till July 1961 by the Weksler thermometer and later with a standard British make thermometer. The water level measurements were carried out correct to the

PLATE No XXXVIII

LOCATION MAP OF THE OBSERVATION STATIONS ALONG THE UPPER GANGES CANAL USED FOR THERMAL REGIME STUDY; ROORKEE AREA.



second decimal place with graduated Lufkin steel tapes. Both the measurements have been taken on the same day in the forenoon, preferably in the first week of every month. A few of the open wells, already in existence in the area, were selected as observation stations for recording the water table and temperature measurements. The temperature measurements for the canal water have been carried out at points along the bank of the canal which are at the shortest distance from the observation wells. These data have been collected for a period of four years i.e. since July 1960 to the end of June 1964. For convenience of representing the full yearly cycles, the data for January 1961 through December 1963 were utilised wherever it was felt necessary.

The meteorological data have been obtained from the meteorological station located in the Central Building Research Institute, Roorkee and the air temperature data have been recorded daily at 08:30 and 17:30 hrs. The area under study being close to Roorkee Meteorological station, it is justified to utilise this meteorological data for the interpretation of thermographs.

AIR AND CANAL WATER TEMPERATURES:

During the course of the collection of these data, the temperature at the individual stations was also recorded generally between 10.00 and 13.00 hrs. on the day of observation. In view of this, the mean of 08:30 and 17:30 hrs. temperatures have been used for bringing out the air thermographs. Based on the daily average, the mean monthly and annual temperatures are computed and are recorded in Table Nos. 26 and 27 given below. The maxima and minima in air temperatures and the difference in the two for each year are also recorded in Table No. 30 (page No. 170)

TABLE NO.26.

DATA ON AIR, CANAL AND GROUNDWATER TEMPERATURES (°C) ROORKEE AREA:

	Date of Measurement/month and year / Stations	July 1.7.60 (1960)	Aug. 4.8.60 (1960)	Sept. 4.9.60 (1960)	Oct. 1.10.60 (1960)	Nov. 3.11.60 (1960)	Dec. 3.12.60 (1960)	Jan. 16.1.61 (1961)	Feb. 8.2.61 (1961)	March 6.3.61 (1961)	April 1.4.61 (1961)	May 4.5.61 (1961)	June 1.6.61 (1961)
	1	2	3	4	5	6	7	8	9	10	11	12	13
Air Temp.	At 08:00 hrs	32.4	29.0	28.0	26.1	17.3	8.3	6.7	6.2	16.4	20.8	29.7	32.9
	At 17:30 hrs	38.3	28.6	32.0	31.3	26.8	20.5	20.5	14.0	26.6	25.9	39.1	42.0
	Average of 08:00 and 17:30 hrs.	35.35	28.8	30.0	28.7	22.0	14.4	13.6	10.1	21.5	23.3	34.4	37.4
Canal Temp.	At perpendicular point to 1D1 and 85	23.0	20.0	21.8	20.15	N.F.	13.0	13.0	12.2	17.5	20.7	20.5	20.7
	At perpendicular point to 1D2	22.2	20.2	22.5	20.8	N.F.	13.9	13.1	13.1	18.5	21.2	21.4	20.75
Obs. Station	1D1	24.6	24.4	24.4	24.0	22.0	19.5	17.8	18.3	20.0	21.1	23.1	23.6
	85	SNE	SNE	24.8	23.6	18.7	17.5	16.1	16.6	17.8	19.2	21.4	22.8
	2D1	27.5	27.0	26.1	25.0	22.2	19.5	18.3	18.3	18.3	19.1	21.4	23.6
	3D1	24.4	24.0	23.6	23.5	20.75	18.3	17.6	17.5	17.9	18.3	19.5	21.85
	12D1	26.9	25.4	26.1	25.7	21.4	17.5	15.0	15.25	17.0	19.6	21.4	23.6
	1D2	25.6	26.5	26.1	25.0	22.2	21.2	17.5	17.0	17.5	19.1	21.5	23.1

Note:- N.F. Stands for 'Not Flowing'
SNE Stands for 'Station not Established'.

			1961					1962				
July 6.7.61	August 5.8.61	September 5.9.61	October 7.10.61	November 6.11.61	December 5.12.61	January 3.1.62	February 6.2.62	March 1-3-62	April 3.4.62	May 8.5.62	June 12-6-62	July 16-7.62
14	15	16	17	18	19	20	21	22	23	24	25	26
28.4	27.5	28.2	25.3	16.6	7.1	5.1	11.3	13.4	17.3	25.4	26.5	24.4
33.9	32.5	30.9	27.8	22.8	18.8	17.7	20.9	24.3	29.5	34.0	32.8	30.0
33.1	30.0	29.5	26.5	19.7	12.9	11.4	16.1	18.8	23.9	29.7	29.6	27.2
19.1	20.5	21.7	20.0	16.9	13.3	11.9	14.7	16.6	19.0	19.5	20.0	23.0
20.5	22.2	22.8	21.1	17.2(?)	13.9	12.2	15.5	16.6	19.0	19.5	19.0	-
24.4	24.4	25.0	24.4	21.7	18.8	17.7	19.1	20.0	21.5	22.5	23.5	24.0
24.4	24.4	25.5	23.9	20.5	17.2	15.5	17.2	18.8	19.0	21.0	23.0	24.0
27.3	27.2	27.2	25.0	22.2	20.0	18.55	18.8	19.7	19.5	22.75	24.75	26.5
22.4	24.4	24.4	24.4	20.5	18.8	17.7	18.3	18.8	18.25	21.0	23.0	24.5
27.7	28.3	28.8	25.5	21.1	17.2	15.25	16.1	17.7	18.5	22.25	25.0	28.0
26.1	27.7	28.8	25.0	21.7	19.4	16.9	18.3	18.8	20.5	23.0	24.0	26.0

1962					1963						
August 13.8.62	September 6.9.62	October 4.10.62	November 13.11.62	December 10.12.62	January 3.1.63	February 6.2.63	March 13.3.63	April 4.4.63	May 2.5.63	June 3.6.63	July 3.7.63
27	28	29	30	31	32	33	34	35	36	37	38
28.0	28.7	24.2	15.1	8.1	4.4	10.5	13.5	20.0	28.9	33.4	31.5
33.9	33.7	30.8	25.1	18.4	17.3	24.5	25.3	30.1	35.4	39.5	36.2
30.9	31.2	27.5	20.1	13.2	10.8	17.5	19.4	25.0	32.1	36.4	33.8
20.25	20.5	20.25	16.0	14.0	12.0	15.0	15.0	19.0	21.0	20.0	19.5
--------- Not taken ------------------------ (Taken only at perpendicular point to 1D1/85 and 12D1)					-	-	-	19.0	21.0	21.0	20.0
24.75	24.5	23.5	20.5	18.21	18.0	17.50	19.0	21.0	22.5	24.0	23.5
24.5	24.75	22.5	19.5	17.0	16.0	17.5	18.0	20.0	21.0	23.0	24.0
26.5	26.0	24.5	21.5	19.5	19.0	18.0	18.5	19.5	21.2	26.0	27.0
23.75	24.0	22.5	19.25	18.0	18.0	17.5	17.5	18.5	20.0	24.0	23.0
27.0	28.0	25.5	20.0	17.0	16.0	16.0	16.5	18.5	22.0	28.0	29.0
27.0	26.5	25.0	21.0	18.75	18.0	18.0	19.0	20.0	22.3	26.0	25.5

1963						1964				
August 1-8-63	Sept. 4.9.63	October 1-10-63	November 2-11-63	December 2-12-63	January 3.1.64	February 1-2-64	March 2.3.64	April 6.4.64	May 2-5-64	June 5-6-64
39	40	41	42	43	44	45	46	47	48	49
27.3	25.4	25.1	18.5	11.7	9.0	3.2	13.9	23.9	27.8	31.0
32.7	27.3	32,3	28.5	23.4	21.2	20.2	28.4	35.3	41.1	41.2
30.0	26.3	28.7	23.5	17.5	15.1	11.7	21.1	29.6	34.4	36.1
18.5	20.0	20.5	-	16.0	13.0	11.0	16.0	19.5	20.0	22.5
19.0	20.5	21.0	-	16.5	13.5	12.0	16.5	20.0	20.5	23.0
24.5	24.5	23.5	22.0	20.0	18.0	16.0	18.0	20.5	22.0	24.0
24.5	24.0	22.5	21.0	19.0	17.0	14.0	17.0	19.5	21.0	23.0
27.0	26.0	24.0	23.0	21.0	19.0	17.0	18.0	20.0	21.5	24.5
25.0	24.0	23.0	21.0	19.5	18.5	16.5	18.0	19.0	20.0	23.0
28.0	26.0	24.5	22.0	19.5	16.5	14.0	16.0	20.5	21.0	24.0
28.0	26.0	24.5	22.5	21.0	19.5	17.0	19.5	22.0	23.0	25.0

TABLE NO.27.

DATA ON MEAN MONTHLY AND ANNUAL AIR TEMPERATURES ROORKEE AREA:

Month/Year	Mean Monthly Temperature (Average of 08:30 and 17:30 hrs) °C	Mean Annual Temperature °C
1	2	3
1960		
July	28.3	
August	27.8	
September	29.4	
October	25.2	
November	18.5	
December	14.7	
1961		
January	14.1	
February	15.0	
March	22.5	
April	29.1	
May	33.4	
June	33.7	
July	29.6	
August	28.5	
September	29.5	
October	25.0	
November	18.1	
December	11.8	24.1
1962		
January	11.6	
February	17.1	
March	21.6	
April	30.2	
May	34.2	
June	34.2	
July	31.4	
August	29.2	
September	27.8	
October	24.9	
November	18.5	
December	13.7	24.3

1	2	3
1963		
January	12.2	
February	17.5	
March	22.0	
April	29.1	
May	32.6	
June	32.7	
July	30.9	
August	28.7	
September	28.1	
October	27.0	
November	21.0	
December	16.2	24.8
1964		
January	13.1	
February	17.8	
March	25.1	
April	31.0	
May	31.3	
June	34.9	

The air thermographs are brought out in three categories. In the first, the average air temperature recorded on the date of ground water temperature measurement is plotted along with the canal and groundwater temperature data (Plate Nos.XXXIX A and B). Secondly, the mean monthly air temperature curve is also drawn and shown in a similar manner. Thirdly the mean annual air temperature graph has been studied in relation to mean annual groundwater temperatures of selective stations (Fig. No.XL). Similarly, the canal water temperatures have also been obtained at the time of collection of the ground water temperatures (Table No.26). These have been plotted as surface water body thermographs alongwith the groundwater thermographs (Plate Nos. XXXIX A and B). The difference in the maxima and the minima of the canal water temperature year wise is noted in Table No.30 (Page 170).

DATA ON GROUNDWATER REGIME:

Temperature deviations in an area depend on many factors. In such studies, it is also essential to record the data related to the water table depths, depth of the observation points, the maxima and minima of the ground water temperatures and allied factors. These might have some bearing on the temperature regime too. The data for the individual stations have been recorded in Table Nos. 28 to 30 given below:

TABLE No.28.

DETAILS OF OBSERVATION STATIONS USED FOR THERMAL REGIME STUDIES IN ROORKEE AREA:

Station	Location	Distance from canal	Depth of the well below land surface	Diameter	Use	Approx. depth to water below the canal bund.	REMARKS
1	2	3	4	5	6	7	8
1D1	In the compound of Sri Kedar's building, on the Highway Delhi-Dehradun at M/S 104.	618 Yds.	32.75'	6.45'	Gardening.	14'	Not in very heavy use.
2D1(i)	In the compound of the Inspection Bungalow (canals)	48 Yds.	22.15'	5.00'	Not in use	2' from east point 1' from west point	Station set in between the main canal and the diversion channel.
(ii)	2 furlongs east of M/S 101 on Delhi-Dehra Dun Road.	205 Yds. west point					
3D1	100' in N 60°E direction from western end of Manglaur (29° 47'30"; 77°52'30") across U.G. Canal.	25 Yds.	15.00'	3.00'	Not in use	13'	Station set very close to the canal.

1	2	3	4	5	6	7	8
12D1	NW.quadrant of the road junction at M/S 97 on Delhi-Dehra Dun Road.	393 Yds.	8.52'	4.90'	Domestic	7'	Station set close to the irrigation field, not in heavy use.
1D2	150' NE. of road mile 95/2 on Delhi-Dehra Dun road	712 Yds.	21.78'	4.45'	Domestic	6'	Station close to a pool of water during rainy season only.
85	In the compound of British Insulated Cable Co.,Roorkee	310 Yds.	25.00'	9.00'	Gardening	14'	Not in very heavy use.

TABLE NO.29:

DEPTH OF WATER LEVEL DATA FOR THE OBSERVATION STATIONS USED FOR THERMAL REGIME STUDIES IN ROORKEE AREA:

Note:- Depth to Water Level given in feet below Land Surface.

Year	1960						1961			
Station	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April
1	2	3	4	5	6	7	8	9	10	11
1D1	27.87	26.70	26.50	26.63	27.20	27.40	27.50	27.49	27.60	27.77
85	Station not established		17.78	18.02	18.70	19.14	18.94	18.77	18.77	18.94
2D1	6.65	7.15	7.65	7.40	12.15	8.35	8.40	8.59	8.16	8.38
3D1	8.83	9.30	9.75	9.00	14.42	9.90	10.45	10.62	10.37	10.54
12D1	1.78	1.35	1.70	1.00	2.90	2.10	1.95	0.41	2.04	2.40
1D2	6.82	2.85	2.60	2.54	4.88	-	5.90	4.23	6.10	6.51

1961									1962	
May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March
12	13	14	15	16	17	18	19	20	21	22
28.20	28.54	28.77	27.94	26.43	26.50	26.80	27.10	27.03	26.85	26.90
19.11	19.30	19.30	18.33	17.38	18.15	18.88	18.79	18.25	18.10	18.24
7.35	6.24	6.65	5.49	7.64	8.10	12.10	8.33	7.74	8.25	8.59
9.18	8.80	9.05	8.77	10.24	9.65	13.30	9.50	9.45	10.17	10.83
2.42	2.10	1.10	0.19	1.04	1.90	2.84	1.93	1.69	1.16	1.87
6.53	6.50	6.40	0.99	1.84	2.95	4.40	5.53	5.38	4.05	5.64

1962									1963				
April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May
23	24	25	26	27	28	29	30	31	32	33	34	35	36
27.26	27.75	28.33	28.55	28.08	27.96	27.75	28.22	28.22	28.13	28.39	28.62	28.83	29.28
18.38	18.95	19.10	18.00	19.04	18.96	18.96	19.45	19.00	18.95	19.80	19.63	19.80	20.12
7.53	6.44	6.30	5.85	7.00	8.06	8.84	8.71	7.38	8.08	8.60	7.80	8.28	7.70
9.36	8.90	8.75	8.25	8.84	9.60	10.69	10.06	9.22	9.85	10.89	9.99	10.58	9.80
2.52	3.46	2.06	0.19	1.25	1.25	1.54	2.08	1.54	1.75	1.95	2.43	2.82	2.48
6.71	7.04	5.74	3.90	2.45	2.15	3.89	5.04	4.53	5.15	5.51	6.13	6.30	6.30

1963							1964					
June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June
37	38	39	40	41	42	43	44	45	46	47	48	49
29.70	29.47	29.70	28.50	26.76	27.20	27.63	27.34	27.90	28.13	28.70	29.24	30.01
20.33	20.30	19.75	18.55	17.99	17.72	19.64	18.98	19.05	19.45	19.73	20.05	20.46
6.83	7.13	6.39	6.85	8.53	10.39	7.03	6.90	7.54	7.70	7.45	6.68	6.80
9.46	10.00	8.19	9.70	10.60	12.95	9.24	9.45	10.65	10.80	10.35	8.85	8.61
2.55	1.65	0.43	0.20	1.58	2.33	1.85	1.65	1.90	2.10	2.85	2.16	2.18
7.20	6.15	1.79	0.47	2.10	4.16	5.20	4.85	5.13	4.53	5.80	6.30	6.69

TABLE NO.30.

DATA ON MAXIMA AND MINIMA OF AIR, CANAL AND GROUNDWATER TEMPERATURES AND AVERAGE WATER LEVELS IN ROORKEE AREA:

Well No.	1961			1962			1963		
	Max.Temp. (0°C)	Min.Temp. (0°C)	Diff.Bet. Max & Min. Temp.(0°C)	Max.Temp. (0°C)	Min.Temp. (0°C)	Diff.Bet. Max & Min. Temp.(0°C)	Max. Temp. (0°C)	Min.Temp. (0°C)	Diff.Bet. Max & Min Temp.(0°C)
1	2	3	4	5	6	7	8	9	10
1D1	25.0 (5.9.61)	17.7 (30.12.61)	7.3	24.8 (13.8.62)	17.7 (3.1.62)	7.1	24.5 (1.8.63)	17.5 (6.2.63)	7.0
85	25.6 (5.9.61)	15.7 (30.12.61)	9.9	24.8 (6.9.62)	15.5 (3.1.62)	9.3	24.5 (1.8.63)	16.0 (3.1.63)	8.5
2D1	27.3 (6.7.61)	18.3 (16.1.61 & 6.3.61)	9.0	26.5 (9.7.62 & 13.8.62)	18.5 (3.1.62)	8.0	27.0 (3.7.63)	18.0 (6.2.63)	9.0
3D1	24.4 (6.8.61 & 6.10.61)	17.6 (8.2.61)	6.8	24.4 (9.7.62)	17.7 (3.1.62)	6.7	25.0 (1.8.63)	17.5 (6.2.63)	7.5
12D1	28.4 (6.9.61)	15.0 (16.10.61)	13.8	28.0 (10.7.62 & 6.9.62)	15.2 (3.1.62)	12.8	29.0 (3.7.63)	16.0 (3.1.63)	13.0
1D2	28.8 (1.6.61)	17.0	11.8	27.0	16.9	10.1	28.0 (1.8.63)	18.0 (3.1.63)	10.0
Air Temp. (0°C) Aver. of record at 08:30 & 17:30 hrs.	37.4 (1.6.61)	10.1 (8.2.61)	27.3	31.2 (6.9.62)	10.6 (3.1.62)	20.6	36.4 (3.6.63)	10.8 (3.1.63)	25.6
Canal Temp.	21.7	11.9	9.8	23.0	11.9	11.10	21.0 (2.5.63)	12.0 (3.1.63)	9.0

Average of Diff. Bet. Max.& Min.Temp.(0°C) 1961-62-63.	Average water level 1961 (in ft.)	Average water level 1962 (in ft.)	Average water level 1963 (in ft.)	Average Water Level 1961-62-63 (in feet).	Depth of station below land surface (in feet)	Mid point of water column (average of 15 and 16)	Remarks.
11	12	13	14	15	16	17	18
7.13	29.22	27.74	28.52	28.49	32.75	30.62	
9.23	18.72	18.70	19.36	18.93	24.00	21.46	
8.66	7.95	7.55	7.80	7.77	22.15	14.96	
7.00	10.04	9.51	10.10	9.88	15.00	12.44	
13.20	1.69	1.72	1.83	1.75	8.52	5.13	
10.63	4.82	4.63	4.70	4.72	21.78	13.25	
24.50	-	-	-	-	-	-	
9.96	-	-	-	-	-	-	

The depth to water values for individual stations have been averaged for the year 1961, 1962 and 1963 and similarly the difference between the maximum and minimum ground water temperature (magnitude of variation in temperature) for the same period has also been averaged. These data have been further utilised to demonstrate through graphical representations the relationship between the various factors.

DISCUSSION:

According to Todd,(34a) temperature is one of the most conservative properties of ground water. Probably, because of this, there are very few references available related to ground waters in the field of thermometry. A few of the applications of this science to ground water hydrology are enumerated below with a view to figure out the difference between the present study and the earlier ones.

In 1956, Rorabaugh(33a) while working in Kentucky (USA) has established through the temperature measurements the recharge conditions from the surface streams to the ground water body under pumping conditions.

Stallman(58) determined the velocity of ground water or the permeability of an aquifer by using the finite difference approximations of the differential equation relating to the head and temperature in an aquifer. He further showed that the temperature data could also provide a means for these determinations. These studies would be of great help in places where facilities needed in other methods of determining the hydraulic constants are not available.

By resorting to the temperature measurements recorded through a thermistor in a well in the city of Easton in Talbot country, Maryland (USA), Andreasen (59) demonstrated that the reverse water level fluctuations observed in the region are more related to the mechanical forces developed due to pumping on the confined aquifers rather than to temperature.

In a study of natural groundwater recharge in Minnesota (USA) a close relationship was observed by Schneider (73b) between air temperatures and ground water levels in the winter and spring under permafrost conditions.

Here, the main purpose of the present study is to segregate the individual factors which influence or govern the magnitude of variation of groundwater temperatures. Writing on the 'methods of study of under ground water temperature' Konoplyantsev (55) states that the temperature of underground waters and its chronological variations depend upon a number of factors -- climate, terrestrial heat, chemical and biochemical processes, percolating atmospheric precipitates, surface streams, filtration properties of the rock, velocity of the underground flow, fluctuations in water level, the economic activities of man, and a number of other factors. Further he adds that the establishment of types of thermal regimes for free ground waters is difficult.

It may be noted that in the present area, the chief factors taken into consideration are the climate, surface water bodies and the water levels. The thermal regime is studied under free groundwater conditions only.

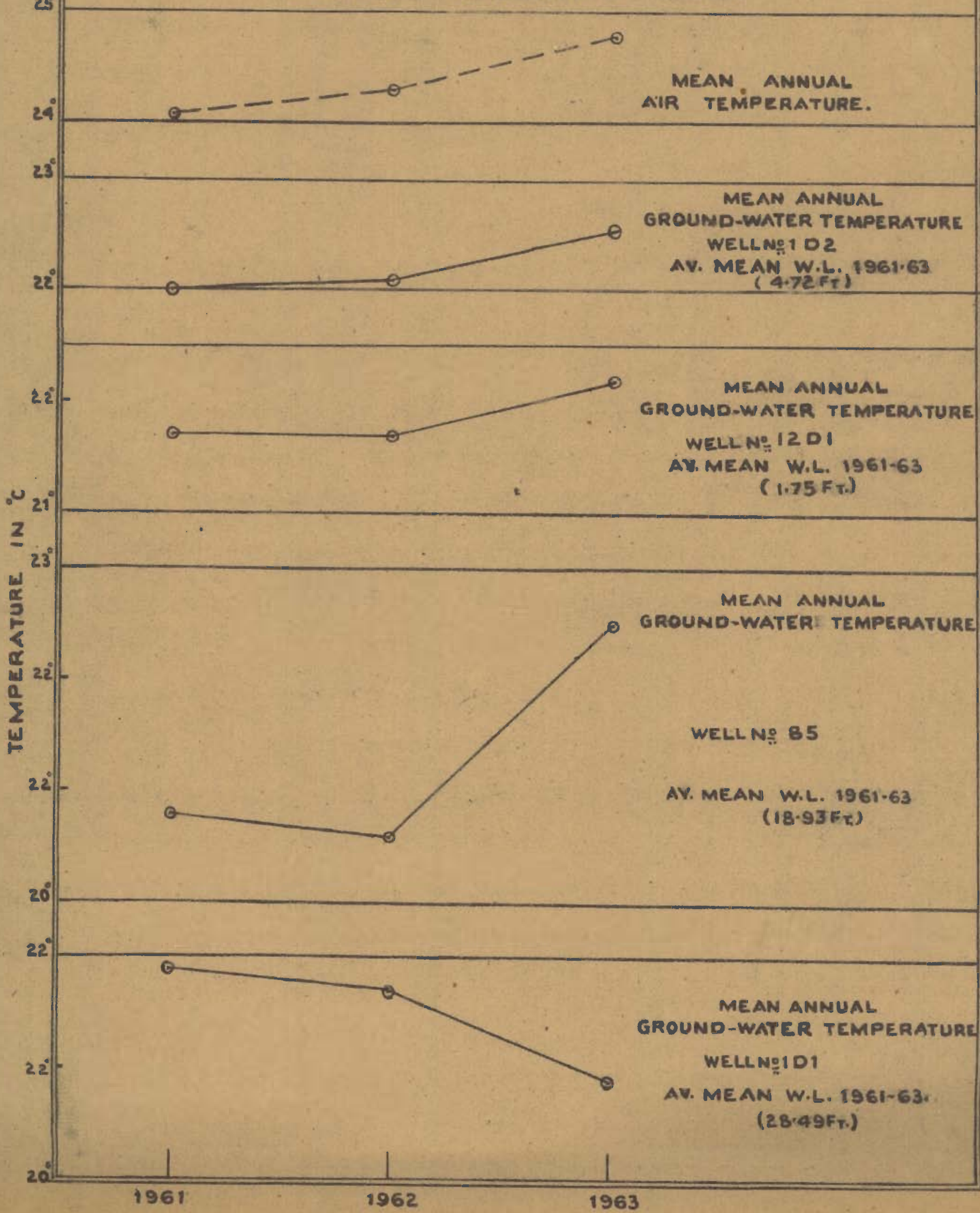
Since it has been established elsewhere (73 and 34a) that groundwater temperatures at very shallow depths follow closely the mean annual temperature, an attempt has been made to study this relationship from the daily, monthly and annual thermographs of air temperatures in the area and the near surface ground water temperatures (Plates Nos. XXXIX A,B and XL).

a) AIR TEMPERATURE VERSUS GROUND WATER AND CANAL TEMPERATURES

As is evident from Plate Nos XXXIX A & B, the thermographs (air and ground water) indicate a lack of general similarity in their trends at six stations. The lag effect between the maximum air temperature and that of ground water temperature is not systematic. Though the air temperature peaks are maintained in May-June for all the years under study, the ground water temperature peaks appear earlier in July-August 1963 which is a slight departure from the usual period of August-September (1961-and 1962). From the trend of the curves it may be said that the same phenomenon as noted in 1963 may repeat for the groundwater peak temperatures during 1964. The minimum temperature lag effect between air and ground water temperatures works out differently for the mean monthly and daily air thermographs. The former indicates either a coincidence with the minimum ground water temperature or precedes the same. In the latter case it coincides or follows the minimum temperature of the groundwaters. During the year 1963 it preceded the ground water temperatures. It may further be noted that the mean monthly air thermograph nullifies the prominent high temperature peaks shown usually in the August-September periods of the daily air temperature hydrograph. Further from graph (Plate No.XL) it can be inferred that the mean annual ground water temperatures at very shallow depths (within 5 feet below land surface) follow closely the mean annual air temperatures but this relationship gets disturbed as the depth to water level increases by fifteen feet or more.

The air temperature graphs when compared with the surface water body (Upper Ganges Canal) temperature curve also fails to

RELATIONSHIP BETWEEN MEAN ANNUAL AIR TEMPERATURE AND MEAN ANNUAL GROUNDWATER TEMPERATURE AT THE SHALLOW WELLS, ROORKEE AREA



bring out any significant relationship between the two -- the high air temperature peaks during May to July period are reversed in the surface water body themmograph.

b) CANAL TEMPERATURE VERSUS GROUND WATER TEMPERATURE:

The canal water thermograph, in comparision to the ground water thermograph reveals that the surface water body temperature is significantly lower than that of the ground water temperature recorded at any one of the observation stations in the area. For a short period in the spring season (March-April), the graph shows a higher temperature than many of the ground water temperatures observed at the stations through all years of record. A similar feature has been noticed when the canal water thermograph is compared with the air temperature for the coldest period of the year (December to February) except for 1964. These phenomena are difficult to explain at this stage of the study. However, it may be considered that seasonal changes especially at the transition periods introduce rapid climatic variations whose immediate effects are more pronounced on the surface water body than on the ground water body. The small but prominent peaks in the canal water thermographs during July-October period of the year represent the effects of rainfed water on the temperature of the surface water body. This is due to the fact that the canal at at its higher reaches receives directly part of the hill stream discharges too. The prominence and distribution of the peak on the thermograph depends on the spread of the monsoon season each year in the area.

A significant feature of the thermograph, is the low temperature (20-24°C) range recorded by the canal water during the peak summer months (May-June) in the area, especially when viewed in comparision with the higher peaks of air temperature during that period. The reason for this is attributed to the thawing of ice in the source region of the river Ganges which feeds the Upper Ganges Canal.

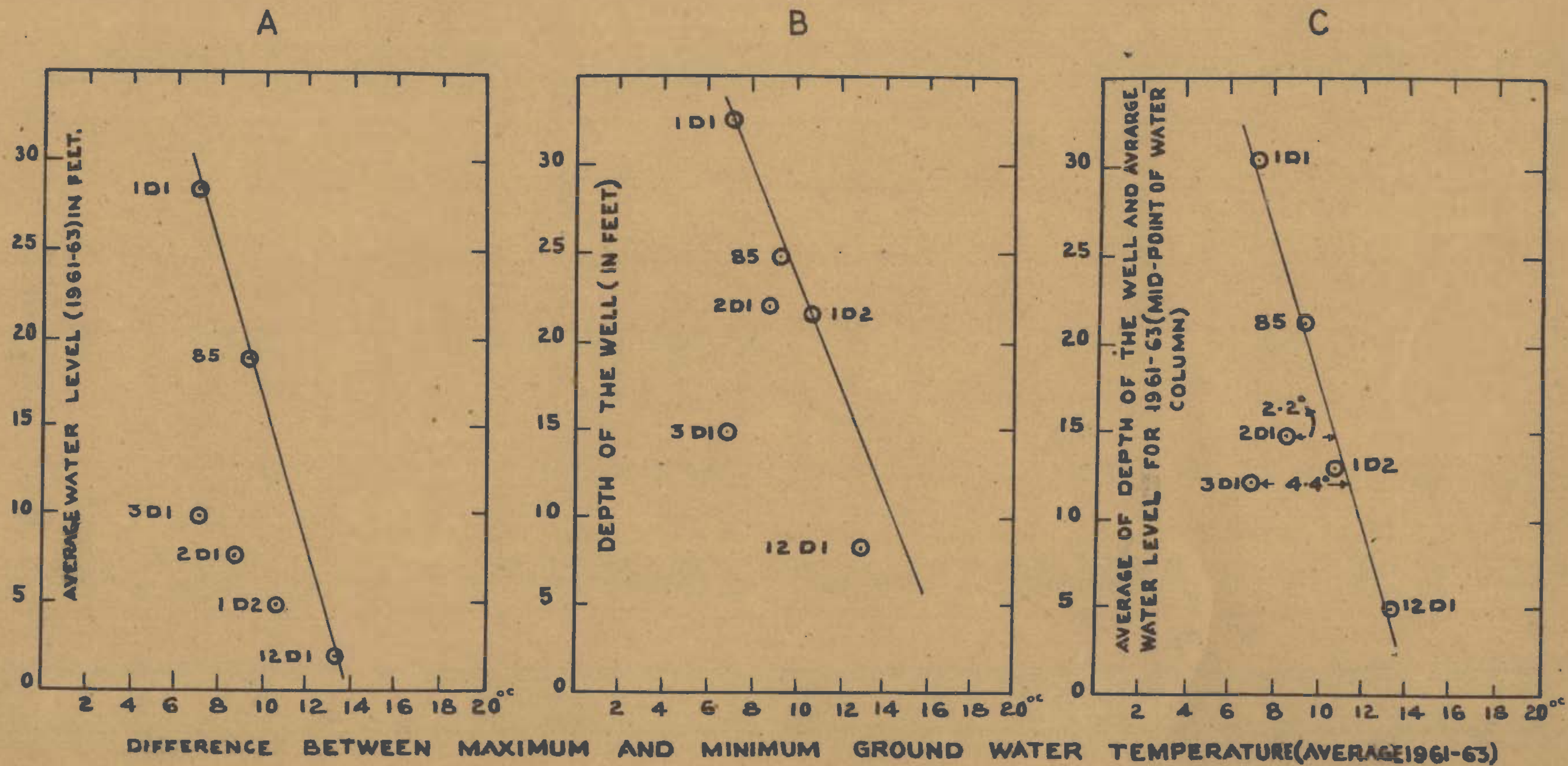
While reviewing the use of temperature fluctuations as a tool for studying the elements of the hydrologic cycle involving groundwater, an example of the comparative study of the thermographs for the wells close to Ukabana lake alongwith air thermograph has been given in one of the articles of Johnston Drillers Journal (1962).[40] An inspection of the graphs indicates substantial differences for each well when compared with the air thermograph; the fluctuations have been correlated to other factors such as induced lake water to ground water body, confined nature of the aquifers, rate of groundwater movement etc. The temperature data from various sources such as Clinton, Louisville, Schenectady in USA as presented by Schneider[73] in the shape of thermographs, show the range in the low temperature cycle of ground water in relation to the corresponding low and high temperature cycle of the surface waters. These studies indicate that it is extremely difficult to segregate the amount of temperature change which is caused by each factor. In the present study, from the above discussions, it is evident that no uniform relationship exists between air/or canal temperatures and ground water temperatures in the area. Prof. Todd in his book on "Groundwater Hydrology" has observed that the ground water temperatures at shallow depths follow closely the mean annual air temperature. Under the present study, the mean annual air temperature data have been studied against mean annual air temperatures for only 4 years duration. This study confirms the observations made elsewhere. The relationship holds good for the ground water temperatures recorded within 5 feet depth below land surface. The same gets disturbed as the depth of water level increases beyond 15 feet. However, it would be interesting to study the relationship between annual ground water temperature (computed from daily observations round the year at all the stations) and the mean annual air temperature in the area for longer periods of observation.

c) DEPTH TO WATER TABLE AND DEPTH OF STATION VERSUS MAGNITUDE OF VARIATION IN TEMPERATURE OF GROUNDWATER:

The depth of the well relationship to that of the ground water temperatures was studied by drawing out a graph with average water level (1961-63) on the ordinate and magnitude of variation in temperature (1961-63) on the abscissa (Plate No.XL1-A). From the plot it is inferred that some relationship exists between depth to water table and magnitude of variation in the temperature of 1D1, 85 and 12D1 study points. Only the station 1D2 falls slightly away on the graph and the relationship of 2D1 and 3D1 are due to their proximity and hydrological connect -ion with the surface water body (Chapter V, page 126). It is also evident from the graph that apart from depth to water table factor there are also other dominant factors which are responsible for temperature variations of ground water in the region. To evaluate this a graph showing the relationship between depth of the observation station and difference in maximum and minimum ground water temperatures (Plate No.XLII-B) is drawn. From a study of this plot it is also established that the importance of depth of observation station is an effective factor governing ground water temperatures at individual stations. But 12D1 station which fits into the earlier plot is out from this relationship.

The above deviations and the observations help to infer the individual factors which influence the magnitude of ground water temperature in the area. They are (i) Depth to water table (ii) Depth of the observation station and (iii) Canal water influx on near surface ground water and its consequent effect on the temperature of the latter. The dependence of ground water temperature on the first and second factors, leads to the inference that the existing water column at the individual observation stations has some bearing on the magnitude of ground water temperature fluctuation in the region. To decipher this, the temperature variation is studied against the average of depth to water table and depth of the station by graphical methods (Plate No.XLII-C). This additional factor also represents the mid-point of the water column. The deviations of 1D2 and 12D1 noted in the earlier graphical representations have been nullified in the last plot thereby demonstrating a linear relationship between the average of depth of station and depth to water table (average) and the difference of maximum and minimum ground water temperature (average). The plot also signifies that the greater is the depth of the observation station the lesser is the magnitude of difference in the maximum and minimum temperature. Stations 2D1 and 3D1 are an exception to the above conclusion as these are influenced by the canal water influx. But a note-worthy feature is the position of the above stations (on the graph) in between 85 and 1D2 and 12D1 and 1D2 respectively. This signifies that, but for the influx of extraneous lower temperature water source on ground water, the wells would have followed the linear trend exhibited by the rest of the stations in the region. Apart from the above, the magnitude of their

GRAPH SHOWING THE RELATIONSHIP BETWEEN WATER LEVEL, DEPTH OF THE WELL AND MID-POINT OF WATER COLUMN VERSUS DIFFERENCE BETWEEN MAXIMUM AND MINIMUM GROUND WATER TEMPERATURE (AVERAGE 1961-63) ROORKEE AREA.



deviation from the general trend (slope of the line) follows an inverse relationship to the distance of the station to the canal--the distance of 3D1 being almost half (25 yds) that of 2D1 (40 yds) from the canal, the magnitude of deviation from the general trend is recorded as double (4.4°C for 3D1 and 2.5°C for 2D1).

CONCLUSIONS:

The study of the temperature fluctuations of near surface ground water along Upper Ganges canal in Roorkee area has established a linear relationship between the average of depth to water table and depth of the station (mid-point of the water column) and magnitude of difference in the maximum and minimum ground water temperatures. Deviation from this relationship is noted for stations situated close to the canal. This anemoly is interpreted as a result of the influx of canal water into near surface groundwater. The magnitude of such deviation from the general relationship is inversely related to the distance of the station to the surface water body. The trends of canal water and air thermographs in comparison to the ground water thermographs indicate no noteworthy and uniform relationship between the two. It has also been established that the mean annual ground water temperatures at very shallow depths (within 5 feet from land surface) follow closely the mean annual air temperatures. The significantly low temperature of canal water during summers is attributed to the thawing of ice in the source region of the streams which feed the Upper Ganges Canal. These studies have been attempted almost for the first time and need to be projected in other settings close to the Upper Ganges Canal and other canal systems in the Indo-Gangetic plain.

--- ... ---

CHAPTER VII:

QUALITY OF GROUND WATERS:

INTRODUCTION:

Of late, ground water studies aimed mainly towards establishment of sub-surface water resources are considered unimportant unless chemical quality of the waters is assured to be satisfactory. In view of this, geochemistry of ground waters has to be studied with special reference to the need for which the water is put to maximum use in any region. In the present area of study, the chemical nature of natural waters are studied with reference to their use mainly for irrigational purposes. The subject under consideration is treated under two heads namely, (i) shallow ground water chemistry and (ii) chemical quality of deep confined ground waters. This is all the more necessary as there are some chances for changes in the chemical quality of waters in the water table reservoirs due to free movement, circulation and flushing of ground waters and equally in the confined under ground reservoirs where movement of water is usually very slow and there is enough time for chemical reactions between the water and the rocky/or unconsolidated alluvial sediments. As such, the investigations on the quality of water constitute an important phase of the integrated water resources evaluation attempted for the area.

SAMPLING OF WATERS:

The shallow ground waters in the area have been sampled from the open wells during the summer months of 1963. During this season, addition to ground water from extraneous sources (recharge) will be limited. Water samples from the confined ground waters have been collected during the winter months of 1964. Water samples have been collected from the tubewells directly from the discharge pipe while they are being run for watering the irrigation fields. Nearly 163 water samples have been collected from the shallow ground water reservoir, and 16 samples from the deep confined aquifer. The samples from the confined aquifers are chosen in such a manner that they represent the entire well field area. The samples from the former source are analysed partially (i.e. for a few important radicals) and all the samples from the latter source are subjected to complete chemical analysis (determination of more number of radicals than in the partial analysis). The quality maps practically cover the data regarding partial analyses of the waters and the analytical results pertaining to the confined aquifers are given in Table No. 32.

MODE OF DATA PRESENTATION:

Since standard works on the subject are available (36,61,62) detailed description of laboratory procedures are omitted. Over years, a good number of units have been used for reporting the water analyses. Water composition is commonly expressed in two systems, (i) in terms of dissolved matter and weight of solution and (ii) in terms of weights per unit volume. Under the first category one part per million represents 1 milligram of solute in 1 kilogram of solution. For the second, this conversion is made by assuming that one litre of the water used weighs 1 kilogram.

For purposes of the present study the first method has been used extensively.

GROUNDWATER QUALITY IN SHALLOW AQUIFERS:

i) AREAL STUDY OF WATER QUALITY:

The chemical quality of the water samples collected from an area of 250 sq. miles has been shown on the map, by drawing the contours of equal concentration of sulphates, bicarbonates and chlorides (Plate Nos. XLII, XLIII and XLIV). The areal distribution of the water of various kinds can be inferred in a general way. Since many of the open wells in the area end in the shallow reservoir, these maps represent more for the chemical changes in the reservoir. The following inferences emerge from a study of the quality maps.

a) The formation waters associated with the shallow groundwater reservoir are chemically a bicarbonate type; Bicarbonate varies from 30-780 ppm but usually is of the order of 100-300 ppm.

b) Sulphate content in general is low; it varies from 18-140 ppm but usually lies within the limits of 20-25 ppm; similarly, the chlorides also vary from 5-480 ppm and usually lies within the range of 10-60 ppm.

c) High salt concentrations are recorded generally in the Northeast and South-western parts of the area.

d) The last feature may be attributed to the fact that flat hydraulic gradients in the south-western part inhibit frequent and vigorous flushing of ground waters and as such help longer contact with the formations and concentration of salts. But in the north-eastern part, keeping in view the fact that the drainage is effluent and the hydraulic gradients in the shallow

PLATE No XLII

MAP SHOWING DISTRIBUTION OF CHLORIDE IN THE SHALLOW GROUND WATERS IN ROORKEE AREA (SUMMER 1963)

0 1 2 3 4 5 6 7 8 KILOMETRES

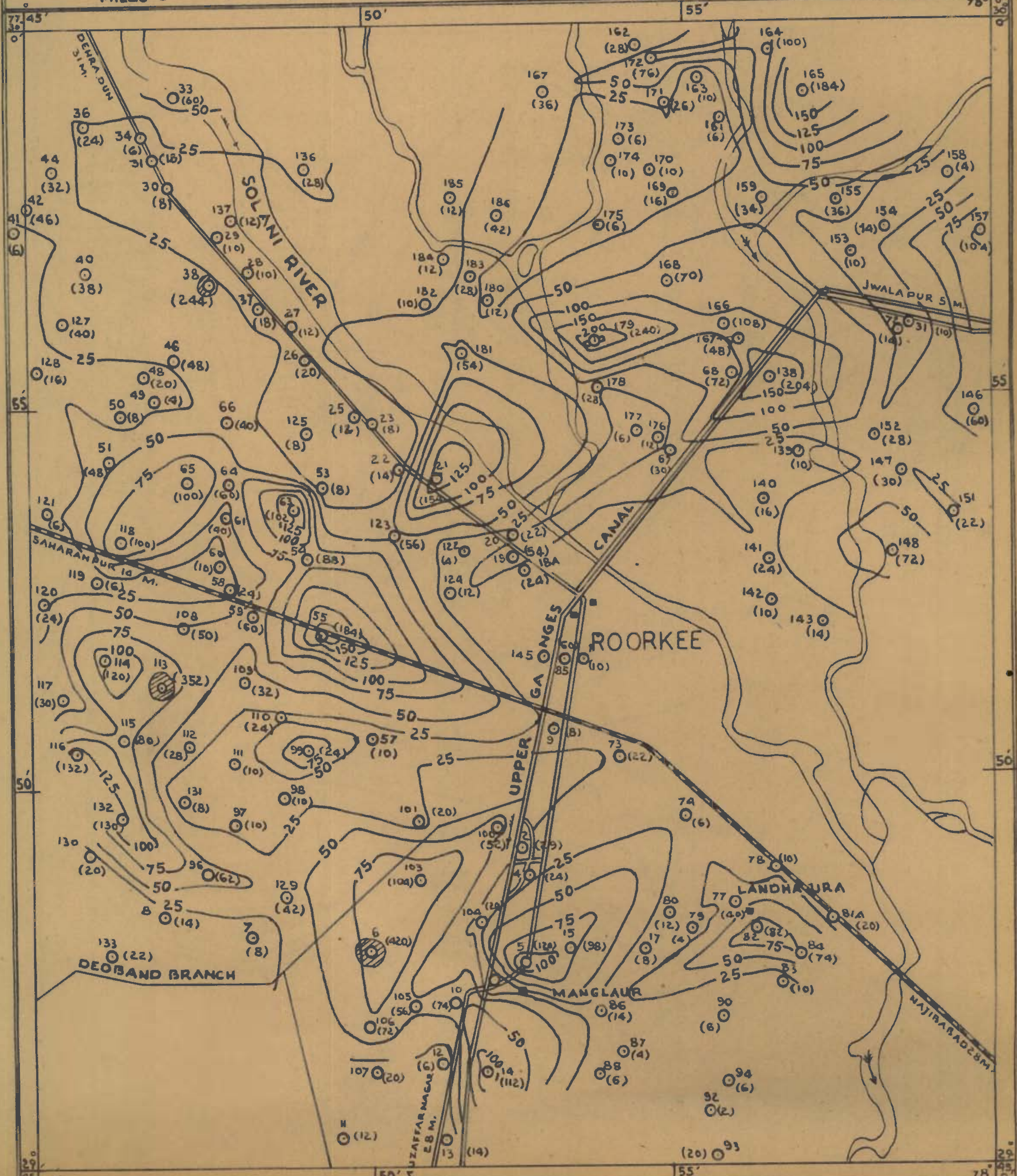
MILES 0 1 2 3 4 5

INDEX

100 = LINE JOINING POINTS AT WHICH THE SHALLOW AQUIFER YIELDS WATER HAVING SPECIFIED CHLORIDE VALUE; FIGURE DENOTES CHLORIDE CONTENT IN PARTS PER MILLION; INTERVAL IS 25 PPM

⊙7 (19) = LOCATION OF SHALLOW OPEN WELL FOR WHICH CHEMICAL ANALYSIS IS AVAILABLE. VALUE IN BRACKETS INDICATES (Cl.) IN PPM

⊙ = LOCAL CONCENTRATION (ABOVE 250 PPM.)



aquifer are fairly steep, the reason for localised concentration of salts in groundwater seems to be more due to the chemical nature of the sediments. It may, however, be noted that it would be difficult to give a qualified answer to this situation from the present available data.

e) Around well no.6, high concentration of sulphate, bicarbonate and chloride radicals is recognisable on a localised scale.

ii) RANGE IN CHEMICAL COMPOSITION AND SUITABILITY OF THE WATERS:

In order to obtain a comparative idea regarding chemical nature of ground waters in the shallow aquifers, the data are grouped as follows:

TABLE NO.31:

RANGE OF CHEMICAL QUALITY OF GROUND WATERS IN THE SHALLOW AQUIFERS: ROORKEE AREA:

Chemical constituent	Range of Chemical Composition (in ppm)						
	0-50	50-100	100-150	150-200	200-300	300-400	400
1	2	3	4	5	6	7	8
Bicarbonate	-	17	-	78	46	10	12
Chloride	119	26	8	10 (>150)	-	-	-
Sulphate	139	22	2 (>100)	-	-	-	-

From the above table it is evident that except in the case of bicarbonate, all the other radicals or salts show that maximum number of the open wells fall within 0-50 ppm range. The maximum number of wells in the HCO_3 - group fall in 100-200 ppm

PLATE No XLIII

MAP SHOWING DISTRIBUTION OF BICARBONATE IN THE SHALLOW GROUND WATERS IN ROORKEE AREA (SUMMER 1963)

0 1 2 3 4 5 6 7 8 KILOMETRES.
MILES. 0 1 2 3 4 5

INDEX

—200— LINE JOINING POINTS AT WHICH THE SHALLOW AQUIFER YIELDS WATER HAVING SPECIFIED BICARBONATE VALUE; FIGURE DENOTES BICARBONATE CONTENT IN PARTS PER MILLION; INTERVAL IS 50 P P M

36.0(120) LOCATION OF SHALLOW OPEN WELL FOR WHICH CHEMICAL ANALYSIS IS AVAILABLE. VALUE IN BRACKETS INDICATES (HCO3) IN P P M.

LOCAL CONCENTRATION (ABOVE 600 P P M)

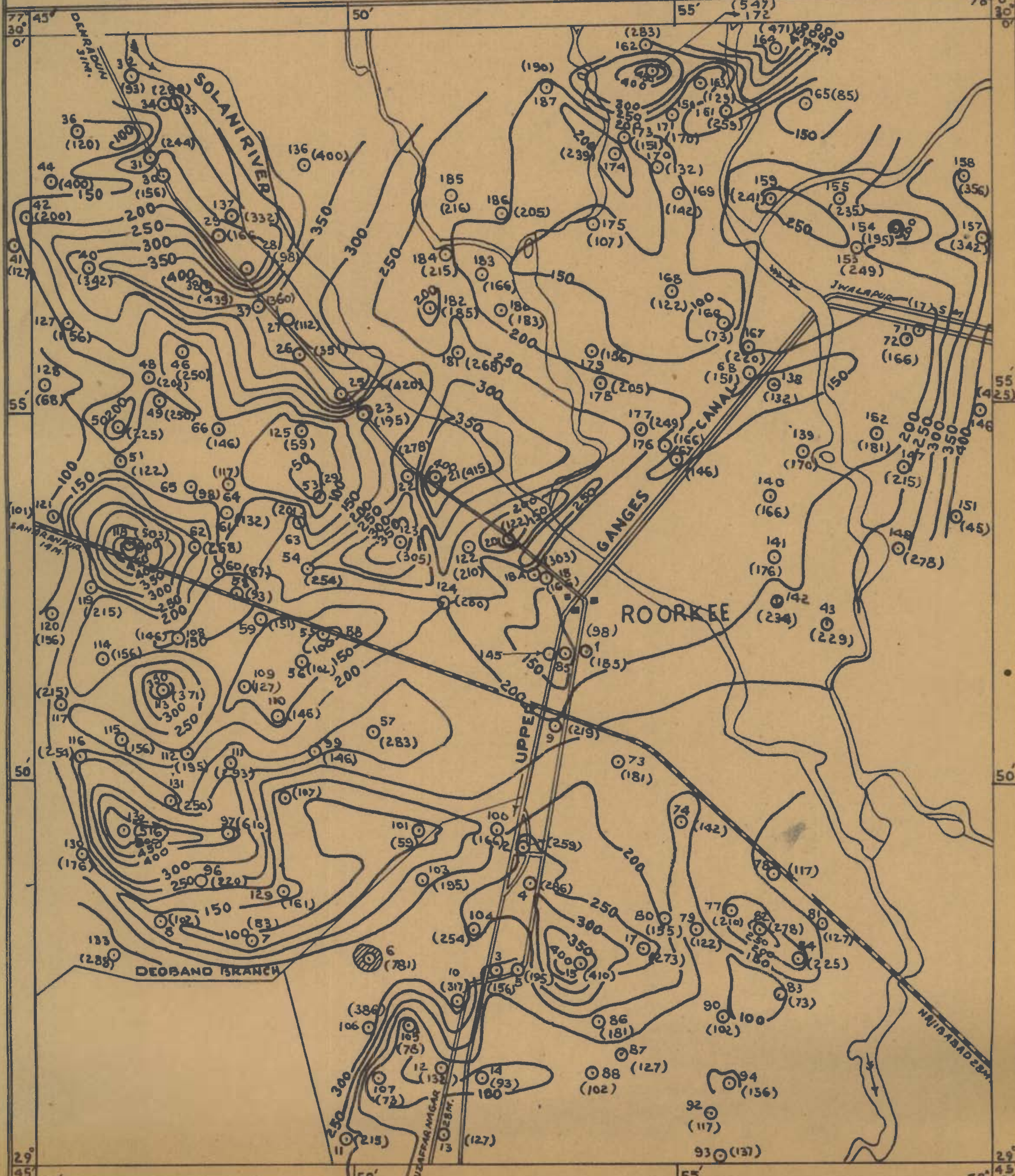
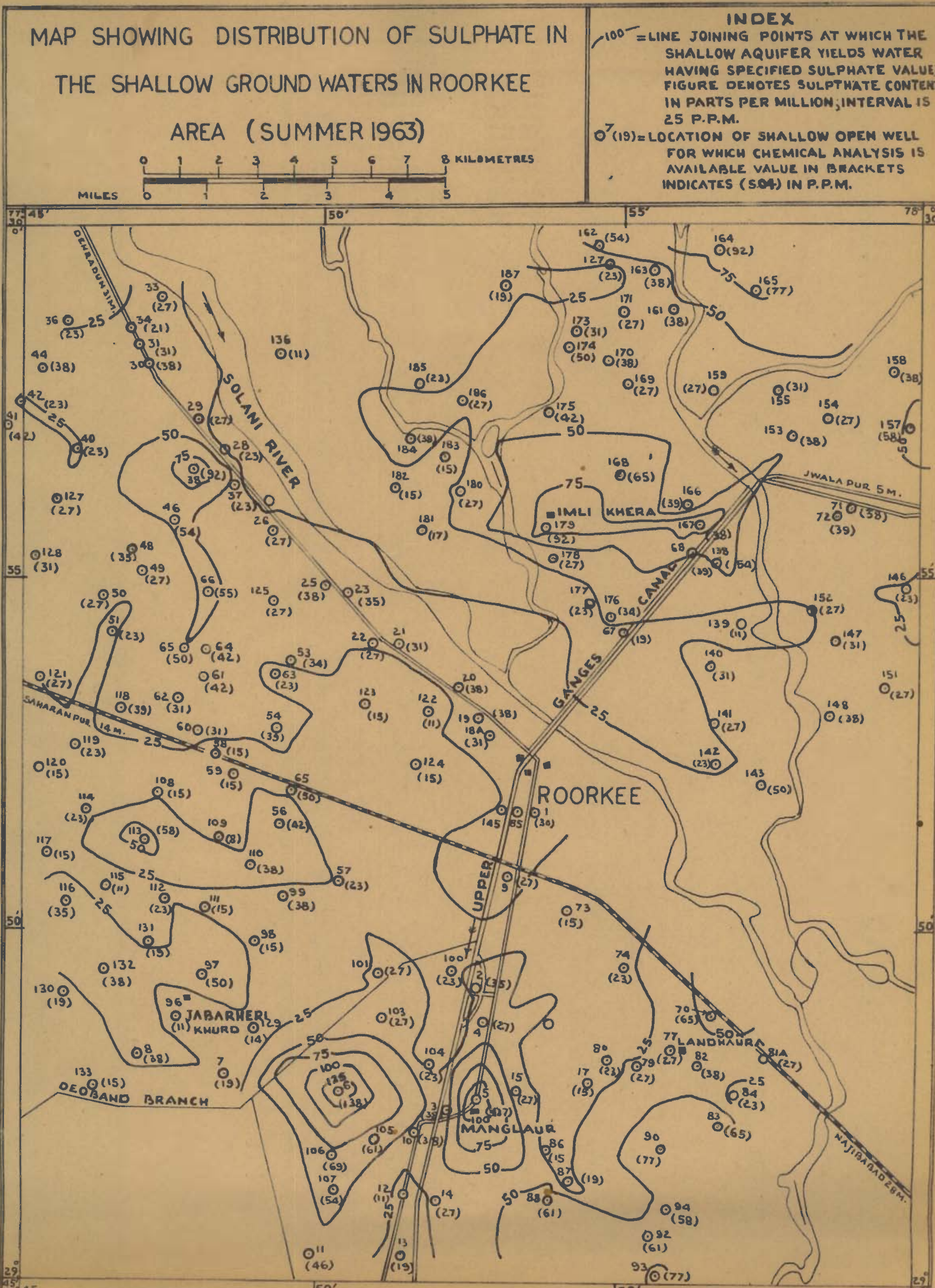


PLATE No XIV


MAP SHOWING DISTRIBUTION OF SULPHATE IN THE SHALLOW GROUND WATERS IN ROORKEE AREA (SUMMER 1963)
0 1 2 3 4 5 6 7 8 KILOMETRES
MILES 0 1 2 3 4 5
INDEX
100 = LINE JOINING POINTS AT WHICH THE SHALLOW AQUIFER YIELDS WATER HAVING SPECIFIED SULPHATE VALUE FIGURE DENOTES SULPHATE CONTENT IN PARTS PER MILLION; INTERVAL IS 25 P.P.M.
O7(19) = LOCATION OF SHALLOW OPEN WELL FOR WHICH CHEMICAL ANALYSIS IS AVAILABLE VALUE IN BRACKETS INDICATES (SO4) IN P.P.M.
77° 45'
50'
55'
78°
DEHRADUN 31M.
SOLANI RIVER
IMLI KHERA
JWALA PUR 5 M.
UPPER GANGES CANAL
SAHARANPUR 14 M.
ROORKEE
JABARHERI KHURD
DEOBAND BRANCH
MANGLAUR
LANDHAURA
NAJIBABAD 28 M.

range.

It may be recalled that the water from shallow wells aside from its use for domestic purposes is also used for agricultural purposes (Appendix No.1) and as such the suitability of the water for irrigational purposes should also be ascertained. Based only on the range of chloride concentrations, nearly 90% of the well waters are under Class I type of Scofield's classification (63) of Irrigation Waters (Cf: page 189). As such, the shallow ground waters are considered as safe for irrigation under ordinary conditions of climate and soils. Since the toxic constituents if any and the bacteriological factors have not been studied, no generalisation should be made with the available data regarding the suitability of the waters for drinking purposes.

GEOCHEMISTRY OF CONFINED GROUND WATER:

i) GRAPHING SYSTEMS AND GEOCHEMICAL CLASSIFICATIONS:

In order to demonstrate similarities and differences of chemical composition and also facilitate study of the massive chemical data in the shortest possible time, graphical representation of the same is adopted. In the graphing system of data presentation, diamond and logarithmic plots and other hatched maps are used to represent the chemical data.

The immediate purpose of the quality of water study should be to determine if the water is satisfactory for a proposed use. Under geochemical classifications the procedures mainly directed to classify the chemical data are those related to irrigation requirements as the maximum utility of groundwaters tapped from the confined aquifers is for such purposes only. As such, the classifications adopted are mainly based on those of Scofield[72] and Wilcox[64] and also application of Sodium Adsorption Ratio (SAR). The diamond plot as suggested by Piper[65] has also been attempted to study the chemical nature of water in relation to any admixtures to the ground water source through recharge.

The chemical composition of the ground water samples from the confined reservoir are given below.

TABLE NO.32.

RESULTS OF CHEMICAL ANALYSES OF GROUND WATERS FROM THE CONFINED AQUIFERS IN ROORKEE AREA FOR THE WINTER 1964:

Sl. No.	Tubewell No.	Date of sample collection	pH	Electrical conductivity in micromhos per cm	RESULTS EXPRESSED IN PPM			
					SiO_2	Fe	R_2O_3	CO_3
1	2	3	4	5	6	7	8	9
1.	5	24.11.64	7.50	330	20	Nil	Nil	5
2.	8	25.11.64	8.00	340	20	Nil	Nil	7
3.	11	24.11.64	7.40	260	20	Nil	Nil	8
4.	14	24.11.64	7.30	340	20	Nil	Nil	12
5.	17	24.11.64	7.80	320	20	Nil	Nil	8
6.	19	25.11.64	7.70	330	20	Nil	Nil	2
7.	22	5.12.64	8.35	251	10	Nil	Nil	12
8.	34	25.11.64	7.40	420	20	Nil	Nil	10
9.	35	1.12.64	8.30	360	12	Trace	6	19
10.	38	1.12.64	8.35	370	20	Nil	Nil	17
11.	43	25.11.64	7.40	320	20	Nil	Nil	10
12.	44	25.11.64	7.50	400	40	Nil	Nil	7
13.	45	1.12.64	8.40	260	8	1	6	17
14.	47	29.11.64	7.40	340	20	Nil	Nil	2
15.	53	1.12.64	8.10	340	16	2	8	10
16.	54	1.12.64	8.30	330	14	Nil	Nil	17

Note:- The samples were analysed by the Indian Agricultural Research Institute, New Delhi.

TABLE NO.32 CONTD.

Results in Parts per Million								
HCO_3	SO_4	Cl	Ca	Mg	Na	K	Total hardness as $CaCO_3$	Total alkalinity as $CaCO_3$
10	11	12	13	14	15	16	17	18
200	Nil	12	44	13	8	3	165	172
193	Nil	16	40	11	21	1	145	170
151	Nil	10	42	8	6	1	138	138
200	Nil	20	60	9	6	3	186	184
156	Nil	14	46	5	11	2	136	142
200	Nil	27	50	9	20	2	160	168
151	Nil	8	18	17	17	4	116	144
279	Nil	12	40	13	44	3	156	244
184	Nil	20	14	30	24	4	160	183
237	Nil	7	24	26	26	4	170	222
212	Nil	17	60	5	17	3	172	190
249	Nil	14	54	14	18	1	193	216
139	Nil	8	25	13	17	4	116	142
227	Nil	8	30	22	15	2	165	190
210	Nil	10	28	17	24	9	142	188
204	Nil	6	19	26	25	3	158	195

ii) REACTION OF QUALITY OF WATER TOWARDS SOIL IN IRRIGATED AREAS:

In recent years from agriculture point of view emphasis is laid not only on the quality of ground water but also on the phenomenon of base exchange involved in the reaction of ground waters with various soils. The exchange is between the cations held by the water and that of soils and is directed towards an equilibrium of the bases. This involves consequent changes in the soil characteristics - tilth, permeability etc. This demands an orientation of geochemical studies towards finding a solution for the applicability of ground waters to various soils and crop-patterns.

a) SAR Diagram:

In view of this, the chemical data of waters obtained from the confined aquifers have been analysed for the 'Sodium Adsorption Ratio' (SAR) as follows:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

The values of 'SAR' have been plotted in the diagram (Plate No.XLV), developed by the U.S. Salinity Laboratory.(66) The values for SAR for the sixteen representative samples of the area range from 0.20 to 1.55. All the values are within the group C_2-S_1 and almost close to the group C_1 - S_1.

b) Percent Sodium Diagram:

For nearly a quarter century, the percent sodium value has been reported in chemical analyses of irrigation waters. As per Wilcox the magnitude to which irrigation waters could promote loss of exchangeable Ca^{++} and Mg^{++} from the soil can be approximately predicted on the basis of sodium percentage and the total concentration of dissolved solids. On this basis, the analyses of the water from the confined reservoir are plotted on the diagram (Plate No.XLVI) showing classification of irrigation waters based on percent sodium and electrical conductivity modelled after Wilcox. The position of points in the diagram representing waters from different wells uniformly spread over the area indicate that all of them are classified as 'excellent to good waters' for irrigation.

c) Diamond Diagram:

The points plotted in the diamond diagram developed by Piper indicates the character of water as represented by the relationships among the Na + K, Ca + Mg, CO_3 + HCO_3, and Cl + SO_4 ions. This graphic method is most useful when the possibility of mixtures of ground water of different sources needs to be explored. The chemical analyses data of the waters from deeper sources in Roorkee area have been plotted in the diamond diagram (Plate No.XLVII). The points in the plot suggest their classification as Type - 5 waters which indicate that in these waters secondary alkalinity (carbonate hardness) exceeds 50% (i.e. chemical properties of the water are dominated by alkaline earths and weak acids).

d) Scofield's classification:

According to Scofield, in irrigation projects the relation between salt inflow and outflow is called 'Salt balance'. It is considered 'favourable' when out flow of salt equals or exceeds the inflow. For permanent nature of irrigation, salt balance must be maintained in an irrigated area. Further, he framed a classification of waters for irrigation based on total dissolved salts, chloride, Boron and Percent alkalies expressed as selective ranges in parts per million. The analytical data related to confined ground waters are tabulated below as per Scofield's classification.

PLATE N° XLV

SODIUM ADSORPTION RATIO DIAGRAM FOR THE CHEMICAL ANALYSIS OF WATER OBTAINED FROM THE CONFINED AQUIFERS; ROORKEE AREA.

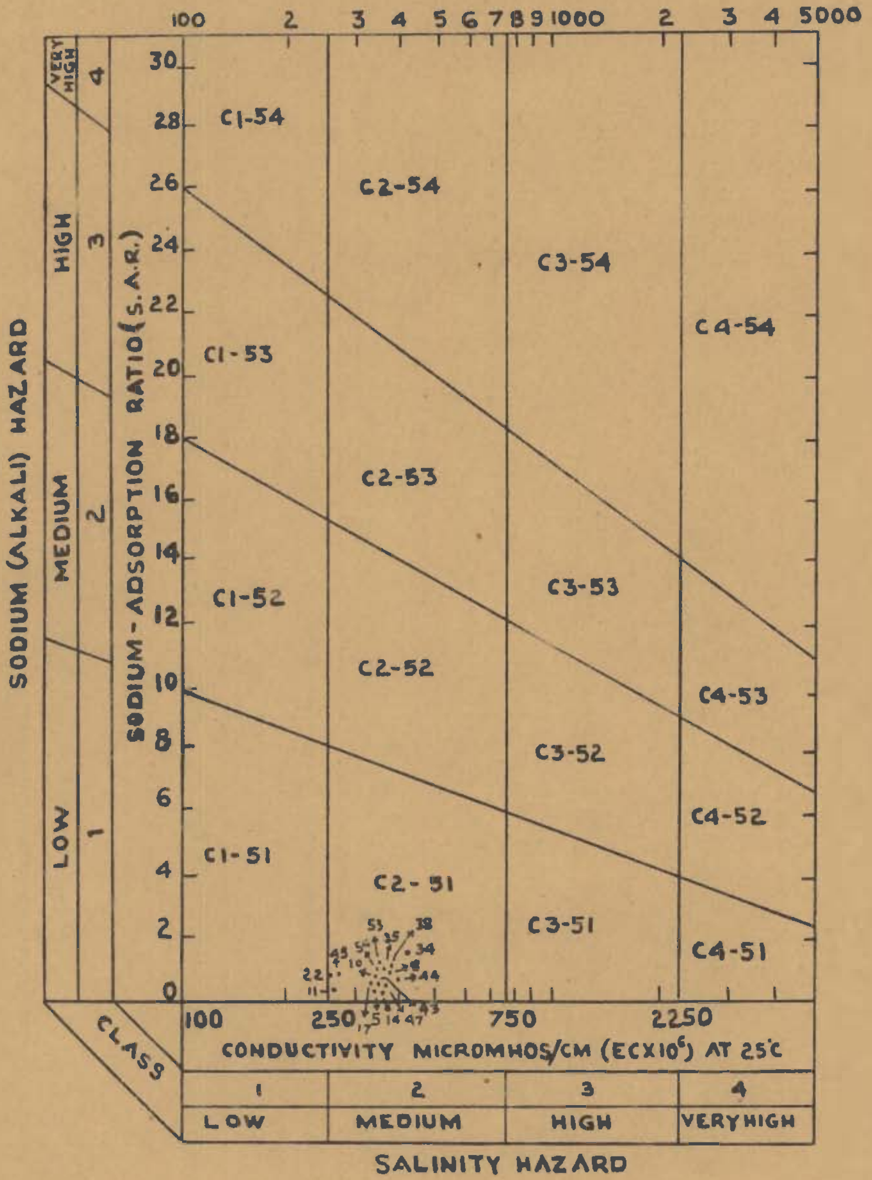


PLATE Nº XLVI

DIAGRAM FOR IRRIGATION WATER CLASSIFICATION OF THE CONFINED GROUNDWATERS IN ROORKEE AREA BASED ON ELECTRICAL CONDUCTIVITY & PERCENT SODIUM.

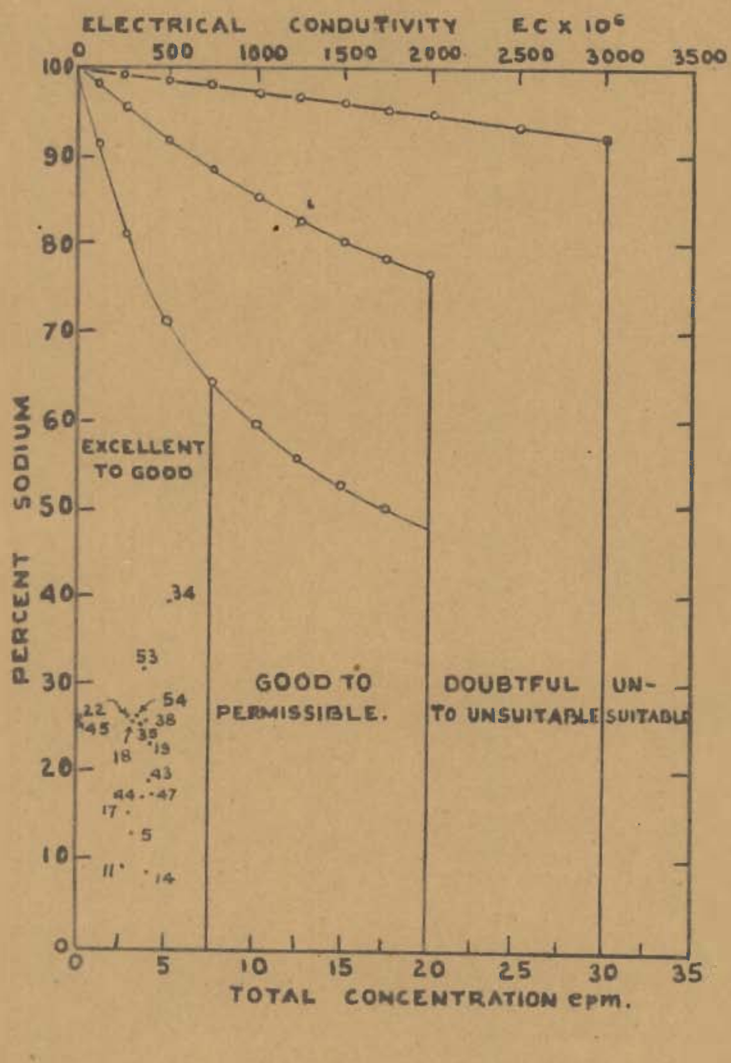
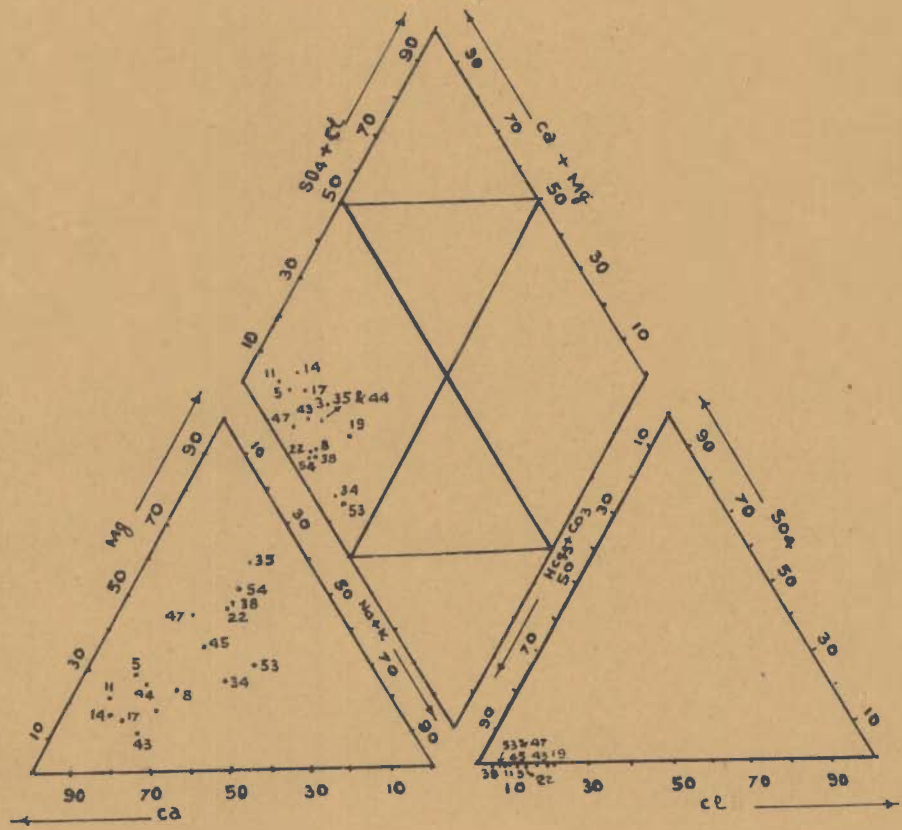


PLATE No. XLVIII

DIAMOND DIAGRAM FOR THE CLASSIFICATION OF CONFINED GROUNDWATERS IN ROORKEE AREA.



SUB-DIVISIONS OF THE DIAMOND SHAPED FIELD (ACCORDING TO ARTHUR. M PIPER)

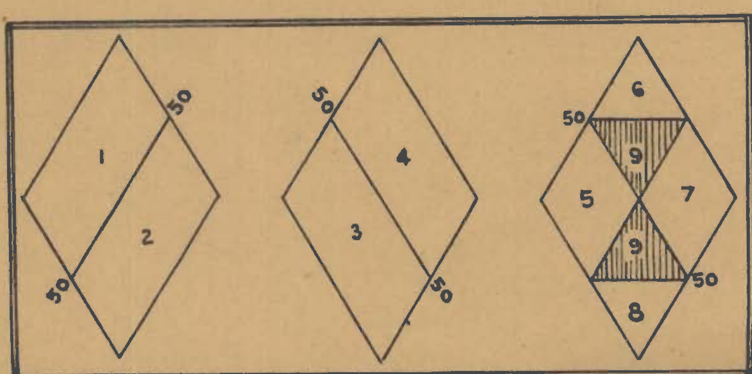


TABLE NO.33:

SCOFIELD'S CLASSIFICATION FOR THE ANALYTICAL DATA RELATED TO CONFINED GROUND WATERS: ROORKEE AREA:

Constituent	Class I	Class II	Class III
	0-150 ppm	150-500 ppm	Over 500 ppm
Chloride:	All sixteen well samples fall in this group.	Nil	Nil
	Under 60%	60-75 %	Over 75%
Percent Alkalies	All sixteen well samples fall in this group.	Nil	Nil

$\left(\frac{Na + K \text{ in EPM}}{Na + Ca + Mg \text{ in EPM}} \times 100 \right)$

Class I: Waters regarded as entirely safe for irrigation under ordinary conditions of climate and soil even for sensitive crops plants.

Class II: Waters which may be safe for certain conditions or certain crops, yet may be unsafe under other conditions or for other crops.

Class III: Water with concentration of one or more constituents too great to be safe for irrigation use or atleast unsafe in a great majority of cases.

Note: The Boron constituent in parts per million could not be determined.

From the above it may be said that the ground waters from the confined aquifers come under Class I waters of Scofield and are regarded safe for irrigation.

iii) CHANGES IN CHEMICAL COMPOSITION OF GROUND WATERS FROM AREAS OF INTAKE TO AREAS OF WITHDRAWAL:

It has been stated earlier (Chapter No.III, page 40) that ground water flow lines indicate North-west to South-east and North to South flow movement in the well field area of Roorkee. As such, it is necessary to observe or analyse the changes in chemical nature of confined waters from areas of intake to areas of exi$t or withdrawal. In order to analyse this the following method of study has been adopted.

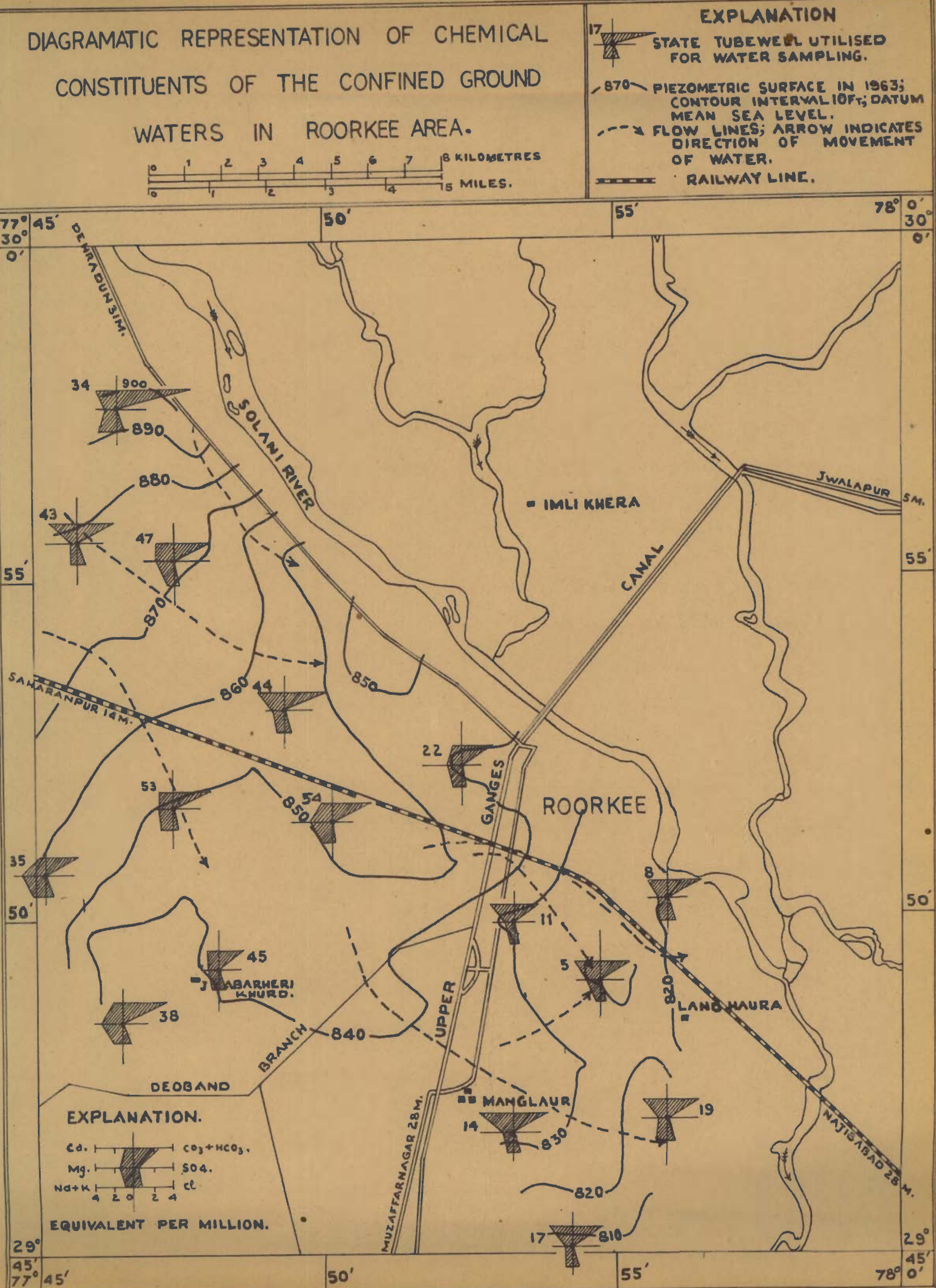
Diagramatic representation of the chemical constituents (in epm) of the waters in the well field area has been made on a map along with the flow lines of ground water movement (Plate No.XLVIII). The shape of the hatched part, representing the chemical quality of the waters on the map, indicates directly the changes in the chemical regime from areas of intake to areas of out flow if the same are pronounced.

The diagram mentioned above gives some indication that the left side part of the hatching showing the cations of waters in the intake area (Western and North-western parts) get reduced in size in the eastern part of the well field area. There is similarly a slight reduction in the bicarbonates also. But for this, there is no marked or striking variation in the chemical composition to warrant any major influx of waters or inherent dissolution of salts.

DIFFERENCE IN CHEMICAL QUALITY BETWEEN SHALLOW AND DEEP GROUND WATERS:

A general comparision of the ground waters from the shallow and deep aquifers, based on the study of the common radicals can be seen from the following:

DIAGRAMATIC REPRESENTATION OF CHEMICAL CONSTITUENTS OF THE CONFINED GROUND WATERS IN ROORKEE AREA.



	Shallow Aquifers (Range in ppm.) (usually met with)	Confined Aquifers (Range in ppm (usually met with
Bicarbonates	100 - 300	150 - 250
Sulphates	20 - 50	Nil
Chlorides	10 - 60	10 - 20

Also from a comparison of the position of the water analyses points in the various graphic diagrams with those of the areal quality maps of the shallow ground waters, it is obvious that the waters in the confined reservoir are better than those met with in the shallow aquifers.

DISCUSSION:

In the study and interpretation of water analyses, various methods are in vogue. It is evident that a particular analytical method or its modification should be selected carefully in order to give a qualified answer to the study purposes.

In investigations on quality of ground waters, the first grouping of analysis data, is according to the aquifers. In the area under study this feature also finds a place as the study is mainly classified as (i) quality of ground waters in shallow aquifers and (ii) chemical quality of water in confined aquifers.

Under the study of shallow ground waters it has been observed that the type of waters mainly relate to that of bicarbonates. The bicarbonates usually range from 100 - 300 ppm and sometimes reach nearly 800 ppm. While reviewing the absolute values and products of chemical constituents of ground waters, Schoeller (36) is of the opinion that (HCO_3^-) values are above normal when the water is in contact with

CO_2 in abnormal proportions of volcanic or metamorphic origin or generated by organic materials such as lignite, coal and other hydrocarbons. In the area under study it has been pointed out earlier (Chapter II, page 10) that the fluviatile alluvium around Roorkee contains lenses of peaty organic materials. In view of this it is not unlikely that the ground waters in the shallow aquifers in the area under study are partly enriched in the bicarbonates due to the activity of the free carbon dioxide released by the organic materials. According to Garmonov[(67)] the quality of phreatic water varies with the zonation of types of climate, over-burden and other changing factors. In this regard, the bicarbonate rich zone in the Tunisian steppes has been attributed to the optimum temperature, vegetation, soil moisture and humidity which facilitated enrichment of (HCO_3^-).

This has been further explained as due to the phenomena that vegetation supports vigorous growth of micro-organisms in the soil. This in turn produces more quantities of CO_2 which enhances the bicarbonate content. The area under study also supports good vegetation, soil moisture and falls under reasonable temperature vicissitudes. As such, it would not be unusual to have bicarbonate rich ground waters especially in the shallow zones in the area under study.

While comparing the quality of waters from shallow and deeper aquifers, it has been pointed out that sulphate content in the confined ground waters is conspicuously absent. This could have been explained as due to taking up of large quantities of calcium into the waters, but in the present case the calcium content in the waters is not significantly high to permit any presumption on these lines. But it is true that sulphate reductions take place if organic matter is present in the aquifers and such reductions in sulphates will be progressively more complete as the length of contact is greater between the formation waters and the associated organic materials. In the Gangetic alluvium, especially in the older alluvium, it is not uncommon to find associations of organic materials with the sandy beds. The confined aquifers in the present area of study down to 300 feet depth have been relegated to the older alluvium of the Indo-Gangetic plains (Chapter II, page 10), and the formation waters being under confined conditions, there is enough time for chemical reactions between the water and the rock. As such, it may be possible to have confined ground waters significantly low in sulphates.

Schoeller[36] is of the opinion that percentile values cannot be very suitable for the presentation of Chemical Analyses data. Under the present study, the only use of the percentile diagram is that of the diamond plot modelled after Piper. The very fact that in recent years, trilinear system of water analysis plotting[68 and 69] is gaining ground with modifications[70], acts as a pointer that chemical relationships among waters can be brought out in definite terms by the application of this diagram. Under the present study, it has been utilised for two purposes - (i) to classify the chemical nature of the confined ground water and (ii) to observe whether any admixtures of ground waters have taken place in the confined reservoir. The chemical nature of the waters has been proved to be rich in alkaline earths and weak acids. As no straight line trends are noticed in the plot, as usually representative of mixtures of waters, it may be inferred that the well field area of Roorkee drawing water from the confined aquifers is devoid of influxes of two or more sources of waters. This also supports the inferences drawn in the lack of large scale change in the chemical composition from areas of intake to areas of withdrawal or exit based on the diagramatic representation of the chemical constituents (in epm) of the ground waters in the well field area of Roorkee (Plate No.XLVIII). As such, it may be noted that in many practical problems, this use of trilinear graphs is still invaluable.

In evaluating the quality of ground waters for irrigational needs, it is not correct to depend exclusively on the classification system that takes only the composition of water into account. In order to overcome this difficulty, the calculation of 'Sodium Adsorption Ratio' values have been determined. These are better expressions of the tendency an irrigated water may have, to take part in the base exchange reactions of the soils. As such, the 'SAR' value is more directly significant than the percent Sodium. The position of the points in the SAR - diagram (Plate No.XLV) indicated that the confined ground waters are significantly low in salinity and sodium hazards and as such the water can be used on all soils and for most crops. As the calcium and magnesium ions exceed sodium ions considerably, the waters are useful for maintaining good tilth and permeability of the soils. As such, the SAR-diagram is not only helpful in classifying the waters but also demonstrates its utility in inferring the soil conditions in relation to irrigation projects.

It may be of interest to note that the points representing the chemical quality of waters sampled from the entire well field area of Roorkee covering nearly 125 sq. miles when subjected to various classifications, uniquely demonstrated their closeness in chemical nature in all the plots, indicating that there is good deal of chemical homogeneity in the confined ground waters. In confined reservoirs ground water movement is usually slow and there is time for reactions between the formation water and the rocks or aquifer materials. As such, this phenomenon is not very common. Besides this the chemical classifications indicate significantly that the well waters are extremely suitable for irrigational purposes.

CONCLUSIONS:

i) The chemical nature of shallow and confined ground waters in Roorkee area has been studied with special reference to their suitability for irrigational purposes. It has been proved through the application of various chemical classifications that these waters are extremely suitable in their application to irrigation projects.

ii) The ground water in the shallow aquifers is proved to be rich in bicarbonates. The confined ground waters which are at present heavily used for irrigational purposes are classified as Class I according to Scofield Classification, 'Excellent to Good' as per Wilcox diagram, 'Low in salinity and sodium hazards' as per 'SAR' diagram and as 'Waters dominated by alkaline earths and weak acids' as per diamond plot.

iii) The presence of high concentration of bicarbonate both in the shallow and confined aquifers is attributed to the reaction of the formation waters with the organic materials associated with the alluvial formations and partly to the favourable chemical zonation by climate. The significantly low sulphate in waters from the confined aquifers is also explained as an action of formation waters in time on the organic materials associated with the alluvial aquifers.

iv) The chemical homogeneity in the confined aquifers is established. It has also been proved that there is no recognisable phenomena of intermixture of waters in the deeper aquifers. It has also been indicated that there is no marked variation in the chemical regime of confined waters from areas of intake to areas of exit in the well field area of Roorkee.

— ... —

CHAPTER VIII:

QUANTITATIVE GROUNDWATER ASSESSMENT:

INTRODUCTORY REMARKS:

Progress of mankind mainly depends on the water availability in a region and its utility. Estimates of these two factors constitute mainly the budgeting of ground waters in an area where surface waters are not available or impure. In view of this, ground water balance studies are important in many developing well field areas. Of late, ground water reservoir investigations divorced from assessment studies on the total useable sub-surface water resources, are considered as unrealistic. In such investigations it is necessary to make measurements of total storage, movements, recharge, discharge or draft and allied components in order to identify the functional conditions of the ground water system.

Such investigations will also have the objectives (i) to determine the amount of recharge and the manner of its fluctuations (ii) to determine the amount of storage in the aquifers of the reservoir (iii) to determine the rate of present ground water withdrawal and its effect on the available supply (iv) to determine the amount of natural drainage and (v) to estimate the amount of salvage from such inflows and outflows for optimum development of the ground water basin.

It may be noted, however, that establishment of such relationships precisely would take considerable time and more so for ground water basins which have been put to use by way of development for short periods. The principal function of the present attempt is to formulate a basis for evaluating quantitatively such relationships in the area under study. It is believed that the methods employed here may have general application elsewhere in the Gangetic Valley and other similar ecological and hydrogeological settings.

COLLECTION OF DATA:

Rainfall record data at Roorkee station, operated by the Central Building Research Institute, are available for the study since 1935. Estimates of pumpage are available for each State owned tubewell for the entire period of 1937 - 1964 from the U.P. State Tubewells Department. Besides this water levels in the wells are measured as part of the study. Information is not available on the discharges of Solani river and evapotranspiration losses in the channels of river drainage and its tributaries.

PART A:

SHALLOW GROUND WATER RESERVOIR:

It is gathered from well inventory (Appendix I) that in the area the open or dug wells are constructed mainly down to a maximum depth of 75 feet below land surface and tap ground water from the water bearing sand horizons encountered within this depth. From the sub-surface correlation charts (Chapter II, page 29) it is observed that in the region the clay beds separating the dug well zone aquifers from the deeper aquifers (below 100 feet depth) are of reasonable thickness and areal extent. It has been proved earlier (page [illegible]) that the coefficient of storage value for the confined aquifers is not close to the range generally met with in the water table aquifers. Its value indicates well established confined ground water conditions and is suggestive of the fact that no large scale leakage exists between the near surface and the confined ground waters (usually below 100 feet depth) at this stage of ground water development. Besides this it is reasonable to assume that the influences of precipitation, sub-surface drainage to the rivers and the influence of canal seepages are more pronounced in their contribution and other effects on the near surface ground water body rather than on deep confined aquifers. In view of this, it is very necessary in the present area to study the assessment problem under two broad heads namely 'Confined ground water reservoir' and Shallow ground water reservoir'. For purposes of this study, the shallow ground water reservoir body is defined as the group of aquifers encountered above the first effective and well defined aquiclude in the depth zone between 75 - 100 feet.

It may also be noted that in such studies it should be kept in mind that estimate of ground water potential in different segments of the basin is more important than a general estimate of the basin as a whole. Based on this fact only the area strewn with fairly large number of tubewells close to Roorkee has been chosen for the assessment study of the confined aquifers and the area along the main drainage course of Solani and its tributaries and close to the Upper Ganges Canal and its distributories has been taken for the study of shallow water potentialities. In the following pages, Part - A, deals with the ground water potential in the shallow aquifers and Part - B, covers the assessment studies of the confined aquifers.

GROUND WATER STORAGE IN THE SHALLOW RESERVOIR:

It has been stated under the Chapter "Ground water Flow Analysis" that the shallow near surface aquifers in the area are generally under water table conditions. In view of this any assessment of storage of the free ground waters involves knowledge of the specific yield of the saturated sands and their exact volume. The sub-surface lithologenetic correlation charts (Plates Nos. XI-A, B,C) indicate that it would be difficult to estimate the exact volume of the saturated alluvial material as the aquifers occur some times as inter-connected beds, lenses and as 'cut outs' in the clay beds. As such, an indirect method of volume estimation of the saturated water bearing material has been adopted as follows:

The 75 feet thickness of the alluvium usually lying above the first effective and well defined aquiclude of the Gangetic Alluvium, contain on an average 20 feet thickness of clay. As such, the thickness of the group of aquifers in the shallow Groundwater Reservoir works out to be 55 feet. The average water level for the shallow aquifers is of the order of 20 feet in the area. From the above, average thickness of saturated sands of the reservoir will be of the order of 35 feet (55-20 ft. = 35 ft.). The volume of the saturated aquifer will be a product of the area (250 sq. miles) and the saturated thickness of the aquifer.

Volume of the Saturated Aquifer } = 250 x 640 x 35

= 5200 thousand Acre ft.

In the western Ganges Valley region the specific yield of the shallow aquifers computed from the experimental tests by the Irrigation Research Institute (12) range from 13 % to 18 %.

In the Hindan - Eastern Yamuna Canal Doab which is close to the area of present study, the specific yield of the formations is stated as 14.2%. On an average, the specific yield of the alluvial aquifers of the shallow reservoir in this part of the Gangetic Valley works out to be 15%. This figure is used to compute the total available storage in the near surface reservoir. Ground water storage is the product of the volume of the saturated aquifer and the specific yield.

Ground water storage = $\frac{5200 \times 15}{100}$

= 780 thousand Acre feet.

Leaving 50% of the ground water storage as permanent reserve.

Ground water storage available for any use including pumping of open wells. = 390 thousand Acre feet.

RECHARGE TO THE SHALLOW GROUND WATER RESERVOIR:

The sources of natural recharge to the shallow ground water body are mainly (a) precipitation (b) influent drainage (c) inflow to the area due to natural hydraulic gradient (d) seepage from canals (e) irrigation losses (or return flow). These estimates are made individually.

a) RECHARGE THROUGH PRECIPITATION:

The amount of infiltration of rain water towards the ground water body depends mainly on the incidence of rainfall and the infiltration coefficient of the soils. An empirical relationship on the rainfall penetration to the water table for Western Uttar Pradesh region has been derived by the Irrigation Research Institute, Roorkee. (74) In the present area of study this formula has been used to arrive at the total infiltration of rain water to the ground water body. This is justified as the area under study falls in the same 'doab' region and is governed more or less by the same hydrological cycles which lead to the derivation of the general formula. The empirical formula is as follows:

$$R_p = 2.0\ (R-15)^{2/5} \qquad \ldots\ (xxiv)$$

R_p = Rainfall penetration to water table, in inches.

R = Annual Rainfall in inches.

The actual recharge through rainfall infiltration to the area is given as follows:

$$\text{Amount of Rainfall infiltration to the area (Recharge)} = \frac{R_p}{12} \times A \times 640 \qquad \ldots\ (xxv)$$

Acre feet.

(where A is the area).

Part of this water will be lost through evapotranspiration and sub-surface drainage and such losses are considered as 50% of the total rainfall infiltration.

The data for the period of study (1960-'64) as computed from equations (xxiv) and (xxv) stated above are recorded in Table No.34.

TABLE NO.34:

RAIN FALL INFILTRATION FIGURES FOR ROORKEE AREA:

Year	Rainfall in inches	R_p (in inches)	Amount of Rainfall infiltration (Acre feet)	Recharge due to Rainfall infiltration after deducting 50% as evapotranspiration and sub-surface flow (Acre feet).
1	2	3	4	5
1960	37.9	7.00	93,350	46,675
1961	42.8	7.56	1,00,800	50,400
1962	35.6	6.71	89,475	44,737
1963	43.1	7.59	1,01,200	50,600
1964	46.5	7.95	1,06,000	53,000
		Average	98,160	49,080

The amount of recharge to the ground water body by infiltration of rain water varies from year to year and depends on the annual precipitation. As such, the average value for the study period has been worked out so that the same may be taken in the ultimate analysis of the ground water balance.

b) RECHARGE THROUGH INFLUENT DRAINAGE:

The main drainage courses (Solani and Ratmau Rao) in the area of study are essentially effluent in nature. But a small stretch of the river course, extending for about four miles south of the confluence of the above two rivers, is of influent nature at some places. As such, the magnitude of influent drainage will not be of considerable amount. This has been further explained under the study of effluent drainage also.

c) INFLOW TO THE AREA DUE TO NATURAL HYDRAULIC GRADIENT:

The water table map constructed for the shallow aquifer (Plate No.XIV-C) indicates an hydraulic gradient on an average of 10 ft. per mile in the North-western and North-eastern parts of the area for 10 miles and 6 miles of inlet cross/sections respectively. Based on the lithology and average water levels, the saturated part of the aquifer material within 75 feet thickness of the alluvium, is of the order of 20 feet in the Northern part of the area. As the texture of the top aquifers are not very much different from those of the deeper aquifers down to 300 feet depth and both the reservoir aquifers are constituted of fine to medium sands as revealed by the lithological logs, the average permeability (1000 gpd/sq. ft.) worked out from field pump test analysis data has been taken as the representative value of the permeability for the shallow aquifer under consideration.

The inflow to the area due to continuous ground water movement is equal to the product of the transmissibility (T), hydraulic gradient (I) and the width of the cross section through which ground water enters the area (L).

Inflow to the area = TIL ... (xxvi)

$$= \frac{20,000 \times 10 \times 10 \times 365}{3,25,850}$$

$$\frac{20,000 \times 10 \times 6 \times 365}{3,25,850}$$

= 3,586 Acre feet.

d) RECHARGE DUE TO SEEPAGE FROM CANALS:

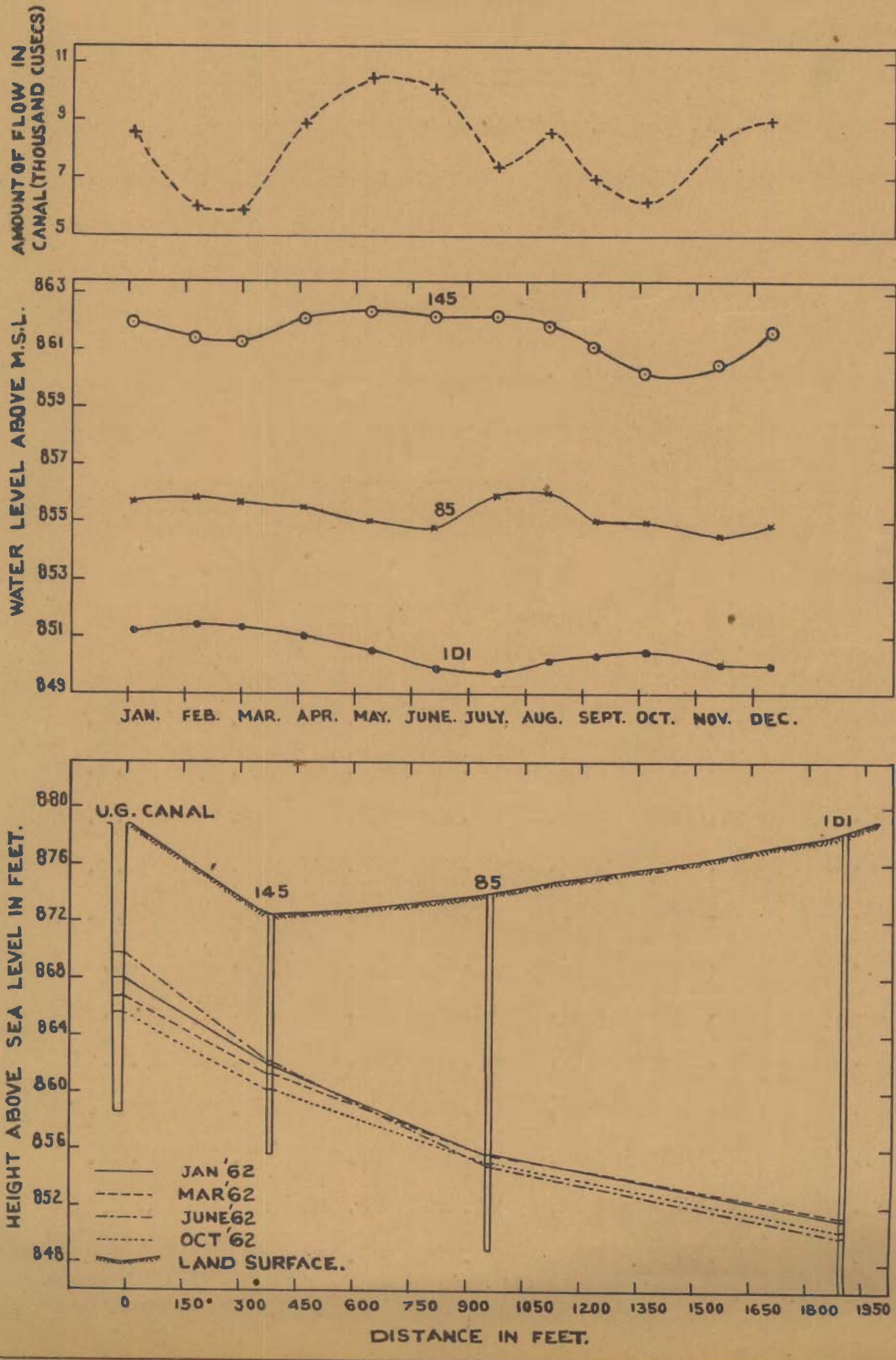
Since Upper Ganges Canal passes right across the area with a fifteen mile non-masonry part, it is reasonable to estimate the seepage losses which constitute a part of the recharge towards the shallow reservoir from the surface water bodies. For this purpose the section covering 145, 85 and 1D1 has been studied for the ground water gradients and effects of canal discharge for the year 1962 (Plate No.XLIX). These data related to monthly measurements are incorporated in the table given below:

TABLE NO.35:

DATA ON WATER LEVEL MEASUREMENTS AND CANAL DISCHARGES FOR THE SECTION COVERING 145, 85 and 1D1 STATIONS:

Date	Water Level Above MSL (in ft.) 1D1-53G/13	85-53G/13	145-53G/13	Amount of flow in canal in cusecs on the date of WL measur-ment.	Reduced level of water surface in canal on the date of WL measur-ment.	Difference of WL in feet bet. 85 and canal.	REMARKS
1	2	3	4	5	6	7	8
3.1.62	851.21	855.68	861.96	8,608	868.11	12.43	Note: Distance bet. well Nos 1D1 & 85 = 940'
6.2.62	851.39	855.83	861.39	6,008	866.79	10.96	" " " " 85 & 145 = 575'
1.3.62	851.34	855.69	861.29	5,880	866.78	11.09	" " " " 145 & Canal = 385'
3.4.62	850.98	855.55	862.13	8,902	869.12	13.57	
8.5.62	850.49	854.98	862.34	10,479	869.40	14.42	
12.6.62	849.91	854.83	862.21	10,133	889.82	14.99	
16.7.62	849.69	855.93	862.21	7,508	868.10	12.17	
13.8.62	850.16	855.99	861.92	8,700	868.53	12.54	
6.9.62	850.28	854.97	861.09	7,004	866.93	11.96	
4.10.62	850.49	854.97	860.20	6,206	865.60	10.63	
13.11.62	850.02	854.48	860.47	8,504	867.69	13.21	
10.12.62	850.02	854.93	861.69	9,035	868.91	13.98	

GRAPH SHOWING THE GROUNDWATER GRADIENTS AND EFFECTS OF CANAL DISCHARGE ALONG THE SECTION COVERING 145, 85 AND 101 STATIONS FOR THE YEAR 1962.



From the inset in Plate No. XLIX, it is evident that the effects of canal discharge are pronounced on station 145 and the same at stations 85 and 1D1 are not to be reckoned. Besides this, choice of ground water gradient (in feet per feet) for estimating the canal seepage losses, should be the one existing between the canal and station 85 as at this point the effect of the canal discharge on ground water levels is practically negligible.

In the following table, the hydraulic gradient between the canal and the observation station 145 (in feet per feet) for all the months of the year 1962 and the amount of influent seepage through one mile cross section of the canal assuming similar hydraulic gradients on the other side of the canal are given. The recharge through seepage is averaged for the year:

TABLE NO.36:

DATA ON HYDRAULIC GRADIENTS AND AMOUNT OF CANAL SEEPAGE IN THE SECTION COVERING 145, 85 and 1D1 STATIONS:

Months & Year	Diff. of WL bet. 85 and canal (in feet)	Distance in ft.	Hydraulic Gradient in ft. per ft.	ΣGr in ft. per ft.	Q in cusecs per one mile cross section.
1	2	3	4	5	6
Jan. 62	12.43	960	0.01295	0.02590	2.122
Feb. 62	10.96	"	0.01140	0.02280	1.869
March 62	11.09	"	0.01155	0.02310	1.893
April 62	13.57	"	0.01413	0.02826	2.316
May 62	14.42	"	0.01502	0.03004	2.462
June 62	14.99	"	0.01562	0.03124	2.560
July 62	12.17	"	0.01268	0.02536	2.078
Aug. 62	12.54	"	0.01306	0.02612	2.139
Sept. 62	11.96	"	0.01246	0.02492	2.042
Oct. 62	10.63	"	0.01108	0.02216	1.814
Nov. 62	13.21	"	0.01376	0.02752	2.255
Dec. 62	13.98	"	0.01455	0.02910	2.387
				Average	2.160

The actual assessment of the seepage losses are worked out on the following basis:

Amount of Influent Seepage or Leakage (Recharge) per one mile cross section of the canal in cusecs (Q) $= \frac{T \times \Sigma Gr}{122}$ ... (xxvii)

Where T is the transmissibility of the aquifer or stretch through which the seepage is taking place and Σ Gr is the sum of hydraulic gradients on both sides of the canal and expressed in ft. per ft.

The average field permeability (P_f) of the shallow aquifers in the area is 1000 (US)GPD/Sq.ft. (refer page 204). The average assumed thickness of the canal section along which seepage is taking place is 10 feet. On basis of this the transmissibility of the seepage zone works out to be 10,000 (US) gpd/ft. The average leakage through canal as shown in table No.36 is 2.16 cusecs per mile. The Σ Gr is taken as double of the observed gradient on one side of the canal. The length of the unlined canal in Roorkee area is 15 miles. By sustituting these values in equation No.xxvii given above, the total recharge to the shallow ground water body due to canal seepage within 1000 feet distance from the canal works out to be 31.80 cusecs or roughly 23,000 Acre ft. per year.

e) RECHARGE THROUGH IRRIGATION LOSSES OR RETURN FLOW:

The recharge due to re-entrance by way of infiltration of excess irrigation water to the ground water body may be appreciable as the majority of the area is covered by irrigation fields. This factor could not be evaluated due to lack of readily available data on the percolation rates and water requirements of the growing crops in the area.

DRAFT IN THE SHALLOW GROUND WATER RESERVOIR:

The total draft in the shallow reservoir is mainly dependent on the factors (i) Effluent drainage to the rivers from the area (ii) outflow from the area due to natural hydraulic gradient of the water table (iii) Evapotranspiration losses and (iv) draft by means of open wells. The estimates of draft due to each factor are given below.

i) EFFLUENT DRAINAGE TO THE RIVERS FROM THE AREA:

In the area the main drainage courses are river Solani and Ratmau Rao which have been established through the study of water table maps as effluent in their nature. As such, estimate of the amount of effluent drainage constitutes one important part of the total draft.

Aside from the consideration of the water table maps, selective sections close to the river courses are taken to study the effluent/or influent nature of the rivers by determining the hydraulic gradients. This data is given below.

A) Solani River:

Section No.1:

Covers well nos. 34, 32 and river Solani.

Distance between well no. 34 and 32 0.7 miles

Distance between well no.32 and River 0.5 miles.

Year	Water levels (in ft.) Well No.34	Well No.32	Difference in water levels (in feet.)	Average difference in water level (in feet)	Average Hydraulic gradient (in feet).
1	2	3	4	5	6
1961	932.16	906.84	+ 25.32	+ 23.52	+ 0.0063
1962	934.48	913.26	+ 21.12		
1963	930.95	906.84	+ 24.11		

Section No.2:

Covers well nos. 29, 137 and River Solani.

Distance between well no.29 and 137 0.4 miles

Distance between well no.137 and Solani River 0.4 miles.

Year	Water Levels (in ft.) Well No.29	Well No.137	Difference in water levels (in feet)	Average difference in water level (in ft.)	Average hydraulic gradient (in ft. per ft.)
1	2	3	4	5	6
1961	913.35	-			
1962	915.54	895.77	+ 19.77	+ 20.69	+ 0.0098
1963	912.14	890.53	+ 21.61		

Section No.3:

Covers well nos. 126, 26 and River Solani.

Distance between well nos. 126 and 26 0.55 miles

Distance between well nos. 26 and River 0.60 miles

Years	Water Level (in feet) Well No.126	Well No.26	Difference in water levels (in feet)	Average difference in water level (in ft.)	Average Hydraulic Gradient (ft. per ft.)
1	2	3	4	5	6
1961	-	878.56			
1962	886.03	881.26	+ 4.77	+ 4.77	+ 0.0016
1963	-	877.85			

Section No.4:

Covers Well nos. 125, 25 and River Solani.

Distance between well nos. 125 and 25 0.75 miles

Distance between well nos. 25 and River 0.75 miles

Year	Water levels (in feet) Well No.125	Well No.25	Difference in water levels (in feet)	Average difference in water level (in ft.)	Average Hydraulic Gradient (ft. per ft.).
1	2	3	4	5	6
1961	-	884.97	-		
1962	886.23	885.09	+ 1.14	+ 1.22	+ 0.0003
1963	883.32	882.02	+ 1.30		

Section No.5:

Covers well nos. 122, 20 and River Solani

Distance between well nos. 122 and 20 — 0.65 miles

Distance between well nos. 20 and River — 0.80 miles

Reduced level of the Bed of river Solani — 843.94 ft.

Year	Water Levels (in feet) Well No.122	Well no.20	Difference in wate? levels (in feet)	Average difference in water level (in ft.	Average Hydraulic gradient (ft. per ft.)
1	2	3	4	5	6
1961	861.83	841.02	+ 20.81		
1962	860.88	843.67	+ 17.21	+ 17.72	+ 0.0052
1963	858.43	843.29	+ 15.14		

Section No.6:

Covers wells Nos. 77, 78 and River Solani

Distance between well nos. 77 and 78 — 0.95 miles

Distance between well nos. 78 and River — 1.10 miles

Year	Water Levels (in feet) Well No.77	Well No.78	Difference in water levels (in feet)	Average differe-nce in water level (in ft.)	Average Hydraulic Gradient (ft. per ft.).
1	2	3	4	5	6
1961	822.78	818.19	+ 4.59		
1962	822.89	818.70	+ 4.19	+ 4.04	+ 0.0008
1963	820.48	817.15	+ 3.33		

Section No.7:

Covers well Nos. 83, 84, 81 and Solani River

Distance between well nos. 83 and 84 — 0.60 miles

Distance between well nos. 84 and 81 — 0.60 miles

Distance between well nos. 81 and Solani — 0.90 miles

Year	Water Level (in feet) Well No. 83	Well No. 84	Well No. 81	Difference in water levels (in feet)	Average differe-nce in water level (in ft.)	Average Hydraulic Gradient (ft. per ft.).
1	2	3	4	5	6	7
1961	-	804.53	813.95	- 9.42		
1962	804.78	808.29	814.10	(i) - 3.15	- 9.50	- 0.0015
				(ii) - 5.81		
1963	803.48	808.29	813.15	(i) - 4.81		
				(ii) - 4.86		

It may be noted that (+) sign indicates effluent hydraulic gradient and (-) sign indicates influent hydraulic gradient. Section No.7 falls under influent nature of the river course. This Section is below the confluence of Solani and Ratmau Rao rivers. All the Sections above this confluence indicate effluent nature of the river Solani. The average hydraulic gradient of all the 6 Sections above the confluence works out to be 0.004 ft./ft.

Based on the above data, the amount of effluent drainage is calculated as follows:

Q (Effluent Drainage in cusecs per mile length of the river per year)	=	$\frac{T \times \Sigma Gradient}{122}$ ...(Same as equation No.xxvii)
Length of the River Solani upto its confluence with Ratmau Rao.	=	20 miles
Thickness of strata through which percolation is taking place (estimated roughly from the reduced level of the river bed and water levels in the wells)	=	15 feet
Average Field Permeability (P_f)	=	1000 (US) GPD/ft.^{2}
Transmissibility (T) computed from above data for the strata through which percolation is taking place. (T = m P_f: m being the thickness of the strata facilitating percolation).	=	15,000 (US) gpd/ft.
Average Hydraulic Gradient	=	0.004 ft./ft.
Σ Gradient (Double the gradient on one side; to cover the same on the other side)	=	0.008 ft./ft.

Substituting the above values in equation No.xxvii, we obtain the effluent drainage to the River Solani per mile length.

$$Q_1 = \frac{T \times \Sigma Gr}{122}$$

$$= \frac{15,00 \times 0.008}{122}$$

$$= 0.9835 \text{ Cusecs per mile}$$

Q_1

(Effluent Drainage towards Solani River for 20 miles Section in the area)	=	0.9835 x 20
	=	19.67 cusecs.
	=	14,240 Acre ft./year.

B) Ratmau Rao (River):

Section No.1:

Covers well nos. 172 and 163 and River Ratmau Rao.

Distance between well nos. 172 and 163 — 0.70 miles

Distance between well nos. 163 and River — 0.45 miles

Year	Water Levels (in feet) Well No.172	Well No.163	Difference in water levels (in feet)	Average difference in water level (in ft.)	Average Hydraulic Gradient (ft. per ft.).
1	2	3	4	5	6
1962	923.24	914.56	+ 8.68	+ 8.62	+ 0.0023
1963	921.68	913.11	+ 8.57		

Section No.2:

Covers well nos. 171, 161 and River Ratmau Rao.

Distance between well nos. 171 and 161 — 0.85 miles

Distance between well nos. 161 and River — 0.45 miles

Year	Water Levels (in feet) Well No.171	Well No.161	Difference in water levels (in feet)	Average differe-nce in water level (in ft.)	Average Hydraulic Gradient (ft. per ft.)
1	2	3	4	5	6
1962	911.21	905.76	+ 5.45	+ 3.82	+ 0.0012
1963	906.13	903.94	+ 2.19		

Section No.3:

Covers well nos. 142, 143 and River Ratmau Rao.

Distance between well nos. 142 and 143 — 0.85 miles

Distance between well nos. 143 and River — 0.70 miles.

Year	Water Levels (in feet) Well No.142	Well No.143	Difference in water levels (in feet)	Average Difference in water level (in ft.)	Average Hydraulic Gradient (ft. per ft.)
1	2	3	4	5	6
1962	824.92	821.39	+ 3.54	+ 3.25	+ 0.0010
1963	824.23	821.27	+ 2.96		

Limited distribution of the wells prevented similar analysis for more number of sections along the river course. The gradients obtained along the present sections indicate that the river Ratmau Rao is effluent through-out its course in the area of study.

Based on the above data, the amount of effluent drainage is calculated as follows:

Length of the river Ratmau Rao in the area	=	20 miles
Thickness of strata through which seepage takes place (assumed)	=	15 feet.
Average Field Permeability (P_f)	=	1000 (US) GPD/ft.^{2}
Transmissibility (T) computed from above data for the strata through which percolation is taking place ($T = m P_f$; m being the thickness of the strata facilitating percolation)	=	15,000 (US) gpd/ft.
Average Hydraulic Gradient	=	+ 0.0015 ft/ft.

Σ Gradient (To cover the hydraulic gradient on both the sides of the river bed, the worked out gradient is doubled)	=	+ 0.0030 ft/ft.
Q_2 (Effluent drainage towards Ratmau Rao per mile)	=	$\frac{T \times \Sigma Gr}{122}$
	=	$\frac{15.000 \times 0.003}{122}$
	=	0.376 cusecs per mile.
Effluent drainage towards Ratmau Rao for 20 miles section in the area	=	0.376 x 20
	=	6.52 cusecs
	=	4,720 Acre ft./ years.

The total effluent drainage in the region towards Solani and Ratmau Rao rivers will be the sum of Q_1 and Q_2 derived above.

Total Effluent Drainage	=	$Q_1 + Q_2$
	=	14,240 + 4,720
	=	18,960 Acre ft./year
	(Say	19,000 Acre ft./year)

ii) <u>OUTFLOW FROM THE AREA DUE TO NATURAL HYDRAULIC GRADIENT OF THE WATER TABLE:</u>

The water table map constructed for the shallow aquifer (Plate No.XIV-C) indicates a hydraulic gradient on an average 10 feet per mile in the South-Eastern part and 5 feet per mile in the South-Western part of the area for 10 miles and 6 miles outlet cross sections respectively. The saturated part of the aquifer material within 75 feet thickness of the alluvium along these sections will be of the order of 50 feet. The average permeability of the water transmitting sands will be 1000 (US) gpd/ft.^{2} (refer page 204).

The out-flow from the area due to continuous ground water movement is equal to the product of transmissibility (T) hydraulic gradient (I) and the width of the cross section through which flow occurs (L).

Out flow from the area = T I L

$$= \frac{50,000 \times 10 \times 10 \times 365}{325850} + \frac{50,000 \times 5 \times 6 \times 365}{325850}$$

= 7,283 Acre ft.

(Say 7,300 Acre ft.).

iii) DRAFT DUE TO EVAPOTRANSPIRATION LOSSES:

In areas where the water table or capillary fringe is fairly high, water can be taken into the roots directly by plants and discharged by way of transpiration and evaporation. In the area under study, large tracts are under irrigation and fairly thick vegetation cover and the post-monsoon regional water table is fairly high. As such, it is reasonable to assume losses through evapotranspiration as a contributory factor towards the total draft in the region.

Since data on evapotranspiration measurements in the area is not available, an indirect approach to its rough estimate has been attempted. In the area under consideration, it has been stated(refer page 203) that the resultant recharge through rainfall infiltration will be of the order of 49,000 Acre ft. after deducting 50% as evapotranspiration and sub-surface drainage in the region. The sub-surface flow as effluent drainage in the area is of the order of 19,000 Acre ft. As such the draft due to evapotranspiration losses will be 30,000 acre feet (49,000 - 19,000 Acre ft.).

iv) DRAFT BY MEANS OF OPEN WELLS:

It can be infewred from Appendix No.1 that many of the shallow open wells are not put to full use in the area for heavy irrigational purposes. This may be due to availability of canal and tubewell water supplies. However, they are still being used for drinking purposes. The draft from these wells is of limited magnitude. Assuming about 1000 open wells in all, in the area and an extraction rate of nearly 5 acre feet per well per year, the total draft by way of operation of open wells works out to be 5,000 Acre ft.

PART - B:

CONFINED GROUND WATER RESERVOIR:

The hydrological parameters of the alluvial aquifers occurring usually below hundred feet depth in the area indicate occurrence of ground water under confined conditions in these formations. In the quantitative assessment studies of such confined aquifer/group of aquifers/or reservoir, the essential components of importance are recharge and draft. The recharge is influenced by such factors as (i) rate of recharge to the confined aquifers (ii) addition to storage (iii) downward leakage through the confining layer. The draft is influenced by factors like (i) pumpage through tubewells (ii) decline of piezometric head and change in storage (iii) upward leakage through the confining layer.

The extent and nature of confined aquifers, their response to natural and artificial influences and their quantitative aspects are best studied in areas which are strewn with large number of tubewells. Under the present investigation the well field west of Solani River course constitutes the area of study on the quantitative aspects of the confined reservoir. In the North-eastern part there is hardly any scope for this aspect of study.

RECHARGE TO CONFINED GROUNDWATER RESERVOIR:

i) RATE OF RECHARGE TO CONFINED AQUIFERS:

Since the confined aquifers do not expose any-where close to the area, the evaluation of recharge to the reservoir may be through flow-net analysis for the developing well field areas in the region. This has been attempted for the Landhaura well field area and the rate of recharge is estimated as 340,000 gpd/sq. mile (refer Chapter III, page 49). The area lying west of Solani river course will be about 125 sq. miles in areal extent. As such, the rate of recharge to the confined reservoir amounts to 42.5 million gallons per day or 47,600 Acre feet per year.

ii) ADDITION TO STORAGE:

An analysis of the water levels in the tubewells in 1963 for Landhaura well field area indicated a general decline in the piezometric head of the order of 3.50 feet. This acts as a pointer towards the fact that there is some draft in the reservoir which could be accommodated in the storage. This has been further discussed in the following pages.

iii) DOWNWARD LEAKAGE THROUGH THE CONFINING LAYER:

It has been pointed out elsewhere in this Chapter (Page 228) that no large scale leakage through the confining layer, separating the water table aquifers from the confined ones, is inferred at this stage of ground water development of the confined reservoir. But in the area under study special cases, such as canal bed infiltration, may influence some leakage through the confining beds. The Upper Ganges Canal in the area is in operation for the last 120 years. The cumulative effects of vertical percolation from the canal bed and through the confining layers in course of years cannot be altogether ignored. There is a possibility that the perennial canal can influence this way even the group of confined aquifers below 100 feet depth in the region if other hydraulic factors are also congenial. The present data is insufficient to permit any generalisation on the quantitative aspects of such recharge to the confined aquifers.

DRAFT IN THE CONFINED GROUNDWATER RESERVOIR:

i) DRAFT CREATED BY PUMPAGE THROUGH TUBEWELLS:

Pumpage from tubewells is an important component in estimating the draft of any ground water reservoir. As such, the data regarding the total number of hours each tubewell was run in every year since its inception and the average rate of discharge of the tubewell were collected from 68 tubewells located in the area for the period 1937 -'38 to 1963 - '64. This number includes the water supply wells of the Roorkee Municipality (2 wells), University (6 wells), Research Institutes (2 wells) and Military Cantonement (4 wells). The draft from each well is calculated by multiplying the rate of discharge per hour by the total number of hours the well was put to use during the year. The total amount of withdrawal from the area by means of the tubewells is calculated by summing up the total discharge figures of all the wells in the area for each year. The total draft year-wise in the area (for 26 years) is given in Table No.37 below:

TABLE NO.37:

TOTAL ANNUAL DRAFT FROM TUBEWELLS IN ROORKEE AREA:

Year	No. of tubewells commissioned	Annual draft in Acre ft.
1	2	3
1937-38	7	1069
1938-39	7	1379
1939-40	7	1414
1940-41	10	1981
1941-42	10	2062
1942-43	11	1971
1943-44	12	2223
1944-45	13	2263
1945-46	13	2320
1946-47	13	2072
1947-48	13	2354
1948-49	13	2468
1949-50	12	2711
1950-51	12	2782
1951-52	15	3110
1952-53	16	3913
1953-54	20	3699
1954-55	42	7088
1955-56	53	6741
1956-57	55	7646
1957-58	55	9978
1958-59	56	11657
1959-60	58	11724
1960-61	58	15592

1	2	3
1961-62	58	13614
1962-63	57	16428
1963-64	68	20859

It may be seen from the table that with 68 tubewells in commission the total draft in the year 1963-64 is of the order of 20,860 Acre ft.

ii) DECLINE OF PIEZOMETRIC HEAD AND CHANGE IN STORAGE:

It has been stated earlier (Chapter III, page 48) that the well field area close to Landhaura, has shown a depression of nearly 3.50 feet in the year 1963 at the centre of the area utilised for flow net analysis. The areal extent of this is of the order of 15 sq. miles. As the recharge for the well field area works out to be 340,000 gpd/sq. miles, the total recharge for the above stated area works out to be 5,700 Acre ft. The draft exclusively from the tubewells lying within and close to the flow-net analysis area (State Tubewells Nos. 1,2,4,5,7,8,9,10,11,12,13,14,16,19,20,21,40,41,42) is of the order of 7,150 Acre ft. (average of 62-63 and 63-64 drafts). This is in excess by 1,450 Acre ft. to the recharge of the area in 1963. It is not unlikely that because of this additional draft, there is decline in the piezometric head in the year 1963.

iii) UPWARD LEAKAGE THROUGH THE CONFINING LAYER:

In the area under study, there is no recognisable feature (difference in water levels in the shallow and confined aquifers) which warrants analysis of upward leakage through the confining layers.

DISCUSSION ON GROUND WATER BALANCE:

Referring to water balance in aquifers Schoeller(36) remarked that "ground water balance is still a nagging question mark in hydrogeology". He further writes that it is of first importance since the practical aim of hydrogeology is, finally, to determine the groundwater resources available for use. Much of the development of the methods and skills for quantitative appraisal of ground water has occurred within the past few decades. This is a natural outgrowth of the ever expanding use of this resource and its increasing economic value.

Attempts on the quantitative ground water studies in Gangetic alluvium dates back to 1934 when Mackenzie Tylor, initiated such studies before launching the Ganges Valley State Tubewell Irrigation Scheme. Later, attempts in this direction are very limited. These studies from the field point of view have been revised since 1960. In the State of Uttar Pradesh, the Ganges-Yamuna Doab ground water potentials have been assessed by the Irrigation Research Institute,(11) Roorkee. Similarly, the quantitative aspects of ground water studies have been attempted by the Exploratory Tubewells Organisation in parts of Aligarh, Etah and Bullandshahr districts and Ghaziabad area of Western Uttar Pradesh.(13) Potentialities of the same area together with those available in Meerut District have also been studied by the Civil Engineering Department of the University of Roorkee.(41) Studies partly on the quantitative aspects of ground water have been attempted by the Geological Survey of India, in parts of the Eastern Uttar Pradesh around Azamgarh. These studies have brought out some qualified answers to the problems of ground water assessment, in the region.

In the present area of investigation which forms a contiguous belt of the above mentioned places of study, no attempt in regard to ground water balance has been made earlier. The study involves measurements of all the components given in the ground water balance equation which runs as follows.

$$A + (I + R_p) + D = T + E + C + O + (P \pm V.S) \quad ...(xxviii).$$

Where	A	=	Percolation from surface stream
	I	=	Inflow into the basin from the surrounding area.
	R_p	=	Rainfall penetration
	D	=	Deep percolation from artificial irrigation.
	T	=	Transpiration losses
	E	=	Evaporation losses
	C	=	Effluent Seepage
	O	=	Out-flow from the basin into the surrounding area.
	V	=	Volume of ground unwatered (or watered)
	V.S.	=	Change in ground water storage.
	P	=	Pumpage
	S	=	Specific Yield of the formation.

In the components mentioned above, the surface discharge measurements of Solani River within the area of study are not available. Since it is shown (Chapter III page 51) that ground water contribution (both from shallow and deep aquifers) is mainly towards the base-flow of the river Solani which in turn finds way to the swampy region further South of the area, this component plays limited role in the evaluation of the total perennial water resource available for future development.

Most of the ground water assessment investigations are generally initiated to find out whether overdrafts exist in the well field areas. The present study has been initiated with a view to know the existing draft in the area and to work out the additional tubewell potential for the region with the help of the assessed recharge and useable ground water storage of the reservoirs. Such studies would facilitate planning future area-wise ground water development. This study based on the pump test and well log data together with measurements of hydrological components of the ground water balance equation permitted a useful first evaluation of the total sub-surface water resources within the limits of time and facilities imposed upon the investigation.

The evaluation of the water balance in the area, has been attempted under two heads namely, (i) shallow ground water reservoir and (ii) confined ground water reservoir. Before we proceed on the balance studies, it is worth while to recall the statement of Keech (75) that, "the amount of water in storage in a ground water reservoir, is however, no indication of that reservoir's capabilities for sustained yield to wells and springs. The perennial yield is limited by the average annual recharge to the reservoir, just as the useful yield of a surface reservoir is limited by the inflow into it".

GROUNDWATER BALANCE OF SHALLOW RESERVOIR (WATER TABLE AQUIFERS):

The ground water balance of the shallow aquifer is indicated by the major components of the ground water equation below:

a)	Groundwater storage (Leaving 50% reserve) in a 250 sq. mile area, the group of aquifers within 75 feet depth.	:	390 thousand Acre feet.

b)	Recharge through Precipitation	:	98,000 Acre ft.
c)	Inflow (Recharge) to the Basin	:	3,600 Acre ft.
d)	Seepage from canal banks	:	23,000 Acre ft.
e)	Total recharge to the shallow Reservoir (b + c + d)	:	124,600 Acre ft.
f)	Draft due to Effluent Drainage	:	19,000 Acre ft.
g)	Evapo-transpiration losses:	:	30,000 Acre ft.
h)	Outflow from the basin	:	7,300 Acre ft.
	Note: (f + g) constitute 50% of (b) as explained at page No.202.		
i)	Draft due to open wells	:	5,000 Acre ft.
j)	Total existing Draft in the shallow Reservoir (f + g + h + i + j)	:	61,300 Acre ft.
k)	Ground water Balance (e - j)	:	63,300 Acre ft.

The excess ground water could be utilised for various purposes without disturbing the ground water storage of the shallow reservoir which is of the order of 390 thousand Acre ft. In view of these two factors (reasonable recharge to the area and large storage) the question of mining ground water (usage of ground water storage in excess to recharge) will not result in the near future in the area. From the figures on the amount of recharge to the shallow aquifer it is evident that recharge due to rainfall infiltration is the major factor. The method of estimating ground water recharge to the shallow aquifer by application of rise of the regional water table and specific yield, has not been adopted in this area as the water level inventory data are available only for the low water table periods (summers). It is also evident from the balance analysis that to the shallow ground water body, the inflow into the basin due to natural hydraulic gradient is almost half that of the out flow. This is attributable to the low transmissibilities in the North and Northwestern parts of the area compared to the high transmissibilities of the aquifer sands in the Southern part.

The enormous amount of water (98,000 Acre ft.) getting infiltrated into the shallow ground water body through precipitation, gets fairly balanced with the effluent drainage to the river Solani (19,000 acre ft.) and evapotranspiration losses (30,000 acre ft.). It may be recalled that the river Solani almost spreads into a swampy region of nearly 40 sq. miles area close to its confluence with the river Ganges (Chapter II, page 32, Plate No.XII). The swampy region starts almost two to three miles South of the area of present study. A major part of the sub-surface flow of river Solani finds an out-let into the swampy region and gets into the cycle of large scale evapotranspiration from a surface body (Swamp) of nearly 40 sq. miles areal extent. It is not unlikely that the rest flows into the River Ganges. The effluent drainage from the shallow aquifer explains the perennial nature of the rivers in the area and also that of the swampy lake region close to the confluence of river Solani with the Ganges.

GROUND WATER BALANCE OF THE CONFINED RESERVOIR AND ASSESSMENT OF ADDITIONAL TUBEWELL POTENTIAL:

The components of the ground water balance equation for the Confined Reservoir are usually limited. For the area of study they are recorded as follows:

a)	Rate of recharge to the confined aquifers:	47,600 Acre ft.
b)	Addition to Storage:	Do not figure in this case.
c)	Leakage (?) Contribution from the Confining bed:	1,400 Acre ft.
d)	Total Recharge to the Confined reservoir: (a + c)	49,000 Acre ft.
e)	Pumpage draft for the entire area: (250 sq. miles)	20,860 Acre ft.
f)	Balance for the entire area: (d - e)	28,140 Acre ft.

In the balance assessment it has been left as a doubt whether the contribution through the confining bed is considered as recharge or not. While reviewing the decline of piezometric head and change in storage (page 224) it has been stated that the draft in the Landhaura well field area is in excess by 1450 Acre ft. to the recharge in 1963. This excess if taken from the storage should be equal to the product of the depression in the area, the areal extent of the well field area effected by the depression and the storage coefficient. But this figure hardly represents 12 Acre ft. In view of this, the source regarding the amount of excess water of the order of 1400 acre ft. taken out from the reservoir in the year 1963 could not be ascertained fully with the present knowledge of the well field area. In the absence of any other recognisable source of recharge contributing to the confined reservoir, it may not be altogether wrong if it is attributed to some contributions through leakage from the confining bed. But this minor leakage is not reflected in the magnitude of the coefficient of storage value for the aquifers (Page 90). Under these conditions, it would be necessary to repeat the earlier stated fact (page 105) that the present data do not warrant generalisation in regard to leaky confining beds.

Based on the above the excess ground water available in the present well field area (West of Solani River), could be utilised further for irrigational and allied purposes. Since the ground water is mainly used for irrigational purposes in the area, an attempt has been made below to figure out the additional tubewell potential and the spacing of the wells in the area for optimum utilisation of the excess available ground water in the confined reservoir.

According to the existing norms, an irrigation well of 1.5 cusecs capacity put to 4000 running hours per year is considered economical in the Gangetic alluvial plains of Western Uttar Pradesh. The volume of water pumped out from such a well each year is of the order of 500 acre ft. Hence the equivalent of tubewells of 1.5 cusecs capacity in 125 sq. miles area south of Roorkee is as follows:

$$\frac{28,140}{500} = 56$$

The additional potential, apart from the existing irrigational wells, will be 56. These have to be spaced along with the existing 68 wells in an area of 125 sq. miles West of Solani river. This works out to be one well of 1.5 cusecs capacity per square mile or 640 acres. The rate of pumping at this capacity and density of wells do not act in any way detrimental to the safe extraction of ground water from the area.

It may be added here that earlier studies in Aligarh - Hathras area by Chaturvedi (41) showed a similar spacing for wells of same capacity for optimum ground water development in the confined aquifers of the region. Similar studies by the writer (13) in Atrauli area gave the safe extraction figure as 1.5 cusecs per well per square mile for water table conditions. In Muzaffarnagar area, Chaturvedi (41a) indicates 2.3 cusecs wells per sq. mile as safe spacing for the development of the water table reservoir.

It may be noted that this potential works out only for the confined aquifers down to a depth of 300 feet. It is worthwhile assessing the ground water potential of the deeper aquifers below 300 feet depth independently. If the area East of the Solani river (125 sq. miles) is also considered the additional potential in the entire 250 sq. miles area will be to the tune of about 175 tubewells as there are at present only 4 or 5 tubewells in the area East of the Solani river. Further, in due course of ground water development if the hydraulic gradients existing in the confined reservoir are reversed especially close to the river Solani in the well field area, it would facilitate enormous scope for larger ground water development in future than what has been hither-to conceived.

CONCLUSIONS:

1) Quantitative ground water assessment studies have been attempted in an area of about 250 sq. miles around Roorkee with a view to determine (a) the amount of recharge to the

shallow water table and deep confined aquifers (b) the amount of storage in the aquifers (c) rate of present ground water withdrawal (d) its effect on the available supply (e) the amount of natural drainage (f) the amount of salvage from the inflows and outflows to the reservoir and (g) the optimum development of the ground water reservoirs. In evaluating this, the components of the ground water balance equation are worked out both for the shallow ground water reservoir constituting the water table aquifers as well as for the confined ground water reservoir in the area.

ii) The ground water storage for the shallow reservoir is of the order of 390 thousand acre ft. The ground water balance studies for the reservoir indicate an excess water source of the order of 63,300 acre ft. due to recharge. This potential could be utilised for irrigation or allied purposes. It has further been shown that the sizable recharge to the shallow aquifer through precipitation (50,000 acre ft.) and the effluent drainage draft of the reservoir, contribute towards the base flow of the river Solani. This flow finds its out-let into the swampy region just south of the area and explains its perennial nature.

iii) The ground water balance worked out for the confined group of aquifers within 300 ft. depth in the present well field area West of Solani river, indicates an additional recharge of 28,140 acre ft. to the reservoir. Based on this available sub-surface water resource, it has been shown that the well field area supports an additional potential of 56 tubewells of 1½ cusecs capacity. Their spacing for safe extraction of ground has been worked out as one well per square mile. It has been further indicated through the assessment studies that these potentials through the assessment studies relate to aquifers within 300 feet depth and refer to the area west of Solani river.

If the entire area of 250 sq. miles is considered the additional potential will be to the tune of about 175 tubewells of 1½ cusecs capacity as there are very few tubewells existing at present in the area East of Solani river.

— ... —

CHAPTER IX:

SUMMARY:

The twentieth century civilisation faces the major problem of coping up with ever increasing demands of water. In a way to meet this challenge and solve these problems, growth of inter-disciplinary sciences of scientific hydrology have advanced since the beginning of this century. In India, increased demand for water has stimulated development of undergroundwater resources also. But progress in this direction was rather slow in the early parts of the century.

Of late, the pressing demand for quick returns in agriculture has also necessitated the utilisation of ground water resources on a more intensive manner. In order to fulfill this need, the quantitative and large scale applied aspects of studies in ground water geology and hydrology have assumed new significance in this country. As part fulfillment of this objective, the writer attempted the evaluation of the groundwater resources in parts of District Saharanpur with a bias on the applied aspects of research. It is hoped that these methods of study would find application elsewhere in the country also.

The present investigation is a scientific study of the ground water problems of the Indo-Gangetic alluvium covering nearly 250 sq. miles, around Roorkee in Saharanpur District of Uttar Pradesh. Special emphasis has been laid for the collection and interpretation of a large number of observations on ground water data covering nearly a period of four years.

In order to build up complete understanding of the occurrence, movement and behaviour of ground waters, a comprehensive account of regional geology, sedimentological aspects of the soils and aquifer sands, geomorphic history and land form evaluation, isopach representation of the ground water reservoirs are given under Chapter II. From these studies it can be inferred that the soils in the area are predominantly sandy in nature and the clay fraction is low. Most of the sands, constituting the aquifer beds, are 'medium sands' and they are well sorted. It has also been shown that no relationship exists between the mean diameter and the sorting coefficient of the sediments. From the base map of 'former drainage trends' (based on aerial photographs) it has been shown that the area has suffered many a meandering in the West, North and Northeast of Roorkee town. The study of the isopach map for the near surface sandy horizon (50 feet depth) indicates a distinct sandy horizon southeast of Roorkee, presumably a mixed one southwest of it and a predominantly clayey one, northwest of the town proper. Similarly, a noteworthy feature of the isopach map representing the productive formations in the depth zone 100-300 feet is their limited thickness in the North-western part and a gradual increase in thickness in the southeastern end of the area of study.

An analysis of ground water flow situation has been attempted under Chapter No.III with the help of water level data, pressure heads, flow lines and flow nets. This investigation reveals that ground water occurs both in confined and non-confined conditions in the alluvial formations. Productive aquifers are usually encountered in the depth zones 100-175, 220-300 and 400-460 feet. The cumulative pressure head recorded by these aquifers is 20-30 feet below land surface. The disposition of the water table is Northwest to South-east in the area west of Solani River and North to South in the area East to Solani River. The hydraulic gradients of the near surface ground water range from 9 to 15 feet per mile while the same as revealed by the piezometric map is of the order of 6 to 16 feet per mile. The flow lines on the water table and the piezometric maps reveal that the main recharge to the ground water body is from a source North and North-west of the area. The Hindan and Kali nadi act as a source point of recharge to the confined aquifers. The Terai and the Bhabar belts act also as the intake areas for the ground water available in and around Roorkee. Through flow-net analysis it has been computed that the rate of recharge to the well field area around Landhaura (Roorkee) is of the order of 340,000 gpd/sq. mile and the withdrawal from the storage is very negligible.

In analysing ground water situations, it would be necessary to figure out the hydrogeologic parameters of the aquifers under study -- transmissibility, storage and field permeability coefficients. Without this it would be difficult to understand the response of the ground water reservoirs to heavy pumping. The limitations of analytical methods in the evaluation of the hydraulic properties of the confined aquifers have been reviewed under Chapter IV. The hydrological test data has further been utilised to work out the well characteristics such as well losses, formation losses and entrance velocities.

The storativity parameter for the well field area of Roorkee obtained through the analysis of pump test data is of the order of 3.70×10^{4}. The transmissibility values for the alluvial aquifers in the region vary from 41,000 to 1,85,000 gpd/ft. The field permeability coefficients range almost from 500 to 1900 gpd/sq. ft.

It has been concluded that the water bearing formations below hundred feet depth in this area conform to the elastic conditions normally met within the confined aquifers. Through these studies it has also been pointed out that the existence of diverse hydrogeological settings govern the occurrence of ground water in the Ganges Valley. It has further been substantiated that in the Valley alluvium, boundary conditions do prevail and influence the analysis of hydrological parameters even within short periods of straining the aquifers by pumping. In view of this it has been observed that ultimate ground water development in the Ganges Valley is hinged to careful evaluation of the geohydrologic parameters including the vertical drainage and thickness of the confined layers (aquifers).

The geomorphic history of the region has been deciphered and through these studies coupled with aerial photographic interpretation it has been proved that the marked variations in the formation constants at short distances in the alluvial formations of the Ganges Valley have a definite bearing to the lithogenetic variations introduced by former drainage patterns. It has been shown that the geomorphic history of the region explains many of the apparently anomalous ground water situations. An hydrogeological map showing the aerial distribution of the specific capacities of the alluvial aquifers has been brought out for the Roorkee area and it has been shown that such maps act as useful tools for the interpretation of ground water situations as they reflect indirectly the transmissibility distribution of the water bearing formations.

The studies on the well characteristics established that in the area under study, the important components influencing total drawdown in a pumped well are the formation and well losses. The other components are negligible in magnitude. It has been established that the predominance of formation losses over the well losses are due to frequent 'Cut outs' in the alluvial formations and their effects on the hydraulics of flow towards the discharging wells. The safe range of entrance velocities in the pump tested wells (of the order of 0.046 ft./Sec. to 0.092 ft./Sec.) also contribute en a large measure towards the low range of well losses. Further, the applied study has shown that the application of empirical procedures in the determination of well characteristics should be carried out with caution for water wells located in unconsolidated alluvial formations. The graphical method is preferred. The latter method should be used to supplement analysis of data by the empirical method.

Although in the knowledge of the writer, the application of statistical methods to solve ground water problems have not been widely used, the same has been given a treatment under Chapter V. It is evident that the technique of subjecting ground water data to statistical methods proves useful for the ground water regime analysis. In this regard statistical correlation methods have been employed for determining the basic factor/or factors influencing any given element of the water regime. Under the presen attempt the ground water regime close to the non-masonary part of the Upper Ganges Canal has been studied at six hydrogeological stations. As a prelude to the statistical analysis the effects of artificial and meteorological factors affecting the ground water table in the area have been discussed. The correlation coefficients for the variables (a) water levels in the preceding and following months (b) Rise/fall of water levels versus rainfall and (c) water levels versus canal flow or discharge in the canal have been derived by applying two statistical methods of linear correlation successfully. This method of analysis also helped in the evaluation of the basic factor influencing any given element of ground water regime. Under this Chapter, the sub-surface geology of the area has been brought out by drawing a panel diagram using the borehole data. Its role as one of the factors influencing ground water fluctuations has also been discussed.

Thermograph studies act as useful tools in the interpretation of selective hydrogeologic regime situations such as recharge conditions close to streams, ground water velocities, analysis of reverse water level fluctuations and relation between different aquifers. Under Chapter VI, an attempt has been made to study the effects of canal water temperature and air temperature on the near surface ground waters. Further, the relationship of thermal regime to depth of water table and depth of observation stations has also been investigated. The study has established a linear relationship between the average of depth to water table and depth of the station (mid-point of the water column) and magnitude of difference in the maximum and minimum of ground water temperatures. Deviation from this relationship is noted for stations situated close to the canal. This anomaly is explained as due to the influx of canal water into near surface ground water. It has further been shown that the magnitude of such deviation from the general relationship is inversely related to the distance of the station to the surface water body. The trends of canal water and air thermographs in comparison to the ground water thermographs have been studied. It has also been established that the mean annual ground water temperatures at very shallow depths (within 5 feet from land surface) follow closely the mean annual air temperatures. The significantly low temperature of the canal water during summers is attributed to the thawing of the ice in the source region of the streams which feed the Upper Ganges Canal. These studies have been attempted almost for the first time and need to be projected in other settings close to the Upper Ganges Canal and other Canal systems in the Indo-gangetic plain.

Ground water studies aimed mainly towards establishment of sub-surface water resources are, of late, considered unimportant unless chemical quality of the waters is assured to be satisfactory. Geo-chemistry of ground waters has to be studied with special reference to the need for which the water is put to maximum use. As such, under Chapter VII, the chemical nature of natural waters are studied with special reference to their use mainly for irrigational purposes. The ground water in the shallow aquifers is proved to be rich in bicarbonates. The confined ground waters are classified as class I according to Scofield classification, 'Excellent to Good' as per Wilcox diagram, 'Low in salinity and Sodium hazards' as per SAR-diagram and as ~~waters~~ 'waters dominated by alkaline earths and weak acids' as per diamond plot. The concentration of bicarbonates in the shallow and confined aquifers is due to the reaction of the formation waters with the organic materials associated with the alluvial formations and partly to the favourable chemical zonation by climate. The significantly low Sulphate waters from the confined aquifers is also explained as an action of formation waters, in time, on the organic materials associated with the alluvial aquifers. It has been proved that there is no recognisable phenomena of intermixture of waters in the deeper aquifers. It has also been established that there is no marked variation in the chemical regime of confined waters from areas of intake to areas of exit. The waters sampled from the entire well field area of Roorkee covering nearly 125 sq. miles, when subjected to various classifications, uniquely demonstrated their closeness in chemical natûre in all the plots, indicating that there is good deal of homogeneity in the confined ground waters. This phenomenon is not very common.

During recent years, ground water reservoir investigations without assessment on the total useable sub-surface water resources, are considered unrealistic. As such, quantitative ground water assessment studies have been attempted in Chapter VIII as the practical aim of hydrogeology is, finally, to determine the ground water resources available for use. These studies have necessitated the measurements of total storage, movements, recharge, discharge or draft and allied components in order to identify the functional conditions of the ground water system. The components of ground water balance equation are worked out both for the shallow ground water reservoirs constituting the water table aquifers as well as for the confined ground water reservoir in the area. The balance studies indicate an excess water source of the order of 63,000 acre ft. due to recharge to the shallow aquifer. The same for the confined aquifers West of Solani only is of the order of 28,000 acre feet. Based on this available sub-surface water resource, it has been shown that for the entire area of 250 sq. miles the additional potential of tubewells of 1½ cusec capacity would be of the order of 175. Their spacing has been worked out as one well per square mile. These potentials relate only to aquifers within 300 feet.

Since ground water studies demand collection of data for reasonably projected periods, the present study is supported by field data and inventory over a period of four years from 1960-64. This has proved useful for the overall analysis of ground water regime in the area. In the end, it may be added that the results of this study and methodology may prove to be of practical use for analysing ground water situations elsewhere in the Gangetic Valley which is considered as the biggest ground water basin of the country.

— ... —

REFERENCES:

The following list contains only papers referred to in the text of the Thesis. It does not, however, include others referred to in the course of the work.

1. Sir William Stampe - 1936 "The Ganges Valley State Tubewell Irrigation Scheme" U.P. State Government Publication.

2. Auden, J.B. - 1935 Report on "Possible lowering of water table in U.P. as a result of Tubewell Pumping" U.P. Govt. Publication.

2a) -do- - 1934 "The Geology of the Krol belt" Rec. Geol. Surv. Ind. 67, pp. 357-454.

2b) -do- - 1939 "The structure of the Himalaya in Garhwal" Rec. Geol. Surv. Ind., 71, pp. 409-433.

3. Nautiyal, S.P. - 1955 "Artesian water supply of the Terai and Bhabar, Nainital District, Uttar Pradesh". PROC. of the SYMPOSIUM ON GROUNDWATER in 1955 CENTRAL BOARD OF GEOPHYSICS. GOVT. OF INDIA PUBLICATION - 1958.

4. Shah, D.L. - 1961 "The detailed Geohydrological investigations in the areas covered by the exploratory drilling in district Nainital, U.P. including the Terai colonisation area" G.S.I. Progress Report for the Field Season 1959-60, (unpublished).

5. Pandey, M.P. Raghava Rao, K.V. & Raju, T.S. - 1962 "Groundwater Resources of Terai - Bhabar belt and Intermontane Valley of Western U.P." E.T.O. Tech. Bull. Series A. No.1 (In Press).

6. Dubey, M.C. - 1962 "The detailed Geohydrological investigations in parts of Dehra Dun, Saharanpur districts U.P., and Ambala district, Punjab" G.S.I. Progress Report 1960-61.

7. Pathak, B.D. - 1955 "The occurrence of groundwater in the Alluvial tracts of Uttar Pradesh, India" Proc. of the Symposium on Groundwater in 1955, Central Board of Geophysics, Govt. of India Publication - 1958.

8. Mathur, R.N. - 1961 "Some characteristic features of water table in Meerut Distt. Uttar Pradesh". National Geographical Journal of India, Vol.III, part 4, Dec.'61.

9. Ahmad, F. - 1957 " A Preliminary note on the groundwater conditions in the Ghar area of Saharanpur District, Uttar Pradesh". Proc. Ind. Sc. Cong. 1957.

10. Chaturvedi, R.S. & Mithal - 1963 "Groundwater Studies in Ganges - Ramganga Doab of Bijnor District, Uttar Pradesh" Groundwater Symposium by G.S.I. at Calcutta in 1963.

10a) Mithal, R.S. & Srivastava, L.S. - 1959 "Geotectonic position of Gango - Brahmaputra region" Ist. Symposium on Earthquake Engineering at Roorkee.

11. Dwivedi, N.K. & Gupta, P.N. - 1961 "Behaviour of Groundwater table in Ganga-Yamuna Doab" I.R.I. Roorkee - Tech. Memo. No.31; R.R. (G.42) March,1961.

12. Srivastava, B.P. Jindal, J.S. & Bhattacharya, A.P. - 1953 Annual Report on Research Progress. I.R.I. Roorkee - Tech. Memo. No.24.

13. Raghava Rao, K.V. Raju, T.S., et al - 1965 "Groundwater studies with special reference to quantitative assessment in parts of Aligarh, Etah and Bullandshahr districts, U.P.,India". E.T.O. Tech. Bull. (In Press).

13a) Raghava Rao, K.V. and Raju, T.S. - 1962 "Recent observations on the near Surface Groundwaters along the Upper Ganga Canal in Roorkee area" Proc. Nat. Inst. of Sciences of India, Vol. 28 A, No.4, 1962.

14.	Agarwal, G.C. & Srivastava, J.P.	- 1960	"Geological investigations of Mohund anticline between Mohund and Badshahi-bagh, Dehradun and Saharanpur districts;U.P." O.N.G.C., Progress Report 1959-60, (Confidential).
15.	Agoes, W.B.	- 1956	"Report on Airborne Magnetometer Survey in Indo-gangetic plains, India, Ministry of Natural Resources and Scientific Research, Govt. of India (Under Colombo Plan) Unpublished.
16.	Krishnan, M.S.	- 1960	"Geology of India and Burma" Higginbothams (Private)Ltd., Madras-2.
17.	Wadia, D.N.	- 1957	"Geology of India" Third Ed. Macmillan & Co. Ltd., London.
17a)	Wadia, D.N. & West, W.D.	- 1964	"Structure of the Himalayas" International Geological Congress, 22nd Session, India, 1964.
18.	Sahni, M.R. & Mathur, L.P.	- 1964	"Stratigraphy of the Siwalik Group" - International Geological Congress, 22nd Session, India, 1964.
19.	Picard, L.	- 1953	"Out line on Groundwater Geology in arid regions" Bull. of the Research Council of Israel, Vol. II, No.4, pp. 353-371, 1953, Publication No.139.
19a)	-do-	- 1952	"The History of Groundwater exploration in Palestine" Desert Research, Proceedings of the International Symposium held in Jerusalem, May 7-14, 1952. Research Council of Israel in Cooperation with UNESCO. (Special Publication No.2 of the Research Council of Israel 1953) pp. 583-591.
20.	Chaterji, G.C.	- 1955	"Recent Advances in Groundwater Development" - Golden Jubilee Volume of the Geol. Min. & Met. Inst. of India - 1955.

21. Coggin Brown, J. & Dey, A.K. - 1955 "Mineral Wealth of India" Oxford University Press, London.

22. Lueder, K.D. - 1959 "Aerial Photographic Interpretation" Mc Graw Hill Book Co. Inc. New York.

23. Bandat, Von H.F. - 1962 "Aerogeology" Gulf Publishing Co., Houston, Texas.

24. American Society of Photogrammetrists. - 1961 "Manual of Air Photo Interpretation" Published by the American Society of Photogrammetrists.

25. Walton, C.W. - 1962 "Selected Analytical Method for well and aquifer evaluation" Bull. No.49, State of Illinois Water Survey Division, 1962.

25a) -do- - 1960 "Application and limitation of method used to analyse pumping test data" - Part I and II Water Well Journal. Vol.XV, No.2 and Vol.XIV, No.3, 1960.

25b) -do- - 1960 "Leaky Artesian Aquifer Conditions in Illinois". Report of Investigation No.39. State Water Survey Division, Illinois.

26. Ferris, J.G. et al. - 1962 "Theory of Aquifer Tests" U.S.G.S. Water Supply Paper No.1536-E.

27. Ferris, J.G. - 1955 "The quantitative approach to groundwater Investigations" Eco. Geol.50th Anniversary Vol. Part II (1905-1955).

28. Cooper, H.H. & Jacob, C.E. - 1946 "A generalised graphical method for evaluating formation constants and summarising well field history". Trans. Amer. Geophys. Union Vol. 27. 1946.

29. Jacob, C.E. - 1950 "Flow of Groundwater Engineering Hydraulics". John. Wiley & Sons, New York.

29a) Jacob, C.E. - 1964 "An engineering study to determine optimum water well Design and operational Procedures for ground water development, Western Desert, Egypt (U.A.R.)
(Confidential report made available to the author).

29b) -do- - 1946 "Drawdown test to determine effective radius of artesian well".
Proc. Amer. Soc. Civil Engrs. Vol. 72 (5).

30. Chow, V.T. - 1952 "On the determination of Transmissibility and storage Coefficients from Pumping Test data."
Trans. Amer. Geophys. Union. Vol.33, 1952.

31. Bentall, R. - 1963 "Short cuts and special problems in Aquifer Tests"
U.S.G.S. Water Supply Paper No.1545-C.

32. Theis, C.V. - 1935 "The relation between lowering of piezometric surface and the rate and duration of discharge of a well using ground water storage".
Trans. Amer. Geophys. Union. Vol. 16, 1935.

33. Rorabaugh, M.I. - 1953 "Graphical and theoretical analysis of Step drawdown test of artesian wells"
Proc. Amer. Soc. Civil Engrs. Vol. 79, Seperate No.362.

33a) -do- - 1956 "Groundwater in North Eastern Louisville, Kentucky"
U.S.G.S. Water Supply Paper 1360-B.

34. Todd, D.K. - 1963 "Formulas for Flow through Aquifers"
Water Resources Series No.24; UNESCO.

34a) -do- - 1960 "Groundwater Hydrology"
John Wiley and Sons, Inc. New York.

35. Sandor, C. & Walton, N.C. - 1963 "Yield of Shallow Dolomite wells in Northern Illinois" Illinois State Water Survey Division; Report of Investigation No.46.

36. Schoeller, H. - 1959 "Arid Zone Hydrology - Recent Developments" UNESCO Publication No.XII.

37. Thiem, G. - 1906 "Hydrologische Methoden" Leipzig, J.M. Gebherdt.

38. Hantush, M.S. - 1956 "Analysis of data from pumping tests in leaky aquifers" Trans. Amer. Geophys. Union. Vol. 37, No.6.

38a) -do- - 1960 "Modifications of the theory of leaky Aquifers". Jour. Geophys. Research. Vol. 65, No.11.

38b) -do- - 1957 "Preliminary quantitative study of the Roswell Groundwater Reservoir, New Mexico. Report of the New Mexico Institute of Mining and Technology, Socorro.

39. Johnson Drillers Journal - 1961 "Analysis of Water Level recovery data" - Part II Johnson Driller's Journal July - August, 1961.

40. -do- - 1962 "A study of Ground water temperatures" Johnson Driller's Journal Sept. - Oct. 1962.

41. Chaturvedi, R.S. & Pathak P.N. - 1965 "Flow of Groundwater Table towards pumping wells and optimum yield under varying Geohydrological conditions" University of Roorkee, Research Journal Civil Engg. Vol.No.- 1965.

41a) -do- - 1963 "Flow of Groundwater towards pumping wells in the vicinity of a perennial stream" University of Roorkee Research Journal Vol.VI, No.II, 1963.

42. Singhal, B.B.S. - 1964 Some problems in the application of common pumping test methods to field conditions" Jour. of the Institution of Engineers (India). Vol.XLIV No.7 Pt. CI 4 March, 1964.

43. Ubell, K - 1956 "Unsteady flow of groundwater caused by well drawdown" International Association of Scientific Hydrology Symposia, Darcy, Rome.

44. Boulton, N.S. - 1954 "The drawdown of the water table under non-steady conditions near a pumped well in an un-confined formation. Proc. Institution of Civil Engineers (U.K.) Vol.3 Part 3.

45. Santing, G. - 1957 "Report on the Investigation of the Groundwater of the coastal plain, Israel. TAHAL Water Planning for Israel. (This report has been made available to the author by the courtesy of Prof. Leo. Picard).

46. Nace, R.L. et al. - 1961 "Water Resources of the Raft River Basin, Idaho - Utah" U.S.G.S. Water Supply Paper - 1587.

47. Bennison, E.W. - 1947 "Groundwater" Edward E. Johnson Inc. Minnesota.

48. Wenzel, L.K. - 1942 "Methods for determining Permeability of water bearing materials with special reference to discharging well methods" U.S.G.S. Water Supply Paper No.887.

49. Lang, S.M. - 1961 "Method for determining proper spacing of wells in Artesian Aquifers" U.S.G.S. Water Supply Paper No.1545-B.

50. Denisov, N.Ya. - 1956 "Engineering Geology and Hydrogeology" National Science Foundation Washington, D.C.

51. Jones, H.P. et al. - 1956 "Water Resources of South Western Louisiana" U.S.G.S.Water Supply Paper

52. Wisler, C.E. & Brater, E.F. - 1959 "Hydrology" John Wiley & Sons, Inc. New York.

53. Subramanyam, V. and et al. - 1960 "Report on an experimental well Scheme, Lignite field, South Arcot district, Madras State", Unpublished report of G.S.I.

54. Demenico, P.A. et al. - 1964 "Groundwater in Las Vegas Valley" Desert Research Institute, University of Nevada, Nevada. Tech. Report No.7.

55. Altovsky, M. & Konoplyantsev.A. - 1959 "Manual for the Systematic study of the regime of underground waters". Foreign Languages Publishing House, Moscow.

56. Ezekiel & Mordecai - 1941 "Methods of correlation analysis" 2nd Ed. John Wiley & Sons, Inc. New York.

57. Snedecor, G.W. - 1950 "Statistical Methods" 4th Ed. Iowa State College Press. Ames. 1950.

58. Stallman, W.R. - 1963 "Computation of Groundwater Velocity from temperature data " U.S.G.S. Water Supply Paper No.1544-H.

59. Andreason, E.G. & Brookhart, W.J. - 1963 "Reverse Water Level Fluctuations" U.S.G.S. Water Supply Paper 1544-H.

60. Karanth, K.R. & Rao, G.N. - 1961 "A note on the relation of the temperature of groundwater to the thickness of the superadjacent beds of lignite, Neyveli lignite field, South Arcot district, Madras. Rec. G.S.I. Vol. 92 Pt. 2.

61. Brodsky, A.A. & Popov, U.N. - 1959 "Methods of digesting the results of chemical analyses of under-ground waters" Manual for the Systematic study of the Regime of Underground waters. Chapter IV: Moscow, 1959.

62.	Hem, D.J.	- 1959	"Study and interpretation of the chemical characteristics of natural waters". U.S.G.S. Water Supply Paper No.1473.
62a)	-do-	- 1961	"Calculation and use of Ion activity". U.S.G.S. Water Supply Paper 1535-C.
63.	Anderson, E.K.	- 1955	"Water well Hand Book" Chapter IX, Missouri Water-well Drillers Association, U.S.A.
64.	Wilcox, L.V.	- 1948	"The quality of water for Irrigation use". U.S. Dept. Agr. Tech. Bull.962.
65.	Piper, A.M.	- 1944	"A graphic procedure in the geochemical interpretation of water analyses". Amer. Geophyss. Union. Trans. Vol. 25.
66.	U.S. Salinity Lab. Staff	- 1954	"Diagnosis and improvement of Saline and alkali soils" U.S. Dept. of Agr. Hand Book No.60.
67.	Garmonov, I.V.	- 1948	"Zonation of types of Phreatic water in the European Section of the U.S.S.R. Investigations of the Hydrogeological Research Laboratory, U.S.S.R. Academy of Sciences, Vol.III.
68.	Durov, S.A.	- 1948	"Natural waters and graphic representation of their composition". Doklady Akad Nank. S.S.SR Vol.59.
69.	Filatov, K.V.	- 1948	"Graphic Representation of Chemical analyses of water" Doklady Akad, Nank SSSR, Vol.59.
70.	Handa, B.K.	- 1965	"Modified Hill-Piper Diagram for presenting water analysis data". Curr. Science. Vol.34, No.10 May, 1965.

70a)	Handa, B.K.	- 1964	"Geochemical characterisation of groundwaters in India" Proc. Contd. 51st. and 52nd Ind. Sc. Cong. Part III.
71.	Back, W.	- 1961	"Calcium Carbonate Saturation in Groundwater from routine analyses" U.S.G.S. Water Supply Paper 1535-D.
72.	Scofield, C.S.	- 1940	"Salt Balance in Irrigated area". Jour. of Agr. Res. Vol.61 pp. 17-39.
73.	Schneider, R.	- 1962	"An application of thermometry to the study of groundwater". U.S.G.S. Water Supply Paper - 1544-B.
73a)	-do-	- 1961	"Correlation of Groundwater levels and air temperatures in the winter and spring in Minnesota". U.S.G.S. Water Supply Paper - 1539-D.
74.	Bhattacharya, A.P.	- 1954	"Groundwater Supplies, Depletion of water table and penetration of rain water to water table in Western U.P. India" Second Int. Cong. on Irrigation and drainage, 1954.
75.	Keech, C.F.	- 1962	"Groundwater Resources of Hamilton County, Nobraska" U.S.G.S. Water Supply Paper - 1539-N.
76.	Criner, J.H. et al	- 1964	"Hydrology of Aquifer system in the Remphis Area, Tennessee." U.S.G.S. Water Supply Paper - 1779-O.
77.	Baker, A.J. Healy, G.H.H. & Hackett, O.M.	- 1964	"Geology and Groundwater conditions in the Wilmington Reading area, Massachusetts". U.S.G.S. Water Supply Paper - 1964.
78.	Cronin, J.G.	- 1964	"A summary of the occurrence and development of Groundwater in the Southern High Plains of Texas. U.S.G.S. Water Supply Paper - 1963.

79. Schiner, R.G. - 1963 "Groundwater Exploration and Test pumping in the Halma lake Bronson Area, Kittson county, Minnesota". U.S.G.S. Water Supply Paper - 1619-BB.

80. Bogomolof, G.V. - 1963 "Classification of Groundwater resources and Methods of their evaluation" Paper presented to the U.N. conference on the application of Science and Technology for the benefit of the less developed areas. E/Conf.39/A/169; Agenda item No.A 33 .... 1963.

81. Guyton, W.F. - 1941 "Application of 'T' and 'S' to regional problems in Houston District, Texas." Amer. Geophys. Union. Trans. 21st Annual meeting Pt.3; pp. 750-772.

82. Conover, C.S. - 1954 "Groundwater conditions in Rincon and Mesilla Valleys, New Mexico". U.S.G.S. Water Supply Paper No.1230.

83. Mann.F.John(Jr.) - 1961 "Factors affecting the Safe yield of Groundwater basins" Proc. of the Amer. Soc. Civil Engrs. Vol.87, 1 R3, 1961.

84. U.N. Water Resources Development Centre - 1960 "Large Scale Groundwater Development". UN - WRDC Publication, 1960.

85. Burrard, S.G. & Haden, A.M. - 1934 "The Geography and Geology of the Himalayan Mountains" 2nd Ed.

—— ••• ——

GEOGRAPHICAL INDEX:

Sl. No.	Locality	North Latitude °	'	"	East Longitude °	'	"
1	2	3	4	5	6	7	8
1.	Saharanpur	29	58	04	77	33	24
2.	Roorkee	29	51	43	77	53	31
3.	Nainital	29	23	32	79	27	19
4.	Kicha	28	53	00	79	30	00
5.	Dehradun	30	19	12	78	05	17
6.	Azamgarh	26	10	00	83	15	00
7.	Meerut	29	00	00	77	42	15
8.	Muzaffarnagar	29	28	00	77	41	47
9.	Bijnor	29	22	30	78	08	08
10.	Bullandshahr	28	24	07	77	51	43
11.	Atrauli	28	01	50	78	17	21
12.	Khurja	28	15	08	77	50	37
13.	Aligarh	27	53	24	78	04	37
14.	Hathras	27	35	58	78	03	25
15.	Hardwar	29	57	18	78	10	16
16.	Rishikesh	30	06	22	78	18	12
17.	Nahan	30	33	28	77	17	51
18.	Ambala	30	22	42	76	46	53
19.	Mohund	30	14	20	77	34	30
20.	Landhaura	29	48	12	77	55	59
21.	Hatiathal	29	49	27	77	50	59
22.	Hasan Alipur	29	49	48	77	53	05
23.	Bhagwanpur	29	56	30	77	49	00
24.	Jalesar	27	28	24	78	18	05

1	2	3	4	5	6	7	8
25.	Agra	27	11	37	78	01	14
26.	Bangheri	29	51	14	77	54	51
27.	Malakpur	29	52	04	77	54	30
28.	Mohanpur	29	50	31	77	53	36
29.	Dandhera	29	50	17	77	54	06
30.	Nagla Marti	29	49	31	77	55	09
31.	Saidpura	29	48	00	77	51	53
32.	Liberheri	29	45	56	77	52	00
33.	Etah	27	33	31	78	39	39
34.	Ghaziabad	28	38	47	77	25	38

APPENDIX NO.I:

HYDROLOGICAL DATA FOR OPEN WELLS IN ROORKEE REGION:

Well No.	Location	Owner	Type	Depth in ft.	Diameter in feet	Method of lift.	Nature of Water bearing strata	Geological Horizon	Measuring Point Description
1	2	3	4	5	6	7	8	9	10
1.	Near Sri Kedar's Building, Roorkee	Sri M.P. Kedar	Dg	33.65	6.45	Pulley & bucket with rope	-	Gangetic Alluvium	Top of Curb North side
2.	Near Canals Inspection Bunglow Asafnagar.	State Irrigation, Department	Dg	25.15	5.00	-	-	-do-	-do-
3.	100 ft. N60°E of West end of Bridge on UG Canal, Manglaur.	-do-	Dg	16.40	3.00	-	Fine to Medium Sand	-do-	Top of curb West side.
4.	60 ft. North of old Masjid at road Mile 100/4 Manglaur.	Kazi Anwar	Dg	27.90	6.10	-	-do-	-do-	Top of curb South side.
5.	One furlong North of the sharp road bend at Manglaur.	Sri Julahoo	Dg	33.40	4.14	Bucket with rope	-	-do-	Top of curb West side.
6.	20ft. East of Dharamsala in Gadarjude Village.	Sri Rupoo	Dg	24.20	4.75	Persian wheel	-	-do-	-do-

Measuring Point		Depth to Water level below M.P. in feet.				Use	Temperature °F at the time of well inventory	Remarks.
Above land surface	Reduced level	1960	1961	1962	1963			
11	12	13	14	15	16	17	18	19
0.90	879.14	28.77 (1.7.60)	29.44 (1.6.61)	28.65 (8.5.62)	30.18 (2.5.63)	Domestic Gardening	68.5	Water odourless and colourless.
3.00	870.35	9.65 (1.7.60)	9.24 (1.6.61)	9.44 (8.5.62)	10.70 (2.5.63)	Not in use	75.5	Kist nala flows 100ft. East of the well
1.40	866.77	10.23 (1.7.60)	10.20 (1.6.61)	10.30 (8.5.62)	11.20 (2.5.63)	-do-	68.0	Water with Moss smell.
1.80	865.78	12.63 (6.7.60)	12.99 (1.6.61)	12.72 (8.5.62)	14.34 (2.5.63)	-do-	73.5	-
2.33	862.94	17.48 (6.7.60)	18.09 (1.6.61)	17.70 (8.5.62)	19.27 (2.5.63)	Drinking	66.5	-
2.70	861.40	10.64 (6.7.60)	-	11.30 (17.5.62)	12.66 (21.5.63)	Not in use	73.0	Water with slight Fungus smell.

1	2	3	4	5	6	7	8	9	10
7.	In the Village Khana -mpur Kurali (Harijan's well)	Sri Asram of Jaberhera Village.	Dg	28.40	4.81	-	-	Gangetic Alluvium	Top of curb west side.
8.	Near New Dharamsala Jaberheri Village	Sri Nanak Chand	Dg	16.10	4.00	-	Silty & Sandy Clays	-do-	Top of curb East side.
9.	In the compound of Jamedar and Subedar Quarters, Roorkee	Roorkee Military Cantt.	Dg	19.22	4.00	-	-	-do-	Top of curb west side.
10.	50 Yds. South of the Village Kuri	Sri Satish Babu of Liberheri Village	Dg	42.10	13.00	-	-	-do-	Top of curb south side.
11.	Near the Primary School in Udhalledi Village.	Sri Dhata ram	Dg	28.70	7.60	-	-	-do-	Top of curb west side.
12.	NW of road at M/S 99 on Delhi-Dehra Dun Road.	P.W.D.	Dg	13.00	4.90	-	Fine to Medium sand	-do-	Top of curb North side.
13.	30ft. East of M/S 96 on Delhi-Dehra Dun Rd.	P.W.D.	Dg	21.20	4.20	-	-	-do-	Top of curb South side.
14.	Near road bend at Village Liberheri	Panchayat	Dg	28.50	4.65	-	-	-do-	-do-
15.	50ft. SW of furlong St.No.6 on Manglaur -Landhaura road.	Belongs to the Nearby Mosque	Dg	>42.00	6.70	-	-	-do-	Top of curb East side

11	12	13	14	15	16	17	18	19
2.65	862.55	16.74 (6.7.60)	-	16.70 (12.6.62)	18.04 (21.5.63)	Domestic	67.0	-
1.90	866.25	13.37 (6.7.60)	-	14.36 (17.5.62)	16.16 (21.5.63)	-do-	72.0	-
2.60	869.69	14.80 (6.7.60)	15.40 (1.6.61)	14.70 (8.5.62)	16.18 (2.5.63)	Not in use	70.0	-
2.80	859.58	8.35 (7.7.60)	8.70 (1.6.61)	9.40 (8.5.62)	8.79 (2.5.63)	Used for cattle	71.0	-
4.70	858.33	15.72 (7.7.60)	15.40 (6.7.61)	15.55 (12.6.62)	16.53 (4.6.63)	Domestic	71.5	-
2.70	855.75	4.48 (7.7.60)	4.80 (1.6.61)	6.16 (8.5.62)	5.18 (2.5.63)	Domestic	74.0	Reported that water comes upto G.L. in monsoon.
2.45	858.68	13.40 (7.7.60)	13.85 (1.6.61)	13.90 (8.5.62)	14.49 (2.5.63)	Not in use	70.5	-
3.20	859.58	13.42 (7.7.60)	14.71 (1.6.61)	14.90 (8.5.62)	15.54 (2.5.63)	Drinking	67.0	-
4.60	868.45	25.05 (7.7.60)	26.10 (6.6.61)	25.79 (15.6.62)	27.66 (5.6.63)	Domestic	67.5	Well reported to 100 Yrs. old.

1	2	3	4	5	6	7	8	9	10
17.	3½ furlongs East of State Tubewell No.13.	Sri Paroo of Village Landhaura.	Dg	-	6.10	-	Fine sand	Gangetic Alluvium	Top of Curb East Side.
18.	60 ft. west of M/S 105/4 on Delhi - Dehradun road	-	Dg	12.75	3.90	-	-	-do-	Top of curb North side.
19.	Half furlong west of M/S 105/7 on Delhi-Dehradun road.	Sri Pritam Singh of Roorkee.	Dg	19.20	2.70	-	-	-do-	Cement base East side.
20.	East of M/S 106/2 on Delhi-Dehradun road.	Panchayat	Dg	37.10	5.80	-	-	-do-	Near Railing East side.
21.	40 Yds. East of M/S 107/6 on Delhi-Dehradun road.	Panchayat of Saliar Salehpur Village.	Dg	39.20	5.40	-	Silty clay; sand	-do-	Top of curb East end.
22.	South of old temple in Saliar Salehpur Village.	Sri Surjajee	Dg	66.20	7.30	-	-	-do-	Top of curb North side.
23.	80 ft. East of M/S 109/3 on Delhi-Dehradun road.	Sri Musammad Banti	Dg	43.20	7.00	-	-	-do-	Top of curb South side.
25.	100 Yds. East of State Tubewell No.29.	Sri Musaddi Lal of Bhagwanpur Village	Dg	49.20	7.30	-	Fine Sand	-do-	Top of curb North side.

11	12	13	14	15	16	17	18	19
3.60	869.11	33.33 (7.7.60)	35.23 (6.6.61)	35.28 (15.6.62)	37.76 (5.6.63)	Not in use	69.0	-
1.50	849.46	5.56 (16.7.60)	7.90 (25.5.61)	7.10 (1.5.62)	7.86 (6.5.63)	Not in use	73.5	-
1.80	849.87	5.55 (20.7.60)	10.20 (25.5.61)	8.79 (1.5.62)	10.75 (6.5.63)	Domestic and irrigation	74.5	-
7.10	866.72	22.70 (20.7.60)	25.70 (25.5.61)	23.05 (1.5.62)	23.43 (6.5.63)	Domestic	70.5	-
2.70	893.13	18.30 (20.7.60)	23.18 (25.5.61)	20.75 (1.5.62)	24.90 (6.5.63)	Drinking	69.0	-
2.60	893.26	17.60 (20.7.60)	21.39 (25.5.61)	17.44 (1.5.62)	23.40 (6.5.63)	-do-	69.0	-
3.50	897.19	13.25 (20.7.60)	16.88 (25.5.61)	13.95 (1.5.62)	19.36 (6.5.63)	-do-	72.0	-
2.30	901.52	13.55 (20.7.60)	16.55 (25.5.61)	16.43 (1.5.62)	19.50 (6.5.63)	Not in use	73.0	-

1	2	3	4	5	6	7	8	9	10
26.	½ Furlong west of M/S 110/5 on Delhi - Dehra Dun Road	Sri Yadav Habir of Bhagwanpur Village	Dg	50.20	7.70	-	-	Gangetic Alluvium	Top of curb North side.
27.	20 Yds. N10°E of M/S 111/1 on Delhi-Dehradun road.	Sri Kanti Lal	Dg	28.20	4.20	-	-	-do-	Top of curb East side.
28.	Near M/S 112 on Delhi Dehra Dun Road	Sri Muroopa of Mokhampur Village	Dg	23.35	4.20	-	Silty Sand	-do-	Top of curb NE end.
29.	30ft. East of M/S 112/7 on Delhi - Dehra Dun Road	P.W.D.	Dg	22.20	4.65	-	-	-do-	Top of curb East end.
30.	25 Yds. West of M/S 114/1 on Delhi - Dehra Dun road.	Sri Bawini wala of Sikandarpur Village.	Dg	17.00	4.50	-	-	-do-	Top of curb North end.
31.	30 Yds. West of M/s 114/4 on Delhi-Dehra-Dun road.	Sri Asram Patwari of Kubbanpur Village	Dg	34.20	4.50	-	-	-do-	Top of curb North side.
32.	West of Kubbanpur Village.	Panchayat	Dg	44.00	9.35	-	Alluvium of Solani	-do-	Top of curb west side.
33.	In the Masjid compound of Kubbanpur village	Belongs to Mosque	Dg	70.20	3.20	-	-do-	-do-	Top of curb South side.
34.	30 Yds. West of M/s 114/7 on Delhi-Dehra Dun road.	Sri Kakkriram of Kubbanpur Village	Dg	24.20	7.20	-	-	-do-	Top of curb North end.

11	12	13	14	15	16	17	18	19
3.20	904.35	23.64 (20.7.60)	25.79 (25.5.61)	23.09 (1.5.62)	26.50 (6.5.63)	Not in use	69.0	-
2.10	907.56	16.60 (20.7.60)	24.43 (25.5.61)	19.65 (1.5.62)	27.05 (6.5.63)	-do-	69.5	-
0.52	915.23	13.96 (20.7.60)	19.55 (25.5.61)	15.44 (1.5.62)	19.85 (6.5.63)	Domestic	69.0	-
3.30	926.50	11.00 (20.7.60)	13.15 (25.5.61)	10.96 (1.5.62)	14.36 (6.5.63)	Not in use	70.5	-
1.50	939.12	8.85 (22.7.60)	11.44 (25.5.61)	9.46 (1.5.62)	11.99 (6.5.63)	-	73.5	-
1.80	941.51	10.63 (22.7.60)	12.89 (25.5.61)	10.40 (1.5.62)	14.53 (6.5.63)	Drinking	72.0	-
2.00	950.86	28.69 (22.7.60)	Dried (25.5.61)	37.60 (26.6.62)	Dried (6.5.63)	-do-	71.0	Well close to Solani river gets dry in March.
2.30	950.07	25.65 (22.7.60)	29.14 (25.5.61)	27.10 (26.6.62)	32.37 (6.5.63)	Domestic	69.0	Well does not dry up in Summer.
1.92	944.13	9.88 (22.7.60)	11.97 (25.5.61)	9.65 (1.5.62)	13.18 (6.5.63)	Not in use	74.0	Fungus on surface of water.

1	2	3	4	5	6	7	8	9	10
35.	Near Mahadev Mandir in Village Chauli	Sri Khubnand	Dg	49.70	3.45	-	-	Gangetic Alluvium	Top of curb west end.
36.	In the Eastern part of the Chappar Village.	Sri Ismail	Dg	40.20	4.90	-	Fine sand	-do-	Top of curb South side.
37.	In the compound of Inter College, Bhagwanpur	Sri Lal Shemu Chand	Dg	42.20	9.70	Persian Wheel	-	-do-	-do-
38.	75 Yds. SE of the Mosque in the Village Raipur	Panchayat	Dg	36.20	8.65	-	-	-do-	-do-
39.	One furlong East of Sikandarpur Village	-	Dg	19.70	9.00	-	-	-do-	-do-
40.	Two furlong south of Sikandarpur Village.	-	Dg	14.20	4.85	-	-	-do-	Top of curb East side.
41.	½ mile SSW of Amarpur Village	Panchayat	Dg	24.20	7.90	-	-	-do-	Top of curb North side.
42.	In the Amarpur Village proper	-do-	Dg	20.40	8.50	-	-	-do-	Top of curb South side.
44.	50 Yds. East of the Rice Mill in Chandpur Village	-do-	Dg	45.00	11.65	-	Silty clay; sand	-do-	Top of curb North end.
46.	Half furlong west of Kherpur Village.	Sri Munshi Kazam	Dg	42.20	6.20	Persian wheel	-	-do-	Top of curb SW corner.
47.	In the SW corner of the Medhpur Village	Panchayat	Dg	48.00	7.75	-	-	-do-	Top of curb south side.

11	12	13	14	15	16	17	18	19
7.40	960.28	35.20 (22.7.60)	37.15 (25.5.61)	37.50 (26.6.62)	38.90 (6.5.63)	Domestic	68.5	-
3.10	951.23	12.48 (22.7.60)	13.65 (9.6.61)	12.81 (26.6.62)	15.30 (18.5.63)	-do-	71.5	-
2.20	911.86	18.55 (22.7.60)	21.60 (25.5.61)	19.27 (1.5.62)	26.11 (6.5.63)	Domestic, Gardening	71.5	-
2.30	922.06	11.49 (23.7.60)	13.86 (9.6.61)	12.05 (23.5.62)	13.95 (14.5.63)	Domestic	71.5	-
1.60	927.85	11.66 (23.7.60)	13.69 (9.6.61)	11.45 (23.5.62)	14.27 (17.5.63)	Not in use	75.0	Abandoned well.
0.65	926.22	9.53 (23.7.60)	12.50 (9.6.61)	9.89 (23.5.62)	12.14 (17.5.63)	-do-	75.5	-do-
1.50	923.46	6.73 (23.7.60)	9.90 (9.6.61)	9.29 (26.6.62)	16.08 (18.5.63)	-do-	75.0	Fungus on surface of water.
1.70	925.33	10.35 (23.7.60)	12.97 (9.6.61)	11.35 (26.6.62)	12.76 (18.5.63)	Domestic	70.5	
1.75	938.51	13.22 (23.7.60)	15.48 (9.6.61)	14.36 (26.6.62)	16.11 (18.5.63)	-do-	76.5	
0.75	907.88	8.58 (24.7.60)	14.20 (27.6.61)	12.32 (26.6.62)	14.63 (18.5.63)	Drinking & Irrigation	69.5	Well irrigates 6 acres.
3.20	913.15	13.55 (24.7.60)	19.10 (27.6.61)	18.28 (25.6.62)	19.76 (18.5.63)	Domestic	71.5	Reported that water level goes down by 5-6' in summer.

1	2	3	4	5	6	7	8	9	10
48.	2½ furlongs SE of Medh -pur Village	Sri Bashir	Dg	43.70	10.40	Persian Wheel	-	Gangetic Alluvium	Top of curb East side
49.	In the Eastern side of the village Serpur	Panchayat	Dg	26.00	-	-do-	-	-do-	-do-
50.	One mile SW of Village Serpur	Sri Murali Sambhu of Chudiala Village	Dg	25.20	5.58	-do-	-	-do-	Top of curb NW end
51.	One furlong SE of the Village Chudiala	Rajasaheb of Landhaura	Dg	28.00	9.40	-do-	Fine to Medium Sand	-do-	Top of curb East side
53.	1½ furlongs north of Nalhera Anantpur Village.	Sri Govardhan	Dg	28.40	7.20	-	-	-do-	Top of curb SW corner.
54.	20 ft. East of Mosque in Bandakhedi Village.	Panchayat	Dg	32.20	6.85	-	-	-do-	Top of curb North side.
55.	Along the wall of Mosque in Pawdli Village	-do-	Dg	23.10	4.00	-	-	-do-	Top of curb NE end.
56.	In the Village Dharampur	-do-	Dg	18.20	5.20	-	-	-do-	Top of curb west end.
57.	In Northern part of the Village Najampur Paniala.	Late Shri Nathu Singh of Manglaur	Dg	33.10	6.15	-	-	-do-	Top of curb South end.
58.	West of Iqbalpur Rly. Station	Railway	Dg	22.51	4.54	-	Fine to Medium sands	-do-	Top of curb North end.

11	12	13	14	15	16	17	18	19
2.65	907.09	9.59 (24.7.60)	14.45 (27.6.61)	12.44 (25.6.62)	15.48 (18.5.63)	Drinking & Irrigation	72.5	Well irrigates 250 Bighas of land.
2.50	906.89	11.40 (24.7.60)	16.40 (27.6.61)	14.09 (25.6.62)	20.54 (18.5.63)	-do-	70.5	-
3.30	902.59	7.70 (24.7.60)	13.17 (27.6.61)	11.46 (25.6.62)	13.69 (18.5.63)	-do-	71.5	-
3.50	901.17	13.45 (24.7.60)	17.47 (27.6.61)	15.74 (25.6.62)	22.10 (18.5.63)	-do-	69.5	-
1.40	891.83	10.65 (9.8.60)	13.50 (7.7.61)	12.15 (21.6.62)	14.31 (28.5.63)	-do-	76.0	-
0.70	890.78	10.45 (9.8.60)	16.55 (7.7.61)	16.00 (21.6.62)	19.33 (28.5.63)	-	73.0	Hand pump fixed on the well.
1.60	882.98	12.68 (9.8.60)	-	15.55 (21.6.62)	16.42 (25.5.63)	Domestic	68.5	-
0.60	883.12	9.75 (9.8.60)	-	16.70 (21.6.62)	16.06 (21.5.63)	-do-	70.0	-
-	877.66	14.20 (9.8.60)	20.93 (6.7.61)	20.35 (23.6.62)	21.39 (21.5.63)	-do-	70.5	-
2.40	884.47	7.95 (19.8.60)	13.95 (27.6.61)	13.35 (21.6.62)	14.43 (28.5.63)	-do-	72.0	-

1	2	3	4	5	6	7	8	9	10
59.	Old well in Khata Kheri Village.	Panchayat	Dg	21.00	8.40	-	-	Gangetic Alluvium	Top of curb East end.
60.	In the Eastern part of village Amarpur	-do-	Dg	22.50	9.20	Persian Wheel	-	-do-	Land surface north side.
61.	In the Western part of the village Kadarpur	Sri Jagatram Bhagatram etc.	Dg	23.80	8.40	-do-	-	-do-	-do-
62.	In the Northern end of the village Kaleri Yusuffpur	Panchayat	Dg	22.40	7.40	-	-	-do-	Top of curb West side.
63.	In the NW end of the Village Nalheri Anantpur	Sri Mangal	Dg	37.10	7.90	-	-	-do-	Top of curb NW corner
64.	3/4 mile East of Satneri Village	Sri Naginna Singh	Dg	26.20	7.20	-	Medium Sands	-do-	Top of curb South side.
65.	In the eastern end of Village Satheri	Panchayat	Dg	25.70	6.50	-	-	-do-	Top of curb North side.
66.	½ mile SW of Village Rahalki Dialpur	Shri Roola	Dg	23.80	6.50	Persian wheel	-	-do-	Top of curb East end.
67.	North of the Mosque in the village Mahewar Kalan	Panchayat	Dg	38.70	4.40	-	-	-do-	Top of curb south end.
68.	Near Kaliar Mosque on Roorkee- Hardwar Road.	Durbar property of Annual fair	Dg	45.70	8.30	Hand Pumps	-	-do-	-

11	12	13	14	15	16	17	18	19
2.40	881.43	6.85 (19.8.60)	-	12.98 (21.6.62)	14.32 (25.5.63)	Domestic	72.0	-
-	888.22	9.85 (19.8.60)	13.80 (27.6.61)	11.85 (23.6.62)	18.55 (28.5.63)	Domestic/ Irrigation	74.0	-
-	893.06	9.48 (19.8.60)	14.45 (7.7.61)	12.43 (25.6.62)	20.10 (29.5.63)	-do-	71.0	-
2.30	892.42	11.35 (19.8.60)	14.75 (27.7.61)	13.15 (23.6.62)	15.05 (28.5.63)	Domestic	71.5	-
2.50	893.48	15.60 (20.8.60)	21.00 (7.7.61)	19.85 (21.6.62)	22.95 (25.5.63)	-do-	71.0	-
1.90	897.86	11.48 (20.8.60)	16.23 (7.7.61)	14.62 (25.6.62)	17.16 (28.5.63)	Drinking & Irrigation	74.0	-
2.60	898.05	11.63 (20.8.60)	15.65 (7.7.61)	14.38 (25.6.62)	16.13 (28.5.63)	Drinking	72.5	-
1.30	898.84	8.75 (20.8.60)	12.84 (7.7.61)	11.04 (25.6.62)	14.69 (29.5.63)	Drinking & irrigation	72.0	-
1.90	879.87	24.15 (22.8.60)	-	27.02 (10.5.62)	28.82 (21.6.63)	Domestic	69.0	-
1.15	902.42	15.10 (22.8.60)	-	17.14 (10.5.62)	22.17 (18.6.63)	-do-	70.0	-

1	2	3	4	5	6	7	8	9	10
69..	Near the old Drilling School in Daulatpur Village.	Govt. Agr.Farms	Dg/B	25.00	-	-	-	Gangetic Alluvium	Top of brick base
71.	50 ft. South of M/S 7/4 on Roorkee-Hardwar Road.	Sri Basim bar Gir of Daulatpur Village.	Dg	36.60	5.25	Pulley with rope and bucket	-	-do-	Top of curb East end.
72.	In the centre of the Village Daulatpur	Panchayat	Dg	47.60	7.40	-do-	-	-do-	Top of curb North end.
72A.	Near the Panchayat Office, Daulatpur	-do-	Dg	36.40	16.90	-do-	-	-do-	Top of curb East end.
73.	50 Yds. East of the temple in Dandhera Village	-do-	Dg	46.00	6.30	-do-	Fine to medium sands	-do-	-do-
74.	45 ft. West of the Mosque in Village Nagla Marti	-do-	Dg	52.40	7.60	-do-	-	-do-	Top of curb west end.
77.	In the NW corner of Landhaura Village.	Raja Saheb of Landh-aura	Dg	69.70	13.20	-do-	Medium sand	-do-	Top of curb North side.
78.	75ft.SW of Landhaura Rly. Station.	N.Rly.	Dg	56.20	4.60	-do-	-do-	-do-	Top of curb SW end.
79.	In the NW corner of the village Jainpur Jhanjheri.	Harijans of the Village.	Dg	48.60	4.30	-	-	-do-	-do-

11	12	13	14	15	16	17	18	19
1.30	-	13.05 (22.8.60)	-	-	-	Irrigation	73.0	-
3.50	897.61	22.25 (22.8.60)	-	22.24 (10.5.62)	24.24 (13.6.63)	Drilling/ Gardening	70.0	-
4.15	899.71	30.55 (22.8.60)	-	-	36.35 (13.6.63)	Domestic	69.5	-
4.20	894.15	24.85 (22.8.60)	-	29.00 (10.5.62)	-	Not in use	73.0	-
2.60	878.52	33.90 (28.8.60)	36.15 (27.5.61)	36.26 (14.6.62)	39.42 (5.6.63)	Domestic	69.0	-
1.70	873.77	37.00 (28.8.60)	38.74 (27.5.61)	39.65 (14.6.62)	41.63 (5.6.63)	-do-	69.0	-
5.40	875.72	41.50 (28.8.60)	52.94 (6.6.61)	52.83 (15.6.62)	55.24 (5.6.63)	-do-	69.0	-
3.10	863.25	42.75 (28.8.60)	45.06 (6.6.61)	44.55 (14.6.62)	46.10 (5.6.63)	-do-	69.5	-
1.35	869.04	39.00 (28.8.60)	43.69 (6.6.61)	43.78 (15.6.62)	46.26 (5.6.63)	-do-	69.5	-

1	2	3	4	5	6	7	8	9	10
80.	In the centre of the Village Bhagwanpur Chandpur.	Panchayat	Dg	50.80	5.65	-	-	Gangetic Alluvium	-
81& 81A	In the Eastern part of the village Shikarpur	Sri Ghima	Dg	7.65	5.20	-	-	-do-	Top of Curb East end.
82.	In the Eastern part of Landhaura Village.	Sri Lalli	Dg	59.30	6.90	Rope and Pulley	Medi -um Sand	-do-	Top of curb NE side.
83.	2 Furlongs NE of the Village Gandharina	Sri Janki of Landhaura	Dg	18.20	7.20	Persian Wheel	-do-	-do-	Top of curb west side.
84.	Just South of the Village Khempur	Sri Jugla Swarup of Manglaur	Dg	25.40	7.65	-	-do-	-do-	-do-
85.	In the compound of B.I.C.C. Ltd., Roorkee	Dr.Singhal of Jabalpur	Dg	26.30	9.00	-	-	-do-	Top of curb SE Side.
86.	Opposite the Mosque in Banhera Village	Sri Mustaq	Dg	45.50	6.20	-	-	-do-	Top of curb NW side.
87.	In the Northern part of the village Akbarpur Dadheki	Panchayat	Dg	48.40	5.90	Rope and Pulley	-	-do-	Top of curb West side.
88.	One mile SW of the Village Akbarpur Dadheki	Sri Baburam of Manglaur	Dg/B	43.00	7.10	-	-	-do-	-do-
90.	4 Furlongs NW of the Village Bukhanpur	Sri Nihal gir	Dg	61.40	4.60	Rope and Pulley	Medium sand	-do-	Top of curb North side.

11	12	13	14	15	16	17	18	19
3.90	870.00	38.08 (28.8.60)	40.17 (6.6.61)	40.54 (15.6.62)	42.34 (5.6.63)	Domestic	68.5	-
0.50	819.75 813.56	3.00 (29.8.60)	5.80 (6.6.61)	5.65 (14.6.62)	6.60 (5.6.63)	Not in use	78.0	-
3.25	872.48	41.55 (29.8.60)	53.00 (6.6.61)	51.75 (14.6.62)	53.68 (5.6.63)	Domestic	69.5	-
1.00	814.58	4.60 (29.8.60)	-	9.80 (14.6.62)	11.10 (6.6.63)	Domestic and Gardening	76.0	-
1.75	816.91	7.00 (29.8.60)	12.38 (6.6.61)	11.44 (14.6.62)	8.62 (6.6.63)	Not in use	75.0	-
1.30	875.23	19.08 (4.9.60)	20.60 (1.6.61)	20.25 (8.5.62)	21.45 (2.5.63)	Gardening	69.0	-
2.20	868.03	34.50 (5.9.60)	-	37.15 (10.7.62)	38.88 (6.6.63)	Drinking	69.5	-
2.90	866.17	39.95 (5.9.60)	-	41.83 (10.7.62)	43.70 (6.6.63)	-do-	70.5	-
1.50	864.82	34.45 (5.9.60)	-	36.37 (6.7.62)	38.83 (6.6.63)	Domestic	69.0	Reported that boring was done in the well.
2.80	868.46	45.50 (13.9.60)	-	47.58 (15.6.62)	49.79 (6.6.63)	Drinking	69.0	Well on the old terrace of Solani river.

1	2	3	4	5	6	7	8	9	10
91.	One furlong west of Bukhanpur Village.	Panchayat	Dg	55.10	5.90	-	-	Gangetic Alluvium	Land surface.
92.	In the western end of Sikhar Village	Rani of Landhaura	Dg	67.90	11.70	-	-	-do-	Top of curb NW corner.
93.	One furlong SW of Goshipur Village.	Sri Iwrat of Mindlana Village	Dg	70.10	7.60	-	Medium sand	-do-	Top of curb NW corner.
94.	In the centre of the Village Gopalpur.	Harijans of the Village	Dg	71.90	-	Rope and Pulle	-	-do-	Top of curb North side.
95.	In the Northern end of the Village Pirpura	Panchayat	Dg	45.80	9.40	-do-	-	-do-	-do-
96.	In the Southern end of the village Jaberheri Kalan	Sri Jodh Singh	Dg	17.60	5.00	-	Silty sands	-do-	Land surface.
97.	In the SW end of the Village Jaberheri Khurd.	Sri Surta	Dg	31.70	7.40	-	-do-	-do-	Top of curb SE side.
98.	In the compound of the Mosque in Akbarpur Village	Mosque	Dg	15.20	4.95	-	-	-do-	Top of curb west side.
99.	In the centre of the Village Harjauli Jhoga	Panchayat	Dg	28.60	7.95	-	-	-do-	Top of curb SW side.
100.	In the SE corner of the Village Asafnagar	Harijans of the Village	Dg	21.40	-	-	Fine Sand	-do-	Top of curb south side.

11	12	13	14	15	16	17	18	19
-	865.51	51.17 (13.9.60)	-	53.20 (15.6.62)	57.64 (6.6.63)	Drinking	70.5	Well on the old terrace of Solani river.
2.60	863.20	41.35 (13.9.60)	-	52.14 (10.7.62)	53.35 (6.6.63)	-do-	70.5	-do-
1.70	864.04	59.00 (13.9.60)	-	60.82 (10.7.62)	64.99 (6.6.63)	Drinking/ Domestic	69.5	-do-
-	870.68	61.30 (13.9.60)	-	64.20 (10.7.62)	64.25 (6.6.63)	Domestic	69.5	-do-
3.80	869.82	25.79 (14.9.60)	29.77 (6.6.61)	30.00 (15.6.62)	-	Domestic	69.0	-
-	868.06	14.97 (23.9.60)	-	12.85 (17.5.62)	18.37 (21.5.63)	Irrigation/ Domestic	70.0	-
2.10	874.95	15.42 (23.9.60)	-	17.53 (17.5.62)	19.56 (21.5.63)	Domestic	71.0	-
0.50	865.86	7.88 (23.9.60)	-	10.50 (17.5.62)	12.10 (21.5.63)	-do-	69.0	-
2.80	876.41	15.97 (23.9.60)	-	17.36 (23.6.62)	17.95 (21.5.63)	-do-	69.5	-
2.60	870.37	10.25 (25.9.60)	11.20 (6.7.61)	11.00 (16.5.62)	11.72 (3.5.63)	-do-	66.0	-

1	2	3	4	5	6	7	8	9	10
101.	In the SE corner of the village Hathiathal	Harijans of the village	Dg	21.10	4.70	Rope and Pulley	-	Gangetic Alluvium	Top of curb East end.
103.	In the Northern end of the village Thitke	Sri Hari baba	Dg	39.95	9.10	-do-	-	-do-	Top of Curb SW side.
104	In the Northern end of the Village Saidpura	Panchayat	Dg	24.00	9.00	-	Fine Sand	-do-	Top of curb North side.
105.	In the Eastern end of the Village Jhabisaur	-do-	Dg	25.30	8.00	-	-	-do-	-do-
106.	South of the tank in the Village Nagla Imad.	-	Dg	16.20	4.50	-	-	-do-	Top of curb NE corner
107.	In the Northern extremity of the Village Thaskar.	Sri Mahavir Singh	Dg	20.30	4.50	Hand pump	-	-do-	Top of curb North side.
108.	At the SW corner of the temple, North of Baher-ki-Saidabad Village.	Sri Guru Onkar	Dg	15.30	4.90	-	-	-do-	Top of curb East side.
109.	In the Southern end of the village Mulemala	Panchayat	Dg	26.90	5.90	-	Fine to Medium Sand	-do-	-do-
110.	In the Western end of the Vill. Fazilpur	-do-	Dg	27.50	6.50	-	-	-do-	Top of curb south side.
111.	50 Yds. East of the Village Majri.	-do-	Dg	26.50	6.10	-	-	-do-	Top of curb East side.
112.	In the Southern end of the Village Dehra	-do-	Dg	24.80	7.30	-	-	-do-	-do-

11	12	13	14	15	16	17	18	19
3.05	868.10	9.70 (25.9.60)	14.25 (6.7.61)	14.46 (16.5.62)	15.36 (3.6.63)	Domestic	67.0	-
4.20	866.59	14.33 (25.9.60)	-	17.23 (16.5.62)	18.56 (3.6.63)	-do-	71.0	-
3.30	865.02	11.50 (25.9.60)	-	12.24 (16.5.62)	13.30 (3.6.63)	-do-	70.0	-
0.80	857.68	6.97 (26.9.60)	11.20 (6.7.61)	11.15 (12.6.62)	12.63 (4.6.63)	Not in use	70.0	-
1.30	855.80	3.20 (26.9.60)	9.20 (6.7.61)	9.74 (12.6.62)	10.49 (4.6.63)	-do-	72.5	-
2.00	856.27	7.05 (26.9.60)	11.75 (6.7.61)	12.40 (12.6.62)	13.20 (4.6.63)	Domestic	69.5	-
2.10	882.37	7.18 (29.9.60)	-	13.20 (22.6.62)	12.32 (25.5.63)	-do-	69.0	-
2.40	878.06	7.20 (29.9.60)	-	10.85 (23.6.62)	14.15 (22.6.63)	-do-	68.0	-
3.10	877.90	10.61 (29.9.60)	-	14.34 (23.6.62)	15.51 (21.5.63)	-do-	69.0	-
1.50	872.50	9.60 (29.9.60)	-	14.38 (23.6.62)	14.77 (21.5.63)	Not in use	73.0	-
2.00	877.05	12.10 (29.9.60)	-	15.49 (23.6.62)	16.69 (25.5.63)	Domestic	70.0	-

1	2	3	4	5	6	7	8	9	10
113.	In the Eastern end of the village Hargandhpur	Panchayat	Dg	18.90	3.80	-	-	Gangetic Alluvium	Top of curb East side.
114.	In the Southern end of the village Mohra.	-do-	Dg	24.80	7.80	-	-	-do-	-do-
115.	In the centre of the Village Khajuri	Sri Udda-rasy	Dg	22.50	4.30	-	Fine to Medium sands	-do-	-do-
116.	In the Northern end of the village Manak-pur Adampur	Harijans of the Village	Dg	27.00	4.50	-	-do-	-do-	-
117.	In the Northern part of the Village Paoti	Sri Malkan	Dg	24.50	4.40	-	-	-do-	Top of curb NE side.
118.	In the NW end of the village Khwaja Bahadur-pur	Sri Bharat Singh	Dg	35.50	9.20	Persian Wheel	-	-do-	Top of curb west side.
119.	One furlong SW of the Village Sunethi	Sri Khela	Dg	23.65	7.70	-do-	-	-do-	Top of curb South side.
120.	In the Eastern end of the village Balsnaganj	Sri Kher Singh	Dg	27.85	7.50	-do-	-	-do-	-do-
121.	½ furlong NNE of the village Banarasi.	Sri Desh Raj	Dg/B	21.30	6.10	-do-	Silty Sands	-do-	-do-

11	12	13	14	15	16	17	18	19
1.50	880.33	10.90 (29.9.60)	-	16.47 (22.6.62)	13.01 (25.5.63)	Not in use	71.0	-
4.20	881.73	12.20 (30.9.60)	-	17.50 (22.6.62)	24.59 (22.6.63)	Domestic	69.0	-
1.90	877.77	11.30 (30.9.60)	-	14.54 (22.6.62)	19.59 (22.6.63)	-do-	69.0	-
-	881.94	16.15 (30.9.60)	-	21.88 (22.6.62)	25.25 (22.6.63)	Not in use	68.0	-
4.40	881.51	12.27 (30.9.60)	-	17.14 (22.6.62)	20.35 (22.6.63)	Domestic	68.0	-
2.40	901.09	21.65 (9.10.60)	25.89 (27.6.61)	22.48 (23.6.62)	25.90 (28.5.63)	-	67.0	-
2.20	887.93	9.82 (9.10.60)	-	13.42 (23.6.62)	22.19 (22.6.63)	Drinking/ Irrigation	70.2	-
2.00	886.54	10.45 (9.10.60)	-	21.90 (23.6.62)	23.50 (22.6.63)	-do-	68.0	-
2.60	894.29	9.65 (9.10.60)	13.85 (27.6.61)	13.08 (23.6.62)	14.70 (18.5.63)	Irrigation	71.5	70 ft. of Strainer from the bottom of the dug well.

1	2	3	4	5	6	7	8	9	10
122.	One furlong west of the Matlabpur Village	Panchayat	Dg	39.40	5.30	Persian Wheel	-	Gangetic Alluvium	Top of curb North side.
123.	Eastern end of the Village Madhpur	-do-	Dg	25.20	7.10	-	-	-do-	-do-
124	In the Western end of the Village Salempur	Sri Lakhi Magri	Dg	32.20	4.70	-	Fine to Medium Sands	-do-	Top of curb NE corner.
125	One furlong south of State Tubewell No.28	Sri Masaddi Of Bhagwan-pur	Dg	27.60	5.60	-	-	-do-	Top of curb East side.
126	In the Western end of the Village Khanpur	Sri Devi Singh	Dg	23.80	6.50	-	-	-do-	Top of curb East side.
127.	In the northern end of the village Sri Chandni	Harijans of the village	Dg	21.90	4.50	-	-	-do-	Top of curb south side.
128.	In the centre of the Village Dadli	Panchayat	Dg	23.60	6.50	-	-	-do-	Top of curb East side.
129.	In the Centre of the Village Budhpur Chauhan	Sri Sher Singh	Dg	27.00	7.00	-	-	-do-	Top of curb South side.
130	In the Western part of the village Kharkri Diata	Sri Khosal Data	Dg	30.60	8.20	-	Fine to medium sands	-do-	-do-
131	In the northern end of the village Sultanpur	Harijans of the village	Dg	32.85	4.30	-	-	-do-	Top of curb East side.

11	12	13	14	15	16	17	18	19
2.70	883.31	18.23 (10.10.60)	21.50 (25.5.61)	22.43 (29.6.62)	24.88 (22.6.63)	Domestic/ Irrigation	69.0	--
4.35	883.49	9.00 (10.10.60)	-	12.75 (29.6.62)	14.25 (22.6.63)	Domestic	72.0	-
2.90	880.83	13.30 (10.10.60)	22.15 (25.5.61)	-	23.25 (22.6.63)	-do-	68.0	-
1.20	896.25	7.60 (12.10.60)	-	10.02 (26.6.62)	12.93 (6.5.63)	Drinking	71.0	-
2.00	901.39	12.10 (12.10.60)	-	15.36 (25.6.62)	-	-	69.0	-
2.40	918.05	13.20 (13.10.60)	16.26 (9.6.61)	15.62 (26.6.62	17.00 (17.5.63)	Domestic	69.0	-
0.80	913.63	12.54 (13.10.60)	18.10 (9.6.61)	18.24 (26.6.62)	20.01 (17.5.63)	Drinking	68.0	-
2.40	864.93	12.55 (5.11.60)	-	14.66 (17.5.62)	15.24 (21.5.63)	Domestic	63.0	-
2.40	879.93	16.40 (6.11.60)	-	19.17 (22.6.62)	21.79 (25.5.63)	Irrigation	62.5	-
1.60	876.56	17.75 (5.11.60)	-	19.77 (17.5.62)	24.66 (25.5.63)	Domestic	68.0	-

1	2	3	4	5	6	7	8	9	10
132.	Near the small tank in Hoshangapur Village.	Panchayat	Dg	30.10	10.60	-	-	Gangetic Alluvium	Land surface.
133.	In the Northern end of the village Sitapur	-do-	Dg	24.70	9.50	-	Fine sand	-do-	Top of curb east side.
134	Near the house of Ram Dia in the Village Changa Majra	-do-	Dg	20.00	7.20	-	-	-do-	Top of curb South side.
135	In the Eastern side of the village Halu Majra	-do-	Dg	13.00	7.00	-	-	-do-	Top of curb East side.
136	In the Eastern side of the village Manakpur Majra	-do-	Dg	20.00	7.20	-	Fine Sand	-do-	Top of curb SW side.
137	In the Southern side of the village Sushana	-do-	Dg	33.00	4.10	Rope and Pulley	-do-	-do-	Top of curb East side.
138.	25 ft. SE of the Mosque in Piran Kaliar	Mosque	Dg	54.00	5.80	-do-	-	-do-	-do -
139	50 ft. SSW of the small temple in Rahmatpur Village.	Temple	Dg	54.00	8.80	-do-	-	-do-	Top of curb West side.
140.	In the Western end of the village Belra	Panchayat	Dg	31.50	5.20	-do-	Fine to Medium Sand	-do-	Top of curb NE side.
141.	In the Eastern end of the Village Belri Salehpur	-do-	Dg	19.00	7.00	-do-	-	-do-	Top of curb North side.

11	12	13	14	15	16	17	18	19
-	878.26	13.00 (5.11.60)	-	15.86 (22.6.62)	19.62 (25.5.63)	Irrigation	64.0	-
2.70	861.50	7.25 (5.11.60)	-	11.10 (12.6.62)	11.77 (25.5.63)	-do-	63.5	-
1.60	883.06	-	7.80 (22.9.61)	11.82 (29.6.62)	13.04 (21.6.63)	Domestic	81.0	-
1.50	886.67	-	4.70 (22.9.61)	7.14 (29.6.62)	14.74 (21.6.63)	-do-	80.0	-
3.10	902.80	-	7.75 (22.9.61)	12.63 (29.6.62)	13.85 (24.6.63)	-do-	79.0	-
1.00	925.83	-	24.30 (22.9.61)	30.06 (29.6.62)	35.30 (24.6.63)	-do-	79.0	-
3.30	900.97	-	36.60 (26.9.61)	48.27 (3.7.62)	49.05 (14.6.63)	-do-	77.0	-
4.00	889.37	-	45.60 (26.9.61)	49.65 (3.7.62)	48.32 (14.6.63)	-do-	77.0	-
0.50	862.97	-	20.97 (26.9.61)	24.09 (3.7.62)	25.02 (14.6.63)	-do-	77.0	-
1.00	843.06	-	8.50 (26.9.61)	12.46 (3.7.62)	12.76	Drinking/ Irrigation	80.0	-

1	2	3	4	5	6	7	8	9	10
142	In the NE end of the Village Kilanpur	Public	Dg	16.00	6.30	-	-	Gangetic Alluvium	Top of curb SSE side.
143	In the Western end of the village Dandheri Khwajgipur	public	Dg	21.00	4.80	-	Fine Sand	-do-	Top of curb SW side.
144	In the Northern end of the village Birampur	Public	Dg	24.00	8.30	-	-	-do-	Top of curb NE side.
145.	About 200 yds west of well no.85	S.Autar Singh	Dg	21.00	4.00	-	-	-do-	Top of curb, North side.
146.	15ft. NE of temple in Bahadurpur Sahri Village.	Public	Dg	26.00	2.50	-	-	-do-	Top of curb North side.
147.	10 Yds. East of the Mosque in Badheri Village.	Public	Dg	29.00	7.10	Rope & Pulley	-	-do-	Top of curb NE side.
148.	20 ft. NE of the temple in Bharapur Bhauri Village.	Lala Kalu Ram	Dg	19.50	6.60	-	-	-do-	Top of curb west side.
149.	50 Yds. SE of the house of Sri Vali Mohammed in Marghupur Didaheri Village.	Public	Dg	22.50	3.80	-	-	-do-	Top of curb NW side.
150	100 Yds. SE of the Mosque in Qasimpur Village.	Public	Dg	19.50	4.50	-	Fine Sand	-do-	Top of curb SW side.

11	12	13	14	15	16	17	18	19
1.00	834.92	-	7.27 (26.9.61)	11.00 (3.7.62)	10.69 (14.6.63)	Not in use	81.0	-
3.00	834.79	-	9.50 (26.9.61)	13.40 (3.7.62)	13.52 (14.6.63)	Domestic	79.0	-
1.35	841.02	-	8.20 (26.9.61)	12.35 (3.7.62)	11.12 (14.6.63)	Not in use	80.0	-
2.40	875.16	-	14.70 (27.11.61)	12.82 (8.5.62)	-	Not in use	68.0	-
2.00	880.66	-	-	7.06 (7.4.62)	10.53 (13.6.63)	-do-	67.0	-
3.70	869.72	-	-	16.29 (7.4.62)	18.89 (13.6.63)	Domestic	72.0	-
2.00	842.72	-	-	15.90 (7.4.62)	18.11 (13.6.63)	-do-	70.0	-
1.00	830.63	-	-	17.20 (7.4.62)	14.46 (13.6.63)	-do-	70.0	-
1.90	820.69	-	-	12.40 (7.4.62)	-	-do-	74.5	-

1	2	3	4	5	6	7	8	9	10
151	Old well in the fields of Pachyanpur Village	Public	Dg	24.50	9.50	-	-	Gangetic Alluvium	Top of curb SW side.
152	In the Eastern side of the temple in Moldaspur Village.	Public	Dg	22.75	6.80	Rope and Pulley	-	-do-	Top of Curb South side.
153	In the Eastern part of the Village Dhanauri	Public	Dg	24.20	5.75	-	-	-do-	Top of Curb South side.
154	In the NW side of the village Teliwala	Public	Dg	26.50	8.70	-	-	-do-	Top of curb South side.
155	In the Eastern end of the village Jaswawala	Public	Dg	25.00	7.30	Rope and Pulley	-	-do-	Top of curb West side.
156	200 yds. west of the village Ajmerpur	Public	Dg	19.50	9.90	-	-	-do-	Top of curb South Side
157	In the Western end of Village Mirpur	Public	Dg	37.50	10.10	Rope and Pulley	Silty Sands	-do-	Top of curb NW side
158	One mile N 25°W of the village Mirpur	-	Dg	33.00	4.10	-	-	-do-	Top of curb Western side
159	In the NE end of the Village Macharheri	Public	Dg	23.46	8.00	-	-	-do-	Top of curb
160	In the SW end of the Village Kota	Public	Dg	22.15	4.50	Rope and Pulley	-	-do-	Top of curb West side.
161	In the Northern end of the village Shekh-wala	Public	Dg	23.90	5.51	-	-	-do-	Top of curb west side.

11	12	13	14	15	16	17	18	19
2.50	847.22	-	-	9.16 (7.4.62)	11.93 (13.6.63)	Not in use	67.0	-
3.50	864.40	-	-	16.79 (7.4.62)	20.09 (13.6.63)	Domestic	70.0	-
2.00	905.10	-	-	11.90 (18.4.62)	17.56 (17.6.63)	-do-	72.0	-
2.50	915.84	-	-	11.23 (18.4.62)	15.72 (17.6.63)	-do-	72.0	-
3.60	910.22	-	-	10.84 (18.4.62)	15.66 (17.6.63)	-do-	72.0	-
1.00	926.98	-	-	7.90 (18.4.62)	10.39 (17.6.63)	Not in use	72.0	-
3.50	939.88	-	-	22.55 (18.4.62)	27.62 (17.6.63)	Domestic	75.0	-
1.80	945.74	-	-	16.84 (18.4.62)	20.10 (17.6.63)	Irrigation	75.5	-
5.00	912.91	-	-	14.60 (19.4.62)	17.00 (24.6.63)	Not in use	72.0	-
3.00	907.18	-	-	10.45 (19.4.62)	-	Domestic	70.0	-
2.50	920.96	-	-	15.20 (19.4.62)	17.02 (18.6.63)	-do-	73.5	-

1	2	3	4	5	6	7	8	9	10
162	In the SW corner of the Village Manabas	Public	Dg	51.20	6.20	-	-	Gangetic Alluvium	Top of Curb S.Side
163	In the Eastern end of the village Joligarh	Public	Dg	19.20	6.60	-	-	-do-	Land surface
164	Half furlong south of Dharuwala Khurd Village	Harijans of the Village	Dg	23.70	5.70	-	Fine to Medium Sand	-do-	Top of curb West side.
165	In the NW end of the Village Asafnagar	Public	Dg	35.10	2.50	-	-do-	-do-	Top of Curb NW side.
166	In the SE part of the Village Badpur	Naek Mohamad	Dg	42.20	-	Rope and Pulley	-do-	-do-	Top of curb East side
167	In the Mosque compound of the Muqrabpur Village	Public	Dg	39.60	3.85	-	-	-do-	Top of curb West side
168	In the centre of the Village Majri	Public	Dg	44.45	7.50	-	-	-do-	Top of curb East side.
169	In the Mandir compound in Soharpur Village	Public	Dg	24.45	4.30	-	-	-do-	Top of curb North side.
170	In the NE part of the Village Hadipur	Public	Dg	32.80	5.95	-	-	-do-	Top of curb South side.
171	In the Centre of the Village Muhammadbegpur	Public	Dg	30.70	7.00	Rope and Pulley	-	-do-	Top of curb East side.
172	In the centre of the Village Fatehpur	Public	Dg	46.40	7.30	-do-	-	-do-	Top of curb North side.

11	12	13	14	15	16	17	18	19
0.50	970.87	-	-	43.80 (19.4.62)	44.46 (18.6.63)	Domestic	75.0	-
-	924.31	-	-	9.75 (19.4.62)	11.20 (18.6.63)	-	73.5	-
1.50	935.01	-	-	14.34 (19.4.62)	17.78 (24.6.63)	Domestic	72.0	-
2.50	932.44	-	-	17.60 (19.4.62)	21.85 (24.6.63)	-do-	73.5	-
3.20	897.90	-	-	23.33 (22.12.62)	28.59 (18.6.63)	-	72.5	-
2.00	903.47	-	-	28.28 (22.12.62)	36.45 (18.6.63)	-	71.0	-
3.80	914.98	-	-	24.35 (22.12.62)	28.13 (18.6.63)	For cattle	68.0	-
1.70	909.61	-	-	12.10 (22.12.62)	13.96 (18.6.63)	-	71.0	-
2.70	923.87	-	-	18.49 (22.12.62)	23.29 (18.6.63)	Domestic	70.0	-
2.30	931.50	-	-	20.29 (22.12.62)	25.37 (18.6.63)	-do-	70.0	-
1.90	963.34	-	-	40.10 (22.12.62)	41.66 (18.6.63)	-do-	70.0	-

1	2	3	4	5	6	7	8	9	10
173	In the NW end of the village Tandar Manubas	Public	Dg	25.75	4.40	Rope and Pulley	-	Gangetic Alluvium	Top of curb East side.
174	In the Eastern side of the village Tanda Ram gharwala	Public	Dg	39.60	5.50	-do-	-	-do-	Top of curb North side.
175	In the SE part of the Village Ramgahrwala	Public	Dg	61.05	7.70	-do-	-	-do-	Top of curb South side.
176	In the Northern part of the Village Saidpura	Public	Dg	39.40	4.25	-do-	Silty sands	-do-	Top of curb south side.
177	In the Southern side of the village Mahewar Khurd	Public	Dg	38.15	7.75	-do-	-do-	-do-	Top of curb west side.
178.	In the western part of the village Muhmadpur Panda	Lala Nihal Chand	Dg	66.70	9.65	-do-	-do-	-do-	Top of curb North side.
179.	In the centre of the village Imlikhera	Public	Dg	42.15	9.80	-do-	-	-do-	Top of curb West side.
180.	In the western part of the village Dialpur Kalan.	Public	Dg	17.35	8.90	-do-	-	-do-	Top of curb East side.

11	12	13	14	15	16	17	18	19
3.60	925.33	-	-	17.17 (22.12.62)	18.89 (18.6.63)	Domestic	70.0	-
0.70	937.31	-	-	30.88 (22.12.62)	34.95 (18.6.63)	-do-	71.5	-
2.00	933.80	-	-	42.19 (22.12.62)	44.09 (18.6.63)	-do-	73.5	-
2.75	884.73	-	-	-	29.80 (9.1.63) 33.24 21.6.63)	-	72.5	-
3.10	874.03	-	-	-	20.30 (9.1.63) 26.92 (21.6.63)	Domestic	71.5	-
1.60	904.98	-	-	-	50.98 (9.1.63) 55.98 (21.6.63)	-do-	71.0	-
3.20	899.56	-	-	-	36.75 (9.1.63) 43.42 (21.6.63)	-do-	66.0	-
2.30	869.89	-	-	-	8.10 (9.1.63) 14.16 (21.6.63)	-do-	59.0	-

1	2	3	4	5	6	7	8	9	10
181	In the compound of the Mosque in Hakimpur Village.	Public	Dg	18.90	8.80	Rope and Pulley	-	Gangetic Alluvium	Top of curb South side.
182	South of the Village Kalalhatti	Public	Dg	17.45	6.90	-	Fine to Medium Sands	-do-	Top of curb North side.
183	In the centre of the Village Dariapur Dialpur	Harijans of the Village	Dg	15.65	5.15	Rope and Pulley	-	-do-	Top of Curb South side.
184	In the centre of the Village Dher Majra	Public	Dg	23.50	10.00	-	-	-do-	Top of Curb East side.
185	In the centre of the Village Habibpur Nawada	Public	Dg	18.65	4.90	-	-	-do-	Top of Curb West side.
186	In the western part of the village Paloni	Public	Dg	13.85	5.75	-	-	-do-	Top of curb South side.
187	In the centre of the Village Masahi	Public	Dg	60.15	8.75	-	-	-do-	Top of curb West Side.

11	12	13	14	15	16	17	18	19
2.00	-	-	-	-	9.12 (9.1.63) 11.62 (21.6.63)	Domestic	61.0	-
3.00	878.26	-	-	-	11.98 (9.1.63) 15.16 (21.6.63)	-do-	63.0	-
2.00	875.54	-	-	-	15.65 (9.1.63) 14.92 (21.6.63)	-	72.0	-
3.20	882.73	-	-	-	10.26 (9.1.63) 14.12 (21.6.63)	-	63.0	-
0.60	887.85	-	-	-	10.85 (9.1.63) 16.61 (21.6.63)	-	71.0	-
1.20	881.68	-	-	-	9.00 (9.1.63) 12.88 (21.6.63)	Domestic	70.0	-
3.60	969.55	-	-	-	41.38 (9.1.63) 53.77 (21.6.63)	-	69.0	-

1	2	3	4	5	6	7	8	9	10
188	In the NE part of the Village Jatul	Sri Rati Ram	Dg	23.15	7.95	Persian Wheel	-	Gangetic Alluvium	Top of Curb East side.
189	In the Eastern part of the village Kotwal Alampur	Public	Dg	35.50	11.60	-	-	-do-	Top of curb West side
190	In the field of Choudry Ghasita in Hisampur Village.	Choudry Ghasita	Dg	19.15	6.50	-	Fine to medium sands	-do-	Top of curb NW Side.
191	In the centre of the Village Chaundaheri	Pandit Manu	Dg	22.68	4.55	-	-do-	-do-	Top of Curb West side.
192	In the SE part of the Village Sherpur	Sri Tyagi	Dg	27.20	7.30	-	-	-do-	Top of Curb North Side
193 8/1	50 Yds. West of M/s 81/on Iqbalpur - Gurukul road	Sri Bamu of Shada-uli	Dg	20.60	6.00	-	-	-do-	Top of Curb East side.
194	In the Centre of the Village Biswakheri	Sri Gujjar	Dg	22.99	4.60	-	-	-do-	-do-

11	12	13	14	15	16	17	18	19
2.30	864.17	-	-	-	12.32 (15.4.64)	Irrigation	70.0	-
2.30	876.03	-	-	-	19.28 (15.4.64)	Domestic	68.0	-
2.00	867.00	-	-	-	14.27 (15.4.64)	-	68.0	-
1.50	862.90	-	-	-	14.23 (15.4.64)	Domestic	72.5	-
3.00	854.22	-	-	-	10.32 (15.4.64)	-do-	72.0	-
1.30	859.47	-	-	-	13.50 (15.4.64)	Irrigation	73.50	-
2.00	859.09	-	-	-	15.71 (15.4.64)	Domestic	73.50	-

APPENDIX NO.II

HYDROLOGICAL DATA RELATED TO STATE TUBEWELLS IN THE ROORKEE AREA:

Sl. No.	Tubewell No.	Owner	Location (Group and Main Village)	Depth (in feet)	Well			
					Length in (feet)	Diameter in (inches)	Length of the screen (in feet)	Zones screened (in feet)
1	2	3	4	5	6	7	8	9
1.	1	Govt. of Uttar Pradesh	Group: Roorkee Village: Paniala Chandpur. About 3 Furlongs E. of Paniala Village.	345	336	12/6	104.5	66-85 125-152 262-300 315-334.5
2.	2	-do-	Group: Roorkee Village:Latherdeva Shekh. One furlong N. of the above Village	340	323	12/6	107.00	65-74.5 95-155.5 272-282 300-319
3.	3	-do-	Group: Roorkee Near the Village Harajanti	330	322	12/6	91.50	72.8-83.5 146.2-162.9 247.1-288.3 299.1-322.0
4.	4	-do-	Group: Roorkee Village: Nagla 3 Furlongs SE of Naglamar Village	275	266	12/6	96.00	137-186.5 195-212 234.5-266
5.	5	-do-	Group:Roorkee Village: Landhaura About 6 Furlongs East of Bijhauli Village.	207	186	12/6	91.08	94.92-186

Yield in G.P.H.	Date of completion.	Water Level in feet.	Draw down in feet	Specific capacity GPH/ft.D.D.	Geological Horizon	Quality of water	REMARKS
10	11	12	13	14	15	16	17
13,364	14-11-37	19	18.00	12.40	Indo Gangetic Alluvium		
23,520	4-8- 37	16	18.08	38.12	-do-		
40,532	21- 2-51	11	-	-	-do-		
20,348	19- 8-50	44	8.00	42.37	-do-		
35,388	21-10-49	36	13.00	45.38	-do-	Good	

1	2	3	4	5	6	7	8	9
6.	6	Govt. of Uttar Pradesh	Group:Roorkee Village: Doulatpur	100	93	12/8	50.00	-
7.	7	-do-	Group:Roorkee Village:Landhaura 3 Furlongs N. of the Village Naglamar	300	298	12/6	103.00	113-124 134-170 200-228 238-250 259-276
8.	8	-do-	Group:Roorkee Village:Landhaura 6 Furlongs NE of Naglamar Village.	300	292	12/6	86.00	133-173 239-285
9.	9	-do-	Group: Roorkee Village: Landhaura 2 Furlongs NE of Pandhera Village	340	335	12/6	90.00	119-138 148-170 235-252 296-328
10.	10	-do-	Group:Roorkee Village: Landhaura ½ mile S.W. of Pandhera Village	363	358	12/6	89.00	123-167 302-329 334-352
11.	11	-dp-	Group:Roorkee One mile S.W. of Village Pandhera	300	284	12/6	100.00	97-161 203-214 251-276
12.	12	-do-	Group: Roorkee Village: Landhaura 1 Mile West of Bijhauli Village.	400	-	-	-	-

10	11	12	13	14	15	16	17
27,000	25-10-48	12	-	-	Indo Gangetic Alluvium		
35,380	27-6-53	-	10.00	58.90	-do-		
27,251	7-8-53	-	25.00	34.97	-do-	Good	
37,623	1-8-53	-	11.00	57.00	-do-		
36,495	3-8-53	28	12.00	50.67	-do-		
42,340	23-6-53	25	10.00	70.55	-do-	Good.	
58,771	-	-	25.00	34.97	-do-		

1	2	3	4	5	6	7	8	9
13.	13	Govt. of Uttar Pradesh	Group: Roorkee Village:Landhaura 1½ miles NE of Manglaur village	270	256	12/6	71.00	123-165 222-251
14.	14	-do-	Group:Roorkee 3/4 Mile S.W. of the Village Manglaur	260	254	12/6	90.00	135-170 183-216 226-247
15.	15	-do-	Group:Roorkee Village:Landhaura 2 furlongs N. of Nathukhera	272	255	12/6	87.00	124-162 177-215 238-247
16.	16	-do-	Group: Roorkee Village:Landhaura ½ mile E of Akbarpur Village	270	263	12/6	84.00	121-164 216-257
17.	17	-do-	½ mile S. of Akbarpur village	310	307	12/6	100.00	121-16[illegible] 244-274 279-300
18.	18	-do-	Group: Roorkee Village:Landhaura 6 furlongs SW of Sikhar Village	299	297	12/6	91.00	145-171 187-198 227-270 280-291
19.	19	-do-	Group: Roorkee Village: 3 furlongs WSW of the village Gaharona	310	308	12/6	93.00	128-139 150-167 220-263 285-303

10	11	12	13	14	15	16	17
32,158	13-8-53	-	11.00	48.72	Indo Gangetic Alluvium	-	-
32,188	12-9-53	-	11.00	48.75	-do-	Good	
31,161	20-8-53	-	10.00	51.90	-do-		
31,161	18-8-53	-	11.00	47.18	-do-		
31,161	25-8-53	-	7.00	74.14	-do-	Good	
27,840	22-8-53	-	9.00	51.55	-do-		
35,388	15-8-53	-	-	-	-do-	Good.	

1	2	3	4	5	6	7	8	9	10
20.	20	Govt. of Uttar Pradesh	Group: Roorkee Village:Landhaura 5 Furlongs SW of Landhaura Village	300	277	12/6	94.10	118-166 224-270	
21.	21	-do-	Group:Roorkee Village:Landhaura ½ Mile S. of Padli and 1 mile NE of Tansipur Village.	310	308	12/6	104.00	122-166 223-265 283-301	
22.	22	-do-	Group: Roorkee Village:Bhagwanpur About 5 furlongs E. of Salempur and located in the village Shatipur	370	368	12/6	122.00	137-158 239-287 308-361	
23.	23	-do-	Group: Roorkee Village:Shankarpur	430	429	12/6	98.00	70-80 120-140 215.42-235.42 247.42-260.42 346-358 401-426	
24.	24	-do-	Group:Roorkee Village:Salempur ½ mile N. of Salempur (in the village Gangpur)	382	380	12/6	95.16	230.42-270.08 323.36-378.25	
25.	25	-do-	Group:Roorkee Village:Jaber Hera ½ mile WSW of the Ibrahampur village	273	268.61	12/6	91.00	119-160 223.83-262.83	

10	11	12	13	14	15	16	17
34,301	24-8-53	-	7.00	81.57	Indo Gangetic Alluvium.		
34,301	5-8-53	47	7.00	81.57	-do-		
33,234	30-9-53	30	10.00	55.20	-do-	Good.	
40,000	13-5-55	24	18.00	37.00	-do-		
23,220	9-9-53	27	25.08	25.80	-do-		
-	19-9-53	20	-	-	-do-		

1	2	3	4	5	6	7	8	9
26	26	Govt. of Uttar Pradesh	Group: Roorkee Village:Bhagwanpur In the village Salempur	400	370.45	12/6	83.42	116.5-135.61 242.33-281.08 348.33-370.61
27.	27	-do-	Group:Roorkee Village:Bhagwanpur 6 Furlongs E. of Nalhera Anatpur	395	386	12/6	84.00	174-187 243-271 337-380
28.	28	-do-	6 Furlongs S.W. of Karaundi and 2 miles S.E. of Khelpur Villages.	390	381.5	12/6	89.75	116.5-138 268.08-300.66 331.5-344.66 354-375.5
29.	29	-do-	Group:Roorkee Village:Bhagwanpur 1 mile S.E. of Karaundi Village	340	318	12/6	82.00	108-143 236-247 265-301
30.	30	-do-	Group:Roorkee Village:Mandwari 6 Furlongs S.S.W. of Sikandarpur Village	280	270	12/6	97.00	120-126 140-160 170-176 205-270
31.	31	-do-	Group:Roorkee 2 Furlongs N. of Khelpur Village.	390	328	12/6	61.00	136-154 212-229 251-261 291-307

10	11	12	13	14	15	16	17
27,510	21-8-53	30	10.00	45.80	Indo Gangetic Alluvium		
31,161	8-9-53	20	23.50	22.13	-do-		
23,100	-	20	20.00	23.20	-do-		
29,159	20-9-53	26	19.00	25.50	-do-		
25,412	11-3-55	29	12.00	35.30	-do-		
20,450		28	49.00	19.47	-do-		

1	2	3	4	5	6	7	8	9
32.	32	Govt. of Uttar Pradesh	Group:Roorkee Village:Bhagwanpur 1½ mile E of Sikandarpur and ½ mile S.W. of Sisauna Village.	362	281	12/6	54.00	102-130 141-154 256-269
33.	33	-do-	1½ miles N.E. of Sikandarpur Village	385	379	12/6	77	109-120 151-170 218-239 262-275 359-372
34.	34	-do-	½ mile N.E. of Sikandarpur Village.	374.92	369	12/6	55	199-210 220-231 254-276 350-368
35.	35	-do-	Group: Roorkee 5 Furlongs N.W. of Manakpur Adampur Village.	319	313.75	12/6	106.33	139.25-184.92 214.33-264 286.33-307.33
36.	36	-do-	Group:Roorkee Village:Jabarhera About ½ mile S. of Manakpur Adampur Village.	304	294.33	12/6	83.42	195-257 264.33-288.75
37.	37	-do-	Group:Roorkee Village: Jaberhera ½ mile W.N.W. of Husangarh village.	263	259.5	12/6	85	121-154 200-253

10	11	12	13	14	15	16	17
27,251	24-9-53	20	20.00	22.70	Indo Gangetic Alluvium		
-	-	-	-	-	-do-		
-	-	-	-	-	-do-	Good	
15,950		25	15.00	23.80	-do-	Good	
24,964	15-9-53	23	19.50	21.33	-do-		
29,167	22-9-53	25	18.50	27.00	-do-		

1	2	3	4	5	6	7	8	9
38.	38	Govt. of Uttar Pradesh	Group:Roorkee Village:Jaberhera S.W. Corner of the Jaberhera Village.	300	276	12/6	80	190-270
39.	39	-do-	Group:Roorkee Village: Jaberhera ½ mile S.W. of Majri Village	300	291.33	12/6	84.66	135-155.42 219-283.33
40.	40	-do-	Group: Roorkee Village Jaberhera 2½ furlongs N. of Padli village	295	290	12/6	90	128-159 225-284
41.	41	-do-	Group: Roorkee Village: Jaberhera about 1 mile N.E. of Tansipur village	300	297.92	12/6	113.58	109.08-152.92 185.42-215.33 252.08-291.92
42.	42	-do-	Group: Roorkee Village: Jaberhera 1 mile W.S.W. of Hatiathal village	300	288.58	12/6	91.33	109.08-120.08 135.58-164.08 236.92-288.58
43.	43	-do-	Group:Roorkee Village: Chudiala 5 Furlongs S.S.E. of Srichandi Village 1½ miles N.N.W. of Sherpur village.	452	452	12/6	91.16	98.25-117.08 208.33-219.83 238.42-242.42 317-330 403.83-44[illegible]

10	11	12	13	14	15	16	17
31,161	5-9-53	-	23.50	25.50	Gangetic Alluvium	Good	
31,161	24-9-53	22	20.5	25.90	-do-		
23,649	26-8-53	20	16.00	24.60	-do-		
37,223	4-10-53	20	17.00	36.50	-do-		
33,236	29-9-53	25	18.50	30.70	-do-		
36,100	22-5-57	15	18.00	33.40	-do-	Good.	

1	2	3	4	5	6	7	8	9
44.	44	Govt. of Uttar Pradesh	Group: Roorkee Village:Iqbalpur 6 Furlongs N.E. of Iqbalpur Village.	460	450.75	12/6	103.42	109.58-120.08 239-260 341-354.83 391.58-444
45.	45	-do-	Group: Roorkee Village: Jaberhera Kalan in the Village Jaberhera Khurd. 5 Furlongs S.W. of Akbarpur	300	292	12/6	96.5	80-99.75 128.66-140.75 200.33-209.33 230-285.66
46.	46	-do-	Group: Roorkee Village: Nanhera 1 mile 2 furlongs E. of Salheri Village	380	359	12/6	104.83	70-90 105-125 166-176 240-286.83 306-320 350-359
47.	47	-do-	Group: Roorkee Village:Prempur 1½ miles N.E. of Chudiala and Southern extremity of Sherpur village	310	304.66	12/6	80.66	93.33-137 169-180 209-220 261-294
48.	48	-do-	Group :Roorkee ¾ mile E. of Chudiala Village	330	305.5	12/6	104.00	89-138.25 158-169 209-220 255.5-266.5 272-294

10	11	12	13	14	15	16	17
36,100	12-5-57	17	18.00	33.40	Gangetic Alluvium	Good	
35,000	10-4-58	25	14.00	23.30	-do-	Good	
26,100	3-3-58	-	16.00	27.20	-do-		
-	3-3-63	20.6	-	-	-do-	Good.	
-	-	-	-	-	-do-		

1	2	3	4	5	6	7	8	9
49.	49	Govt. of Uttar Pradesh	Group:Roorkee 7 Furlongs West of Chudiala Village	340	321.75	12/6	104.5	103.5-120 197-208 225-280 288-310
50.	M.E.S. Tubewell Roorkee.	Army H.Q. Roorkee	In the Military Cantt. area, Roorkee and one furlong N.W. of the Railway level crossing near Roorkee	255	255	12/6	109.66	100.66-140 150-175 200-210 225-250
51.	C.B.R.I.	Council of Scientific and Industrial Research.	300 Yds.S.S.E. of the Museum building of the Central Building Research Institute, Roorkee	250	244	12/6	108.16	85-95 100-130 156-200 215-239.16
52.	University Roorkee (ETO Drilled well)	University of Roorkee	About 430 yds.S.S.W. of the Vice Chancellor's building in Roorkee University	261	255	12/6	115.00	115-165 190-255
53.	Field Works Area	Army Military Cantt.	One mile two furlongs N.E. of the Railway level crossing near Roorkee	330	330	12/6	111.00	140-184 223-250 290-330
54.	University (Drilled by Private Agency)	University of Roorkee.	Near Swimming Pool.	300	295	12/6	118.00	95-120 130-158 209-224 255-295

10	11	12	13	14	15	16	17
-	-	-	-	-	Gangetic Alluvium		
24,450	-	35.02	16.96	38.90	-do-		
43,800	-	6.24	15.06	58.17 (USGPM)	-do-		
36,300	-	34.35	12.28	59.12 (USGPM)	-do-		
22,400	-	48.20	8.55	52.40 (USGPM)	-do-	Good	
35,000	3-4-56	-	18.00	32.44	-do-	Good.	

1	2	3	4	5	6	7	8	9
55.	51	Govt. of U.P.	Group: Roorkee ½ mile S.E. of the village Bhalsua Ganj	450	-	-	-	
56.	52	-do-	Group:Roorkee ½ mile East of the Village Khajni	310	-	-	-	-
57.	53	-do-	Group: Roorkee 2 Furlongs North of the Village Harchandpur	390	-	-	-	-
58.	54	-do-	Group Roorkee 5 Furlongs North of the village Paniala	370	-	-	-	-
59.	55	-do-	2 Furlongs west of the village Kharkasi Diata	380	-	-	-	-
60.	56	-do-	3 Furlongs South of the Village Bonuarsi	390	-	-	-	-

10	11	12	13	14	15	16	17
----------------------------------- Data Not Available -----------------------------------							
-do-							
-do-							
-do-							
-do-							
-do-							