GROUND WATER UTILISATION

IN

CANAL COMMAND AREA

THESIS

Submitted to the
Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur
in partial fulfilment of the requirements
for the Degree of

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(SOIL AND WATER ENGINEERING)

THESIS

By

SURESH SINGH NINGOMBAM

J.N.K.V.V. LIBRARY
33786
JABALPUR

DEPARTMENT OF SOIL AND WATER ENGINEERING
COLLEGE OF AGRICULTURAL ENGINEERING
JAWAHARLAL NEHRU KRISHI VISHWA VIDYALAYA
JABALPUR (M.P.)

1991

C E R T I F I C A T E - I

This is to certify that the thesis entitled "GROUND **WATER UTILISATION IN CANAL COMMAND AREA**" submitted in partial fulfilment of the requirement for the degree of MASTER OF TECHNOLOGY IN AGRICULTURAL ENGINEERING of the **Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur** is a record of the bonafide research work carried out by **SHRI SURESH SINGH NINGOMBAM** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instruction.

No part of the thesis has been submitted for any other degree or diploma (Certificate awarded etc.) or has been published/published part has been fully acknowledged. All the assistance and help received during the course of the investigation have been duly acknowledged by him.

12/3/91

Prof. R.K. Nema
Chairman of the Advisory Committee

THESIS APPROVED BY THE STUDENT'S ADVISORY COMMITTEE

Chairman (Prof. R.K. Nema) 12/3/91

Member (Prof. V.S. Kale) 12/3/91

Member (Prof. R.K. Sharma) 13/3/91

Member (Prof. M.L. Chandak) 12/3/91

C E R T I F I C A T E - II

This is to certify that the thesis entitled "GROUND WATER UTILISATION IN CANAL COMMAND AREA" submitted by SHRI SURESH SINGH NINGOMBAM to Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, in partial fulfilment of the requirements for the degree of MASTER OF TECHNOLOGY IN AGRICULTURAL ENGINEERING in the Department of Soil & Water Engineering has, after evaluation, been approved by the external examiner and by the Student's Advisory Committee after an oral examination on the same.

3/9/91
(Prof. R.K. Nema)
Chairman
Advisory Committee

MEMBER OF ADVISORY COMMITTEE

Chairman (Prof. R.K. Nema) 3/9/91

Member (Prof. V.S. Kale) 3/9/91

Member (Prof. R.K. Sharma) Ravindra Kumar Sharma

Member (Prof. M.L. Chandak) 3/9/91

Head of Department Dr. R.N.Pandey 9/9/91

Director of Instruction Dr. M.M. Rai 10-9-91

ACKNOWLEDGEMENTS

Words can not adequately express my deepest sense of gratitude to Shri Rajendra Kumar Nema, Asstt. Prof. Department of Soil and Water Engineering, College of Agricultural Engineering, J.N.K.V.V., Jabalpur, Chairman of Advisory Comiitee, who spared no pains to steer me throughout the study. I am perpetually indebted to him.

I am ever obliged to Shri V.S. Kale, Associate Professor, Department of Soil and Water Engineering, C.A.E., J.N.K.V.V., member of Advisory Committee who was the guiding force behind the study and for his invaluable instructions.

I thank Prof. M.L. Chandak and Prof. R.K.Sharma, member of Advisory Committee for their expert opinions.

I am grateful to S.R. Raje, Dean, C.A.E., J.N.K.V.V. Jabalpur for providing the necessary facilities to carry out the study smoothly.

I offer my sincere appreciation to Dr. R.N. Pandey, Head, Department of S.W.E., C.A.E., J.N.K.V.V., Jabalpur for his keen interest and useful suggestions. I extend my appreciations to all Professors and Staff of the Department for helping me from time to time.

I am also very grateful to R.N. Shrivastava, but for whom, all the data could not have been collected. I acknowledge the help and co-operation of the Senior Geohydrologist and staff of the Sub Division Office (Gangai) of the Irrigation Department, Government of M.P.

I shall fondly remember all my friends who extended their helping hand.

N. Suresh Singh. 12/3/91

(SURESH SINGH NINGOMBAM)

LIST OF CONTENTS

CHAPTER			PAGE
I		INTRODUCTION	1
II		REVIEW OF LITERATURE	
	2.1	General	4
	2.2	General observations in Canal Commands.	5
	2.3	Water table behaviour in Canal Commands Area.	9
	2.4	Water logging, causes and solution.	12
	2.5	Water resource estimation and development.	18
	2.6	Integrated Water Management	24
	2.7	Conjunctive use Approach	25
	2.8	Soil Characteristics	28
	2.9	Evaporation and Evapotranspiration	34
	2.10	Seepage through Canals	37
III		MATERIALS AND METHODS	
	3.1	Location of Project Area.	41
	3.2	Demarcation of Project Area.	43
	3.3	Climate	46
	3.4	Soil Characteristics	46
	3.4.1	Determination of Infiltration Characteristics.	47
	3.4.2	Determination of Hydraulic Conductivity.	47
	3.4.3	Drainable Porosity or Specific yield.	51
	3.5	Aquifer Characteristics.	52
	3.6	Approach to the Problem.	54
	3.7	Water Balance Equation	54
	3.8	Collection of Data	55
	3.9	Estimation/Measurement of Different Components.	56
	3.9.1	Rainfall	56
	3.9.2	Inflow from canals and Irrigated fields.	56
	3.9.3	Surface Runoff	58
	3.9.4	Evapotranspiration from Cropped land.	58
	3.9.5	Eavporation through uncultivated land.	59

CHAPTER			PAGE
	3.9.6	Ground Water Draft	60
	3.9.7	Change in Soil Moisture Storage.	60
	3.9.8	Subsurface inflow and outflow	61
	3.10	Observation on water table.,	61
	3.11	Balancing and Analysis for Different Seasons.	62
IV		RESULTS AND DISCUSSIONS	
	4.1	Identification of Area.	64
	4.2	Cropping Pattern	67
	4.3	Soils	71
	4.3.1	Physical and Chemical Properties	71
	4.3.2	Infiltration	73
	4.3.3	Hydraulic Conductivity	76
	4.4	Pumping Test	76
	4.5	Water Balance Equation	80
	4.6	Net Recharge to Ground Water	80
	4.6.1	Rainfall	81
	4.6.2	Seepage from Canals.	81
	4.6.3	Irrigation	83
	4.6.4	Surface runoff	83
	4.6.5	Evapotranspiration	84
	4.6.6	Ground Water Draft	88
	4.6.7	Change in Soil Moisture Storage	88
	4.6.8	Subsurface inflow and outflow	89
	4.6.9	Net Recharge	94
	4.7	Fluctuation of Water table.	94
	4.8	Comprehensive results	95
V		SUMMARY AND CONCLUSION	101
		BIBLIOGRAPHY	105
		APPENDICES	114

LIST OF TABLES

TABLE NO.		PAGE
4.1	Existing Cropping pattern of Project Area (1988-90).	70
4.2	Proposed Cropping pattern of Project Area (1991-92).	70
4.3	Physical and Chemical properties of soil.	71
4.4	Water retention characteristics (Moisture content on volumetric basis).	72
4.5	Specification of main canal (L.B.C.) and Khulri minor.	82
4.6	Details of canal operation for different years (1989-91).	82
4.7	Water table data for a well at Semra.	90
4.8	Water table data for the wells in Project Area.	91
4.9	Inflow Outflow gradients for subsurface flow in different seasons.	93
4.10	Water balance for monsoon period (1989-90)	97
4.11	Water balance for non-monsoon period (1988-89 to 1990-91).	98
4.12	Effect of possible increase in ground water draft on water table.	99

...

LIST OF FIGURES

Figure No.		Page
2.1	Schematic diagram of auger hole.	31
3.1	Location of Project Area.	42
3.2	Pre-monsoon water table contour map (1978)	44
3.3	Post-monsoon water table contour map (1978)	45
3.4	Schematic diagram of auger hole test of K.	48o
4.1	Post-monsoon depth to water table in a part of Bargi Command	65
4.2	Water table profile along left Bank Canal of Bargi Irrigation Project (Chainage 40-42 Km)	66
4.3	Map of Project Area.	69
4.4	Relationship between infiltration rate/ cumulative infiltration and elapsed time at village Barkhera site 1.	74
4.5	Relationship between infiltration rate/ cumulative infiltration and elapsed time at village Barkhera Site 2.	74
4.6	Relationship between infiltration rate/ cumulative infiltration and elapsed time at Village Semra Site 3.	75
4.7	Relationship between infiltration rate/ cumulative infiltration and elapsed time at village Semra Site 4.	75
4.8	Best fit for infiltration equation for Site 1.	77
4.9	Best fit for infiltration equation for Site 2.	77
4.10	Best fit for infiltration equation for Site 3.	78
4.11	Best fit for infiltration equation for Site 4.	78
4.12	Draw down and recuperation curves of well A and B.	79
4.13	Graph showing moisture content in different month.	86
4.14	Graph showing moisture depletion factor in different weeks.	87
4.15	Pre-monsoon and Post-monsoon water level for POW in Village Semra.	92

...

APPENDICES

APPENDIX		PAGE
A-1	Comparison of seepage estimation by different seepage formulae.	114
A-2	Binnie's Percentage.	115
B-1	Weekly potential evapotranspiration of Jabalpur.	116
B-2	Crop coefficients for major Kharif Crops.	117
B-3	Crop coefficients for major Rabi Crops.	118
C-1	Double cylinder infiltrometer test for determination of infiltration rate at village Berkhera Site 1.	119
C-2	Double cylinder infiltrometer test for determination of infiltration rate at Village Barkhera Site 2.	120
C-3	Double cylinder infiltrometer test for determination of infiltration rate at Village Samra Site 3.	121
C-4	Double cylinder infiltrometer test for determination of infiltration rate at Village Samra Site 4.	122
D-1	Observation and calculation for determination of hydraulic conductivity by single auger hole method at Village Barkhera.	123
D-2	Observation for determination of hydraulic conductivity by single auger hole method at Village Semra.	124
E-1	Observation for pumping and recuperation test at Village Barkhera Well A.	125
E-2	Observation for pumping and recuperation test at Village Barkhera Well B.	126
E-3	Determination of hydraulic conductivity using Ernst equation from the recuperation test data at Village Barkhera Well No. A.	127
E-4	Determination of hydraulic conductivity using Ernst equation from the recuperation test data At Village Barkhera Well No. B	128

APPENDIX		PAGE
F	Computer Programme.	129
G 1	Daily rainfall at Patan.	130
G 2	Runoff from Daily Rainfall data 1990.	133
G-3	Soil moisture depletion in fallow land of black cotton soil.	135
G 4	Moisture deplection factor with respect to Standard meteorological week.	136

...

ABBREVIATIONS AND SYMBOLS

Agr.	Agriculture
Agrl.	Agricultural
A.S.A.E.	American Society of Agricultural Engineers
C	Runoff coefficient
C1	Runoff coefficient from paddy & haveli fields.
°C	Degree celcius
C.A.E.	College of Agricultural Engineering
C.B.I.P.	Central Board of Irrigation and Power
cm	Centimeter
C.S.S.R.I.	Central Soil Salinity Research Institute
cumec	Cubic meter per second
Engg.	Engineering
E.T.	Evapotranspiration
E.T.C.	Evapotranspiration from Cropped Land
E.U.	Evaporation from uncultivated lan
F	Fluctuation calculated
Fig.	Figure
F.O.	Fluctuation observed
FVAR	Variation in fluctuation
G.C.A.	Gross Command Area
G.O.	Outflow gradient
G.I.	Inflow gradient
G.W.D.	Ground Water draft
ha	Hacter
hr.	Hour
I.C.A.R.	Indian Council of Agricultural Research

I.S.A.E.	Indian Society of Agricultural Engineers
J.N.K.V.V.	Jawaharlal Nehru Krishi Vishwa Vidyalaya
K	Hydraulic Conductivity
K_c	Crop factor
L.B.C.	Left Bank Canal
m	Meter
M	Million
min.	Minutes
mm	Milimeter
M.P.	Madhya Pradesh
M.R.B.C.	Mahi Right Bank Canal
N.I.	Net Inflow
N.O.	Net outflow
N.R.	Net Recharge
O.G.W.U.	Optimization of Ground Water Utilisation
P.E.T.	Potential evapotranspiration
R.B.C.	Right Bank Canal
Sl.No.	Serial Number
S.M.S.	Change in Soil Moisture
S.R.	Surface runoff
S.W.E.	Soil and Water Engineering
W.I.	Inflow from irrigated fields.

...

CHAPTER - I

I N T R O D U C T I O N

1. INTRODUCTION

Ground water equilibrium is generally maintained if the various components affecting the hydrologic cycle do not show large variation. However, in trying to meet the food & fibre needs of an increasing population, the number of irrigation projects in the country have increased. These projects have resulted in greater amount of artificial recharge to ground water and is responsible for creating problem of waterlogging which is graually extending in command area. The rates are alarming and calls for a scientific and judicious management of these resources.

Surface irrigation from canal irrigation projects reinforces recharge components by seepage losses from conveyance system and percolation from the irrigated fields. At the same time discharge components particularly ground water draft reduces as a consequence of the availability of cheaper source of irrigation water in canals. This causes disruption of the original equilibrium between recharge and discharge which results in the rise of water table thus rendering productive land to water-logged ones.

The Bargi Irrigation Project is a major multi-purpose project in Madhya Pradesh. It was built on the river Narmada. The left Bank Canal originating from this dam will be 137.2 Km long when completed and will irrigate upto 65 Km in Jabalpur. It

will irrigate about 0.157 million ha of Jabalpur and Narsinghpur Districts. The L.B.C. became operational for partial irrigation in December 1989. It was, therefore, felt necessary to carry out studies to take preventive measures and combat the problem of water-logging as experienced in most of the canal command areas of the country. Utilising ground water is an effective method of arresting rising trends of water table as reported by Pandya (1972) in the Chambal Command of Madhya Pradesh, Sondhi (1985) in Punjab, Sarma et al. (1987) in Mahi Right Bank Canal in Gujarat and Shakya et al. (1987) in Punjab.

It was concluded in above studies that increased ground water draft brings more area under irrigation and reduces the dependence on surface water irrigation which is a major recharge component to ground water. In order to assess the feasibility and utility of such measures the present study has been undertaken to compute the ground water balance of a Canal Command Area, particularly areas with a high water table. Accordingly command area of one of the minors having water table depths varying from 0.3 to 3 m during post-monsoon period was selected for the project.

The study was carried out with the following specific objectives :-

1. To demarcate the area prone to water logging.

2. To estimate the potential ground water utilisation for the area.

3. To prepare/develop ground water model for integrated development.

000

CHAPTER - II

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

2.1 General

India has witnessed a massive development of irrigation after independence. Prior to 1950-51 the total area irrigated was 22.6 million hectares. This figure has increased with subsequent five years plans. By the year 1981-82 the total area was 61.4 million ha and it is proposed to develope the entire irrigation potential of 119 million hectare by the year 2000 A.D. However there exist a wide gap between the development and utilisation of the irrigation potential. The low efficiency of utilising irrigation water has given rise to considerable problem of water logging. While developing large irrigation net work, little attention is given on the factors related to quantitative and qualitative aspects of water application on the farm. The major lacuna in planning irrigation systems has been non-consideration of water balance on the command areas. Excessive seepage from canal system and deep percolation due to over irrigation adds to water table and causes not only a loss of precarious resource, developed at high initial cost but in loss of fertilizers also. ~~Leads to water logging of large tracts of land~~.

The natural causes of water logging are heavy rainfall, floods and unfavourable conditions of drainage owing to topography and geology. Artificial causes such as construction of reservoirs, seepage from canals, defective methods of irrigation and cultivation

have further aggravated the situation.

2.2 General Observations in Canal Commands

Almost in every irrigation project a rise in the water table with respect to time has been witnessed. The rise in water table results from seepage from the canal system as well as deep percolation losses from fields due to faulty on farm practices. The above statement is supported by data compiled on ground water table as presented in following tables.

Premonsoon water table depth in Kakrapar Command Area (1000 ha) in Gujarat

Year	Upto 1.5 m	1.5 to 3.0 m	3.0 to 6.0 m	6.0 to 9.0 m	Greater than 9.0m
1957	-	1.10	11.40	204.90	178.50
1970	0.10	2.10	104.10	133.40	166.40
1975	1.30	21.60	209.90	88.30	35.00
1980	3.20	54.00	186.50	84.90	--

Source : Sinha, 1982

Ground water table depth (m) in Rajasthan Canal Command Area

	YEAR			AVERAGE RISE m/yr.
	1952	1970	1979	
Eastern Block	41	34	19	1.7
Anupgarh Branch	38	33	24	1.2
Surajgarh Branch	-	33	24	1.2

Source : Mathur et al. 1982

The rise of water table if not arrested timely allows the water table to reach the root zone depth and causes water logging. The water logged areas goes on increasing every year as it is evident from the studies at Punjab and Haryana.

Extent of water logged areas in Punjab and Haryana

(Unit - thousand hactares)

Water Table Depth from ground surface

YEAR	BELOW 1.5 m	1.5 to 3 m	3 to 3.5 m
1950	834	575	292
1951	373	1002	812
1952	352	924	913
1953	304	969	955
1954	487	842	866
1955	999	936	513
1956	1057	1041	606
1957	939	1210	678
1958	1424	1005	484
1959	1264	1230	530
1960	1018	1481	628
1961	1086	1487	571
1962	1642	1240	508
1963	1089	1637	569
1964	1446	1519	476
1965	691	1841	879
1966	802	1715	811
1977	505	1467	560

Source : Singh, 1972

Ground water table depth (m) in Punjab

S.No.	Variation in Water table in Punjab canal tract	Period considered	Average rate of rise or fall in m per year during the period	
			June levels	October levels
1.	Upper Bari Doab-I	1926-40	0.02 fall	0.03 fall
2.	Upper Bari Doab-II	1940-56	0.13 rise	0.18 rise
3.	Eastern Division Sirhand Canal	1940-56	0.13 rise	0.15 rise
4.	Zone A Sirhind Canal	1930-56	0.06 rise	0.08 rise
5.	Zone B Sirhind Canal	1930-56	045 rise	0.15 rise
6.	Western Yamuna Canal Zone A	1930-56	0.04 rise	0.07 rise
7.	Western Yamuna Canal Zone B	1932-56	0.05 rise	0.07 rise

Source - Uppal, 1972

Trends of water table rise were observed in West Punjab during the period 1905-06 to 1954-55, the average annual rate of rise of water table ranged between 0.12 m to 0.25 m in the commands of Jhelum and Chenab canal (UPPAL, 1972). The average depth of water table within 8 Km of Sirhind canal is given in table below :

Average depth of water table in the command of Sirhind Canal.

Year	1900	1925	1947	1950	1960	1962
Average depth of water table from ground surface, m	6.92	6.58	6.00	5.85	5.46	5.43

Distribution of water logged areas in different states is presented as below :

Water logged areas in different States of India

Name of State	Water logged area, lakh (ha)
Punjab	10.90
Haryana	6.20
U.P.	8.10
Bihar	1.17
Rajasthan	3.48
Gujarat	4.84
Madhya Pradesh	0.57
Karnataka	0.10
Andhra Pradesh	3.39
Maharastra	1.11
West Bengal	18.50
Orissa	0.60
Tamil Nadu	0.18
Kerala	0.61
Delhi	0.01
Jammu and Kashmir	0.10

Source - Bhargava (1982)

According to Uppal (1972) water logging in India was experienced as early as in the year 1925 and the studies have been felt essential to get the root causes and symptom to identify the

same. To combat the problem of water logging Kumar and Arya (1972) stressed the need for research to offer practical solution to the problem. They outlined the following requirements :

(i) Investigation on behaviour of water table by observation of water levels in open wells and correlating the behaviour with rainfall and canal seepage.

(ii) Investigation on effect of pumping ground water by tube wells.

(iii) Investigations on functioning of open drains, relative merits of surface and subsurface drainage.

(iv) Investigations on relative tolerance of various crops to water logging conditions.

2.3 Water Table Behaviour In Canal Command Areas

Todd (1959) stated that change in ground water levels can be due to natural or artificial means. The changes in external loads induce variations in ground water levels. He identified them and listed as -

i) Secular and seasonal effects,

ii) Stream flow effects

iii) Evaporation effects

iv) Atmospheric effects

Osborn (1966) showed that the net effect of all the factors affecting storage volume of a ground water reservoir can be evaluated in terms of annual maximum and minimum levels of its piezometric surface. The maximum were found to exhibit normal probability distribution.

Investigations carried out at Navsari, Gujarat by Mehta et al. (1972) show that pumping from tube wells and surface drainage were effective measures to control water table and water logging and salinity conditions on deep black cotton soil areas. They observed a rapid rise in water table in the later part of the monsoon. Wells in the vicinity of the irrigation canal had higher water table as compared to the wells away from the canal. Significant contribution in lowering the water table was through tube wells as compared to shallow pumped wells. Two tube wells constructed to depths of 46-49 m controlled water table on 40 ha of land and also supplemented canal water.

Chauhan H.S. (1983) studied water table fluctuation in Nainital Tarai. They found from the premonsoon and postmonsoon water table that in most of the Tarai belt the water table had a rising trend. The maximum rise of water table of 1.5 to 2.0 m occurred in Khasipur area in the premonsoon period. In other areas the rise had been in the range of 0.5 to 1.5 m. They observed that the water table

depth below ground surface, in the area where there was a rising trend, ranged between 2 to 3 m. They concluded that this had a potential to harm crops and may create salinity problem.

Lohan and Kashyap (1983) reported that the water table was shallow in the eastern areas of Haryana State and that was due to peculiar hydrological conditions of closed drainage and application of canal irrigation. In adequate pumpage had contributed to the rapid and constant rise in water table. The situation along the canal was more critical and water-logging problem had developed.

Agrawal and Malik (1984) studied the water table behaviour of Haryana State by dividing it into two zones, i.e. North Eastern part having good quality ground water and the Central and South Western region with brackish ground water. They found that the average annual rise of water table ranged from 8 cm to 68 cm after the introduction of canal in the Central and South Western region while it declined from 10 to 15 cm per year in the good quality region. This was mainly due to the very limited exploitation of ground water, high rainfall and maintained canal water levels.

Sondhi S.K. (1985) studied the water table behaviour of Punjab by analysing water table depth data

collected for 3 years. They found ~~that~~ from the isobath map of the state that the underground water movement is from North East to South West. As a result of this the water table is rising in districts of Kaporthala, Ferozepur, Faridkot and Bhatinda. In Kapurthala district river Bias was the recharging source. Maximum rise of 0.70 meter per year was found in Faridkot district and maximum fall of 0.59 m per year was found in Roper district. Based on the trend of the water table fluctuation, it was estimated that after 10 years, the water table in district Bhatinda and Ferozpur would stand at 3.0 m and 13.5 m below ground surface respectively.

Naqvi (1987) identified reasons responsible for water table rise and the problem created thereafter at Powerkheda, Zonal Agriculture Research Station, JNKVV, Jabalpur. He studied the effect of rainfall and that of canal introduction on water table and found that rate of rise of water table varied with time after the onset of monsoon and was very fast just before attaining the peak. The rate of rise in water table was found to be more consistant after the introduction of canal irrigation.

2.4 Water Logging, Causes and Solutions

Singh and Singh (1972) studied the causes and remedies of waterlogging in Punjab. They considered the

ground water reservoir as a hydraulic system. They showed ground water balance over a long period of years and the imbalance due to the introduction of numerous canal systems in the State and the developments that follows irrigation such as embankments across natural drainage, which interfere with the free flow of flood water. They suggested the construction of storm water drains particularly surface drains which clears the surface water within 72 hours. They found that lining canals caused the water table to recede to more than 2 m as compared to 1 to 1.5 m in unlined canal. ~~command~~.

Morchan and Rethinam (1972) reported that out of the total irrigated area in Tamil Nadu 23% falls under canal irrigation. The command along the canal shows rise of water table and were generally becoming saline. The areas included Kattali high level channal area of Periyar Project Area. They reported that water table was within 0.3 m in Krishnagiri reservoir project affecting about 4,047 ha. Water logging was also present near Erode irrigated by lower Bhavani Project. They outlined methods and general principles of investigations to reclaim water logged areas.

Pandya (1972) studied the causes of water logging ~~problems~~ in chambal canal system of Madhya Pradesh. He collected and analysed data about the rise and fall of water table through a net work of 523 wells and 700 piezometers since

the year 1967. On the basis of depth of water table below ground level, he demarcated areas with progressive rise of water table and those, susceptible to water logging.

Extent of Water-logging in Chambal Command, M.P.

S.No.	Depth to water table below ground level in October 1971	Area (ha)	Remarks
1.	0.0 to 1.5 m	32,725	Fully damaged
2.	1.5 to 3.0 m	24,980	Damaged
3.	3.0 to 4.5 m	22,470	Protected
4.	More than 5 m	8,304	Safe

He attributed the reasons for water logging as follows -

(i) Large areas of the Chambal Command had clay top soil with clay percent 40% to 18% and permeability as low as 0.1016 mm/hr.

(ii) Excessive irrigation resulting in heavy percolation.

(iii) Improper field levelling.

(iv) The practice of Haveli system of cultivation had caused large natural drains to be reduced and now did not exist any longer.

(v) Seepage from canal beds.

(vi) Inadequate ventways provided in bridges and culverts and railway tracks.

Raj and Bapat (1972) carried out investigations to predict problems of water logging before canal inception in the Command Areas of Shetrunji Irrigation Project in Gujarat State. They opined that such investigations have a predictive value and help in bringing out problematic areas before full irrigation is envisaged. The detailed investigations were in respect of drainage requirements boundary conditions and water transmission properties of soil. They found that an area of 6000 has affected. Pumping of water or sub surface drainage from the sub soil water table was suggested as remedial measures.

While projecting the water logging problems of Tawa Command Area. Sahu (1983) opined that as the potential created for irrigation increases the area under water logging is bound to increase. The Tawa Project was first commissioned in 1974 and potential created had increased in subsequent years. In 1975 the irrigation potential was about 20,000 ha, it increased upto 46,000 ha in 1978 and by the year 1980 it reached to 1,08,000 ha. By 1983 the potential created was 1,92,000 ha. However the water logged areas also increased in the Command area. In Hoshangabad district water logging was

over 50 ha in 1978. The area had increased upto 200 ha in 1982 and in subsequent years it has crossed 400 ha,

Gulshan Rai et al. (1985) evaluated the performance of vertical drainage by studying salt and water balance at village Mundlana, Haryana. The area had severe problem of flooding, waterlogging and salinity with poor quality ground water. A set of battery of five cavity tube wells with a spacing of 150 cm was employed for draining out saline water. They found that vertical drainage helped in decreasing the salinity and water logging conditions as well as in maintaining favourable salt and water balance in the root zone.

Samantrai et al. (1987) conducted research on the determination of different sources and their extent of contribution to rise in ground water in Hirakund Command Areas of Orissa. Analysis of the fluctuation of ground water level at three places near canal irrigated areas, uncultivated areas and dry farming areas showed that ground water remained within the safe limit for field crops in dry farming areas and uncultivated areas but it was not so in the irrigated area. The presence of high water table in the irrigated areas have caused failure of crops in rabi seasons. They concluded that the ground water in irrigated areas can be safely used for irrigating rabi crops.

Shakya et al. (1987) suggested multiple well point system for water logged areas of the South West Punjab. Three rows of parallel multiple well point systems, comprising of 8 wells of 6 m deep and 90 mm dia were tested on 12 hectare area. Each well consisted of strainers wrapped with a nylon wire mesh to 50% depth with 30mm thick gravel pack around. It was tested by pumping water continuously for 49 hours. Method of superposition principles was used for computation of draw-down at different points which agreed well with the observed values.

Raj.Singh (1988) carried out investigations to determine the causes of water logging by comparing features and properties of two sites under the Tawa Command. One site (A) Under the command of Hoshangabad distributory was affected by water logging and the site (B) located on Pipariya distributory was free from the problem. He found that slope, drainage intensity and cropping intensity was more at site B compared to site A and soil characteristics such as infiltration rate hydraulic conductivity and drainable porosity at site A to be more susceptible to water logging. He suggested that 50% of the area under cultivation in Rabi at site A to be irrigated using ground water to maintain water table below 3 m. He predicted that there would be no water logging problem at site B for 10 years to came.

2.5 Water Resource Estimation and Development

Ragunath (1982) listed the following steps for optimum development of water resources of any basin and their management.

i) Identify the basin boundary, the main river, its tributaries and other physiographic features.

ii) Divide into sub basins of controllable size depending on factors like steep hill slopes, forest areas, irrigated and unirrigated lands, fallow areas etc .

iii) Establish hydrometeorological set up for each basin.

iv) Select a convenient base period for the hydrologic equation. The hydrologic equation states that all water entering a river basin or sub-basin during any period of time should either go into storage within its boundaries or leave the basin during the same period and water balance is obtained.

v) Apply the water balance equation for the basin for the period selected (as in iv).

vi) Determine average depth of rainfall over the basin or sub basin by Thiessen polygon or isohyetal methods.

vii) Draw stage and discharge hydrograph at control points.

viii) Draw cropping pattern maps for different seasons and estimate evapotranspiration (E.T.). Evapotranspiration can be determined by climatological data.

ix) Determine evaporation from soil and water surfaces.

x) Draw soil map of the basin and conduct infiltration studies in different soils in irrigated and unirrigated lands.

xi) Determine isobath and ground water level contours monthly or atleast for two different seasons.

xii) Corelate hydrographs of monthly rainfall river stage and discharge and ground water levels.

xiii) Change in ground water storage - change in ground water level x involved area of the aquifer X specific or storage coefficient for confined aquifer.

xiv) Determine specific yield in the laboratory and storage coefficient by pumping test in the field.

xv) Directions of flow can be determined from water table map.

xvi) Arrive by water balance the monthly ground water accretion.

xvii) Construct plots of monthly rainfall ground water levels and cumulative change in ground water storage for period selected.

xviii) The usable capacity of the ground water reservoir can be developed by planned extraction of ground water during periods of low precipitation while subsequent replenishment can be made during periods of surplus surface supply.

Walton & Schicht et al. (1961) estimated the hydrologic budget of three small watersheds in State of Illinois. A hydrologic budget is a quantitative statement of the balance between the total water gains and losses of a basin for a period of time. They determined ground water recharge, runoff and evapotranpiration from hydrology and ground water budgets using precipitation, stream flow and ground water level data.

Ground water runoff under flood hydrographs and during rainless periods and ground water evapotranspiration were determined from rating curves of mean ground water stage versus ground water runoff. Ground water storage changes were computed from data on changes in mean ground water stage by using a graph showing the relationship between gravity yield and average time of drainage. The gravity yield average time of drainage graph were prepared from the results of hydrologic budget studies made for periods during

winter and early spring months when evapotranspiration and soil moisture changes are very small. Annual evapotranspiration were appraised from annual hydrologic budgets and were compared to mean annual potential evapotranspiration and annual water loss.

Anonymous (1982) reported that due to the introduction of Bhakhra Canal System in Haryana, there was a rise in the water table. The water table at Haryana Agriculture University Farm, Hissar was rising since 1973. The depth of water table was within 3.0 m. Therefore, a ground water simulation model was adopted for the farm to study the dynamic behaviour of water table. They found after analysing the water table that the rate of rise was 47 cm per year. Ground water balance for the period of October 79 to September 80 was worked out. Total recharge from the rainfall was taken as 20% of rain received during the period. The model was calibrated by comparing values obtained from model and observed water table fluctuation. On the basis of this model they proposed to install 30 tube wells of 13 lit/sec capacity in the vicinity of ground water mound.

Sharma et al. (1987) presented the ground water resources of the Mahi Right Bank Canal Command (MRBC) area for the period 1976-77 to 1979-80. They estimated the various components of ground water recharge in water balance equation. They reported that the average annual recharge

during the period was of the order of 1260 MCM. Out of this 506 MCM contributed towards the increase of the ground water storage and the equivalent rise in the Gross Command Area (GCA) amounted to 1.14 m. They predicted that the area irrigated by canals from the present level of 1.2 lakh hectares would increase to 2.6 lakh hactares and that this would lead to increased seepage and increased recharge to the ground water. Sufficient scope for substantial increase in ground water development existed in the MRBC command.

Anonymous (1982) estimated the ground water potential in planning for utilisation of ground water resources in the Bist Doab tract in Northern Punjab. This tract spreads over an area of 840,300 ha. It was divided into polygen net work, each polygon containing a station. Ground water potential is given by -

$$GW = D \times A \times P$$

Where

GW = Volume of ground water storage in ha-m

D = Average depth of aquifer in m.

A = Area in ha.

P = Drainable porosity

Hydrologic Balance of aquifer of ground water was written as -

$$I + Rr + Rcr + Ri + Si = Se + O + Et + Tp + S$$

Where

Rr = Recharge from rain in ha-m.

Rcr = Recharge from Canal and river in ha-m.

Ri = Recharge from irrigation in ha-m.

I = Inflow into basin from other basins.

Si = Inflow seepage from streams in ha-m.

Se = Effluent seepage from streams in ha-m.

Et = Potential evapotranspiration in ha-m.

Tp = Draft from ground water in ha-m.

S = Change in storage aquifer in ha-m.

O = Outflow from basin to other basins in ha.m

The following equations were used for calculations -

Recharge from rainfall -

$$Rr = 2.5\ (16P)^{0.5}$$

Where, Rr = Annual rechaarge in inches, and

P = Annual percipitation in inches.

Recharge from rivers -

$$Rcr = Q \times 0.0625$$

Where,

Rcr = Recharge in cumec per km length of river,

Q = River discharge in Cumecs.

Recharge from Canals - Seepage loss from canal was computed by using equation -

$$Rcc = \frac{C}{200}\ (B+D)^{1.5}$$

J.N.K.V.V. LIBRARY 33786 JABALPUR

Where,

Rce = Recharge in Cumecs per Km.

B&D = Bedd width and depth of canal in m.

C = Constant

= 1.0 for intermittent running canal.

= 0.75 for continuous running canal.

Draft Calculation : $Q = a \times n \times h$

Where,

Q = Annual draft in ha.m.

a = average discharge per tubewell in ha-m/hr.

n = number of tube wells

h = number of working hours per year

Based on the criteria of hydologic cycle water balance of Bist-Doab tract had been worked out for the year 1974-75. Total ground water potential of the tract is 25,64,625 ha-m and total recharge due to rain and seepage is 1,159,583 ha-m. Total pumpage work is 1,085,970 ha-m. Therefore the net gain of water to the ground water basin is 73613 ha-m. Assuming an average discharge of shallow tube wells as 11.3 lit/sec an estimate of total number of wells to be installed was worked out for different blocks of the districts.

2.6 Integrated Water Management

Hrabovszky (1970) has discussed the sequence of steps and different activities in the planning of water management

system. He has categorised three stages namely planning stage, development and then utilised net work analysis, using the factors involved in each stage. Taylor (1973) discussed the operation and maintenance of irrigation and drainage system, emphasized on a good administrator for collection of data and implementation techniques. Sims (1973) stressed the necessity of the inclusion of a number of important aspects like proper and efficient irrigation and drainage system consolidation of fragmented holdings, conveyance, simplicity and economic feasibility, in planning integrated water management system. Isao (1975) suggested that a planner must keep in mind the following phenomena for integrated water management planning.

(a) Shortage and excess of rainfall.

(b) Shortage of irrigation water

(c) Saving of water for irrigation

(d) Land consolidation

(e) Lining of canal

(f) Water management system

(g) Availability of an adequate outlet

2.7 Conjunctive Use Approach

In reference to Todd (1969), Brown (1980) discussed merits and demerits of conjunctive use. He stressed better conservation of water through provisions of smaller surface storage, smaller distribution system above ground and utilisation of more ground water, storage development facilities lower down

the losses through evaporation and provide greater control of out flow. The demerits are less possibilities to develop hydropower, greater consumption of power because of pumping, greater mineralization of water and more supervisions for project operations. It is also more difficult to assess cost allocation.

Anonymous (1986) CBIP carried out detailed investigation on hydrological, hydrochemical properties of soil and physiographic, geological and geomorphologic setting of the aquifer system to prepare a model for optimization to specify draft from the reservoir and pumpage from the aquifer in Sarada river basin in Andhra Pradesh towards conjunctive utilization of surface and ground water. The studies showed that temporal distribution of rainfall is an increasing trend. Water balance studies indicate that ground water recharge took place during the South West monsoon period and water surplus has been observed around October.

Gupta et al. (1987) studied effect of prolonged canal water use in areas of poor quality ground water in South West region of Punjab. They reported rise of water table and soil salinization problems which have caused a declining trend of crop yields. They pointed out the requirement of incorporating functional relationship between salinity level of irrigation water and crop yield in the decision model. They developed a mathematical model incorporating the response function for conjunctive use of poor quality ground water and canal water. The model was

applied to a canal command in Punjab. They reported that as tube-well water mixing proportion with canal water is increased, the return goes on increasing upto 40% of tubewell water mixed with 60% of canal water but when 50% of tubewell water is mixed with 50% of canal water, the return decreased considerably. The model developed provided an optimum use of land and water resources without deteriorating the condition of plant growth.

Asthana et al. (1988) examined the prospective use of ground water in Sarda Sahayak and Gandak Command in U.P. A lumped linear programming model was developed for the study of conjunctive use and its availability has been illustrated in case of Sarda Sahayak Project. They stressed the need to study the possible change in ground water status as a result of surface irrigation, alongwith feasibility of conjunctive use in future canal irrigation projects. According to them conjunctive use is a potential measure to check the adverse effects of surface irrigation and to arrest the inevitable rise of ground water table in intensive canal irrigation commands.

Pathak (1988) presented advantages and constraints of conjunctive use. He has advocated conjunctive planning and management of surface and ground water. Conjunctive use has the advantage of timely supply, control of water logging and salinity. According to Dr. Pathak differential rate of development of surface and ground water, besides power

availability and lack of proper ground water legislation are constraints for conjunctive use of ground water. They advocated the following measures :

1. Supplementing surface water by ground water or direct use of ground water during period of low canal supply or closure.

2. Ground water irrigation in the pockets of canal command where terrain is uneven and in areas having tendency of rising ground water.

3. In case of saline ground water dilution with surface water.

4. Heavy duty tubewells in tail end of canal command.

5. Laws to control ground water development specially in the areas of continuous water level rise or decline.

2.8 Soil Characteristics

Smille and Towner (1968) proposed a simple method of analysis for use with steady state measurements to determine the relation between hydraulic conductivity and moisture content of soils. They reported that steady state measurement of hydraulic conductivity, moisture content relationship of soils are often based on the simple difference approximation of Darey's flow.

Anonymous (1972) discussed the auger hole method as a simple and reliable method of determining hydraulic conductivity. In this method a hole was bored to a certain distance below the water table. The depth of water in the hole should be about 5 to 10 times the diameter of the hole. The water level was lowered by pumping or bailing and the rate at which ground water flows back into the hole was measured. The hydraulic conductivity could done be computed by Ernst formula for the following 2 conditions.

1. For the case where the impermeable layer is at the bottom of the auger hole, G = 0

$$K = \frac{15{,}000\ r^2}{(H + 10r)\ (2 - y/H)\ y} \quad \frac{y}{t}$$

2. For the case where the impermeable layer is at a depth $\geqq$ 1/2H below the bottom of the auger hole :

$$K = \frac{16{,}667\ r^2}{(H + 20r)\ (2 - y/H)\ y} \quad \frac{y}{t}$$

Where, K = hydraulic conductivity--inches per hour

H = depth of hole below the ground water table-inches.

r = radius of auger hole-inches.

y = distance between ground water level and the average level of water in the hole-inches, for the time interval t--seconds,

y = rise of water-inches, in auger hole during t-seconds, time interval,

G = depth of the impermeable layer below the bottom of the hole-inches. Impermeable layer;

d = average depth of water in auger hole during test-inches.

Ernst made a detailed study of the flow in to an auger hole and developed graphs which are easier to use than Hooghoudt's formula.

Patel and Nihalani (1982) compared the hydraulic conductivity by auger hole method using different formulae. The formulae are as follows -

i. <u>Hooghoudt's formula</u>

Hooghoudt (Luthin, 1966) used two assumptions. The water table around the auger hole is not lowered due to pumping and the water flows horizontally through sides of hole and vertically up through the bottom of the hole. The first assumption is not correct hence the result obtained are approximately correct. (Kirkham, 1955), Hooghoudt's formula for the case when the impermeable layer coincides with the bottom of the auger hole is -

$$K = \frac{2.30\ a\ s}{2\ .\ \Delta t} \log_{10} \frac{Y_0}{Y_1} \quad \ldots\ldots\ldots\ldots(1)$$

and for impermeable layers at great depth :

$$K = \frac{2.30\ a\ s}{(2d + a)\ \Delta t} \log_{10} \frac{Y_0}{Y_1} \quad \ldots\ldots\ldots\ldots (2)$$

Where S is the geometrical factor, depending upon a, d,s and h as shown in Fig. 2.1

Hooghoudt suggested the relation, $S = \frac{a,d}{0.19}$ which is accurate within 27% from trace value (Luthin, 1966).

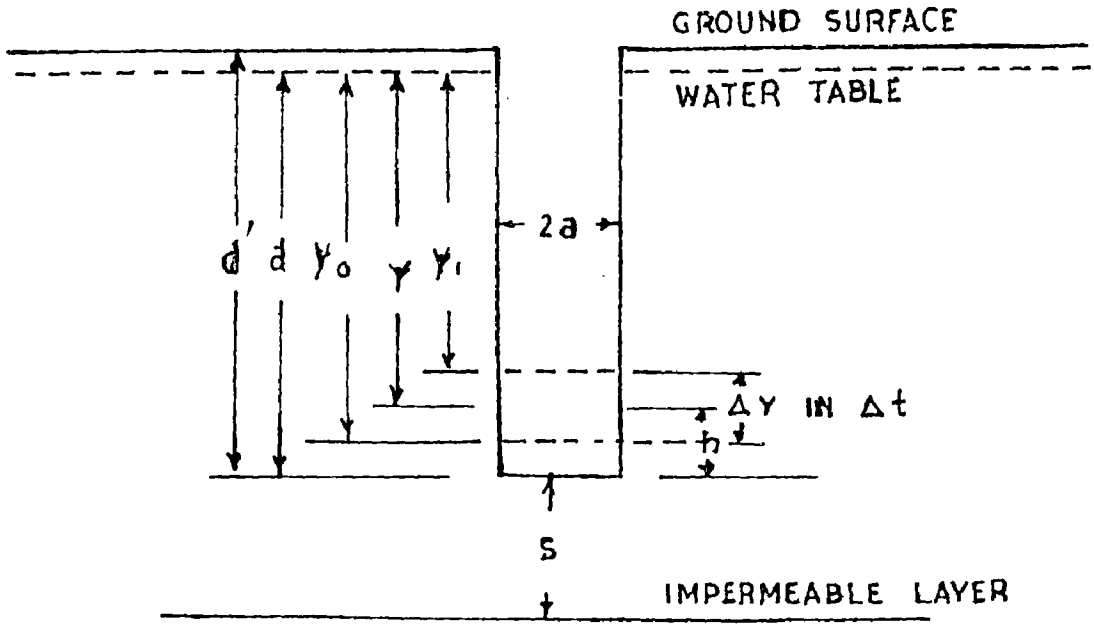


FIG. 2·1 : SCHEMATIC DIAGRAM OF AUGER HOLE

ii. Kirkham's formula

Kirkham (1955) suggested the formula

$$K = \frac{53309\ a}{Sd} \times \frac{\Delta Y}{\Delta t} \quad \ldots\ldots\ldots\ldots\ldots(3)$$

The geometrical factor can be found by refering to the figure as given by Kirkham (1955). The formula is based on the mathematical analysis and valid only if the bottom of the auger hole coincides with the impermeable layer. Thus the formula results in an approximate value of K. The approximation becomes better as the value d/a increase. The use of $\Delta Y/\Delta t$ in place of dy/dt results in an error of the rango of 2 to 3 per cent. If the depth of impermeable layer is known, the geomatrical factor S is replaced by S'. The value of S' can be obtained from the reference (Van Bavel and Kirkham, 1918).

iii. Van Bavel and Kirkham formula

Van Bavel and Kirkham (1948) derived a formula considering the rise of water level in auger holes as function of depth of water level in auger hole from static water table immediately after bailing of water from the auger hole. They suggested the formula as below :

$$K = \frac{193979\ \pi\ a^2}{A} \tan B$$

Graphs were given for the evaluation of A on the basis of information on a/d, s/d and h/d. The value of tan B is obtained from the plot of log Y and t. This formula can be applied to both cases of the location, of impermeable layer.

iv. Formula by Johnson et al.

Johnson et al. (1962) suggested the following formula

$$K = 36600 \frac{A a^2}{A Y} \frac{\Delta Y}{\Delta t} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

This formula is applicable for different values of s/d. Charts are developed by them for factor A.

v. Boast and Kirkham's formula

Formula suggested by Boast and Kirkham (1971) is based on exact mathematical analysis of the flow of system. The formula can be applied for the impermeable layer or gravel (highly permeable) layer at different depth below the bottom of hole. Formula suggested is as below -

$$K = 100\ C \frac{dY}{dt} \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Table has been given for the value C. The value of C between those listed in the table can be determined by intorpolation.

Patel and Nihlani (1982) found that methods given by Kirkham, Van Bavel and Kirkham and Boast and Kirkham yielded reasonably similar values of hydraulic conductivity of different depths.

Rogers and Carter (1987) observed that in layered soils such as alluvial soils of lower Mississippi Valley, hydraulic conductivity in the auger hole varied considerably. The variation presented a problem of deciding the value of K. Numerous tests in silt loam soil and silty clay loam soil showed that K varies not only between holes but also with depth of hole, depth of water removed from the hole. A systematic procedure of measuring hydraulic conductivity, determining design value for yield data and finite element model is discussed.

2.9 Evaporation and Evapotranspiration

As reported by Michael (1978) Penman (1948) proposed an equation for evaporation from open water surface, based on a combination of energy balance and sink strength which is written as-

$$E_o = \frac{\Delta Qn + \gamma E_o}{\Delta + \gamma}$$

in which,

E_o = Evaporation from open water surface, mm/day.

Δ = Slope of saturation vapour pressure Vs temperature curve (de_a/dT) at the mean air temperature T_a per mm Hg per°C.

e_a = Saturation vapour pressure of the evaporating surface (e_s) in mm Hg at mean air temperature T_a (here e_s is considered equivalent to e_a)

T_a = Mean air temperature in °K = 273 + °C

Q_n = Net radiation (mm of water) = Q_A (1-r) (0.18 + 0.55 n/N) - $\sigma T_a 4$ (0.55 - 0.092 $\sqrt{e_d}$) ~~0.10) + 0.90~~ n/N (0.10 + 0.90 n/N)

r = reflection coefficient of evaporating surface, 0.06 for open water surface.

Q_A = Angot's value of mean monthly extra-terrestrial radiations mm of water/day.

n/N = Ratio between actual and possible hours of bright sunshine.

σ = Stefan - Boltzman constant.

e_d = Saturation vapour pressure of the atmosphere, in mm Hg, at dew point temperature =

$$\frac{\text{RH mean} \times e_a}{100}$$

in which RH is mean relative humidity.

γ = Psychrometric constant or the ratio of specific heat of air to the latent heat of evaporation of water (0.49 for 0°C and mm Hg).

E_a = An aerodynamic constant in which, e_s is considered equal to e_a = 0.35 (e_a - e_d) (1 + 0.0098 u_2)

U_2 = Wind speed in miles/day at 2 metres heigh

$= u_1 \frac{(\log 6.6)}{\log h}$ in which u, is wind speed in miles per day at any other height h in feet.

He also reported that Thornthwaite (1948) assumed that an exponential relationship existed between mean monthly temperature and mean monthly consumptive use. The formula was originally developed for the purpose of a rational classification of the broad climatic patterns of the world. Thornthwaite proposed the following formula :

$$e = 1.6\ (10\ t/I)^a$$

in which

e = unadjusted potential evapotranspiration, cm per month.

t = mean air temperature, °C

I = annual or seasonal heat index, the summation of 12 values of monthly heat indices (i) when $i = (t/5)^{1.514}$

a = an empirical component computed by the equation.

$$a = 0.000000675\ I^3 - 0.0000771\ I^2 + 0.01792\ I + 0.49239$$

2.10 Seepage through Canals

A huge quantity of water is lost through seepage from conveyance system meant for irrigation purposes. This creates the problem of drainage due to its contribution in rise of water table.

Lauritzen (1955) reported that about 20% of water entering a water course carrying 30 to 150 litre per second is lost by seepage in a length of 1.60 Km. Formula used for estimation of seepage loss by ponded water method is -

$$S = \frac{W \quad (d_1 - d_2)}{P}$$

S = Seepage rate (m^3/sqm of wetted area/hr)

W = Average depth of channel section (m)

d_1 = Initial water level (m)

d_2 = Final water level in one hour (m)

P = Area of wetted perimeter

Barona (1957) reported that seepage loss through unlined canal system in Mexico showed about 26% in average soil and 35 to 50% in pervious soil.

Nazir et al. (1957) studied the seepage loss through channels plastered on its surface to a thickness of 2.5 cm with

1:10 cement concrete mortor. They found that seepage loss from channel was 7.2 cusec per million square metre.

Ministry of Food & Agriculture, Govt. of India studied the seepage loss through unlined channels under research programme on minor irrigation. Results are tabulated below -

S.No.	Location	Soil	Seepage rate (Cusec/m Sqm)
1.	Punjab (Ludhiana)	Sandy	21.00
2.	Bihar (Patna)	Sandy	23.00
3.	Maharastra (Pune)	Murram	28.81
4.	Tamil Nadu (Coimbatore)	Clay Loam	32.25

Source : Anomymous (1972)

Molesworth Yennidamia ~~et al~~. (1974) suggested emperical formula for estimating conveyance losses of canal. The formula can be written as -

$$S = C \times L \times P \times R$$

S = Conveyance losses x (cumsec/km length (L) of canal)

L = Length of canal (Km)

P = Wetted perimeter (m)

R = hydraulic mean depth (m)

C = A coefficient depending on nature & temperature of soil (for clay c = 0.0015 and for sand c = 0.003)

U.S.D. I.B.R. (1978) suggested that the seepage loss from the channels can be estimated using the following formula -

$$Sq = \frac{K\ (B + 2d)}{3.5}$$

Where,

Sq = Seepage losses (cusec/foot of channel length)

B = Width of water in the channel at normal operation level (ft)

K = hydraulic conductivity

d = depth of water in channel at normal operating level (ft)

Factor of 3.5 is used to adjust hydraulic conductivity test values to seepage loss from pending test.

Offengenden (1979) has given the following equation for estimating seepage losses from earthen canals or ditches.

$$S = s \times \frac{Q \times L}{100}$$

S = water loss per km of canal length (%)

Q = discharge (cumec)

L = length of canal (km)

$$s = \frac{A}{Q^m}$$

Where A and m are empirical constants depending on soil permeability.

Constant	Permeability		
	Low	Medium	High
A	0.70	1.90	3.40
m	0.30	0.40	0.50

Grewal et al. (1982) evaluated the effect of some soil and site properties on seepage losses from small reservoirs and canals. 16 to 42% of total stored water goes waste through seepage and evaporation before its utilization for irrigation in rabi season. They observed that the seepage loss decreased with the decrease in hydraulic head in both the cases. The effects of soil properties and electrolytes concentration of stored water on seepage losses were also studied.

Punamia (1984) used the following formula to estimate seepage loss from the canals in U.P.(India). The formula is written as -

$$dq = 4.8603 \times 10^{-3} \times e\ (B + D)^{2/3}$$

where,

dq = seepage losses (cusec/km)

B = bed width of canal (m),

D = depth of flow in canal (m),

e = is a constant

The value of e = is 0.7 for main and branch canal and 1.0 for other canals.

CHAPTER - III

MATERIAL AND METHODS

3. MATERIALS AND METHODS

GENERAL

Very often canal irrigation causes a rise in water table of the command area. If the rise in water level is not arrested in time, there will be severe water logging problems. The rise in water level is due to increased recharge to the ground water and often reduction in ground water draft. Therefore ground water utilisation in canal command area must be considered alongwith canal irrigation. This chapter deals with the methodology adopted to estimate the potential of ground water utilisation in canal command areas.

3.1 Location of Project Area

The project area lies in the command of the Left Bank Canal (L.B.C.) of the Bargi multipurpose project (Fig 3.1). The Bargi Dam is built on the 5th largest river of India, the Narmada. It originates from the Maikala range in Madhya Pradesh and discharges in to the Gulf of Khambhat. The dam is situated at village Bijora 43.2 Km from Jabalpur City. The L.B.C. passes through the district of Jabalpur. It will be 137.2 Km long and will irrigate upto 65 Km chainage in Jabalpur. The total volume of water to be utilised is 1740 Mm^3. The area for the present investigation is a micro watershed where a shallow water table already exist.

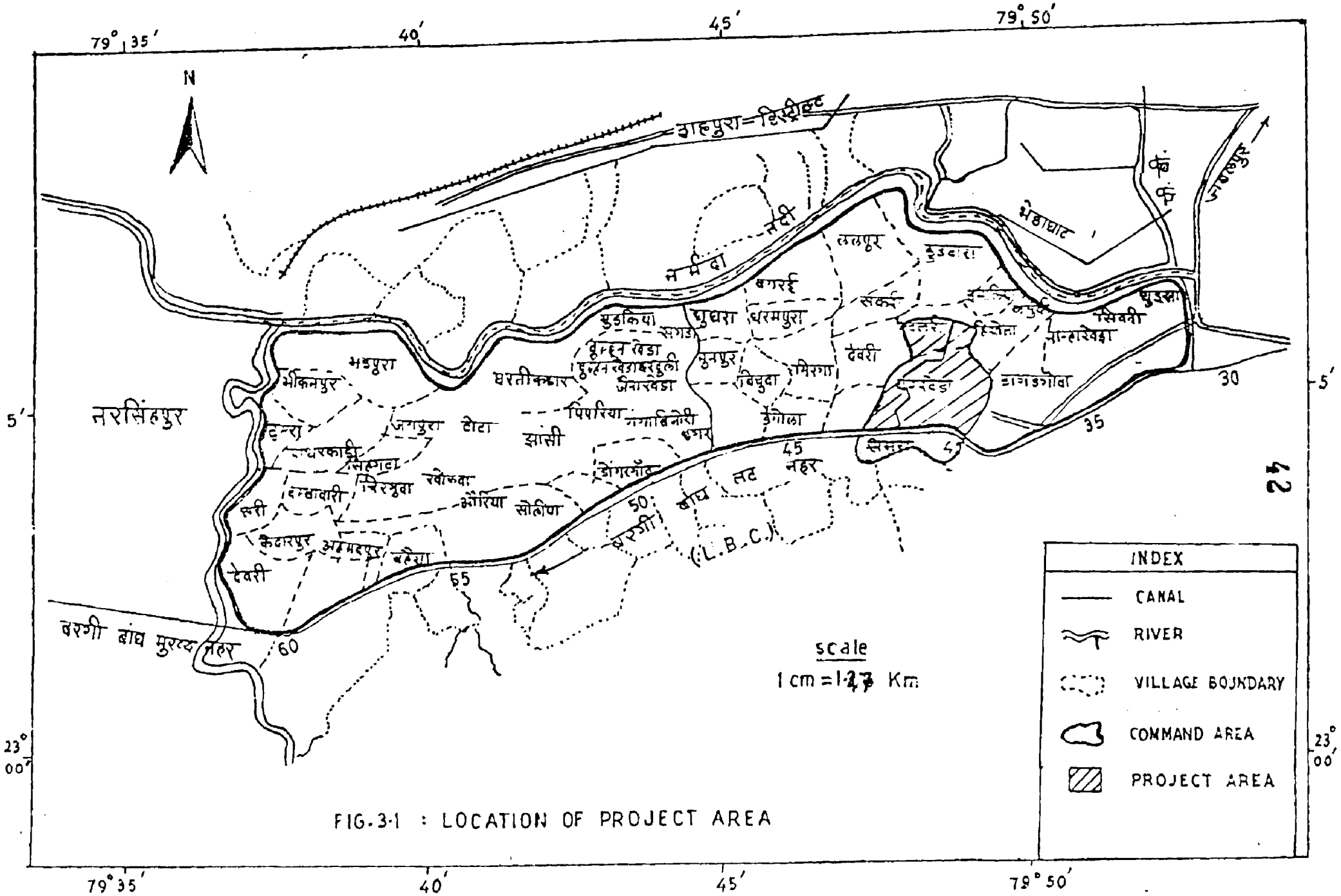


FIG.3.1 : LOCATION OF PROJECT AREA

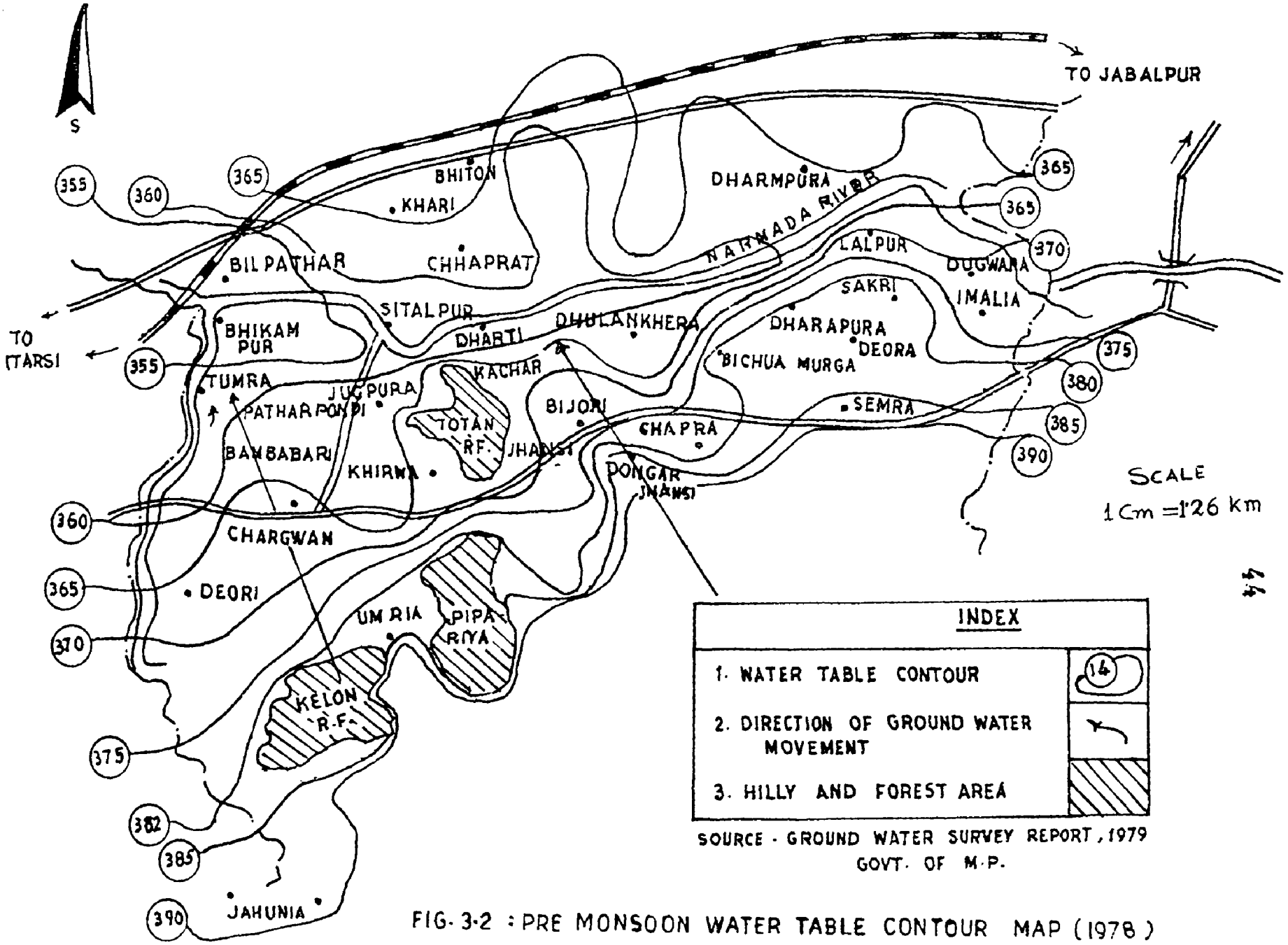
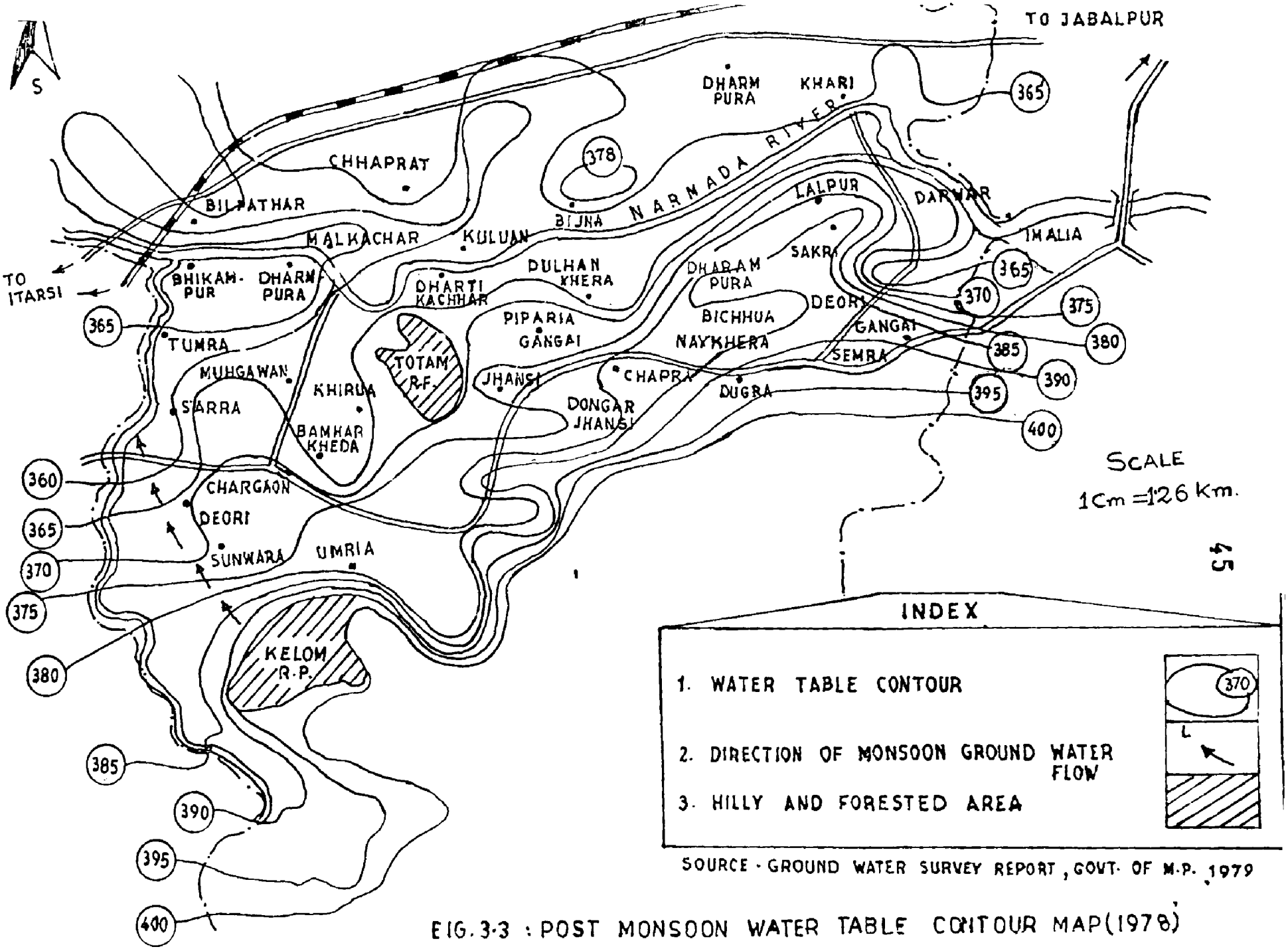


FIG. 3·2 : PRE MONSOON WATER TABLE CONTOUR MAP (1978)



SOURCE - GROUND WATER SURVEY REPORT, GOVT. OF M.P. 1979

FIG. 3·3 : POST MONSOON WATER TABLE CONTOUR MAP (1978)

PLATE 3.1 EXPERIMENTAL SET UP FOR INFILTRATION TEST

PLATE 3.2 EXPERIMENTAL SET UP FOR HYDRAULIC CONDUCTIVITY TEST

PLATE 3.3 EXPERIMENTAL SET UP FOR PUMPING AND RECUPERATION TEST

compiled from the records of the village level workers of the Agriculture Department, Government of M.P.

3.9 Estimation/Measurement of Different Components

Each component of the water balance was determined or estimated using techniques as outlined in the following paragraphs -

3.9.1 Rainfall

The volume of rain occuring in the area during a period was considered as inflow into the area during that period.

Volume of rain = Depth of rain x Area

The daily rainfall records for the period 1980-90, were collected from the observatory situated at Village Patan. Rainfall for non-monsoon season was worked out seperately from daily rainfall data.

3.9.2 Inflow from Canals and Irrigated fields

Since the seepage rates from main canal and minor are not available for Bargi Canal Areas, the same were adopted with reasonable assumptions from the studies carried out on similar soils (Silty Clay) by other workers, Sharma (1987) reported seepage rate as 1.8 to 2.5 $m^3/sec/Mm^2$ of wetted area

for unlined canals. Pandey (1988) had also conducted the study on seepage losses from main canal in Barna Command in district Raisen of M.P. He estimated seepage rate by using different formulae and compared it with measured values as given in appendix A. He finally found that the average measured rate is 1.96 $m^3/sec/Mm^2$ of wetted area which is close to those adopted by Sharma (1987). The above studies however were carried out on canals which were 8-10 years old and have good compaction of their sides and bottom even if they are unlined, whereas the present study has been under taken in a newly constructed canal only 2 years old, which results in higher seepage losses, and therefore, the rate was taken towards the higher limit as suggested by above workers. Therefore the rate of 2.2 $m^3/sec/Mm^2$ of wetted area was adopted for the present calculation.

Seepage losses from main canal = WC = Rate of Seepage x Wetted perimeter x length x duration of operation

To determine the quantity of irrigation water, duration, depth of flow, discharge of the minor at the outlet to the fields was considered as volume of water delivered for irrigation (WI).

WI = Discharge rate at head of minor x time of operation of minor - Seepage loss from minor.

CHAPTER - IV

RESULTS AND DISCUSSIONS

4. RESULTS AND DISCUSSIONS

This chapter deals with the results obtained from the study and a brief discussion thereon. The results of the study are mainly confined to the assesment of the components of hydrological balance with specific reference to the use of ground water to avoid the possible rise in Ground Water table. The studies were carried out in one of the minors of L.B.C. of Bargi Command "Khulri minor", which was observed to fall within the area having 4 m of water table. The sequential results are presented in subsequent paragraphs.

4.1 Identification of Area

The area most prone to water logging are those where the water table is high before the introduction of canal. Isobath map as obtained from geohydrological report of Shahpura Block shows that an area of about 7.0 Km^2 around village Gangai, Semra and Gangai Bijori have water table less than 4 m from ground surface and is presented in Fig. 4.1. The studies on the pre and post-monsoon water table along the canal were carried out to identify the location of water valley. Profiles of the water table for 1986-89 were drawn along the main canal and are presented in Fig. 4.2. The figure indicates the presence of water valley between 39th Km to 41st Km chainage. The water table was observed in the open wells around this chainage to locate the patches of high water table. It was observed that command area of Khulri minor, Lalpur minor,

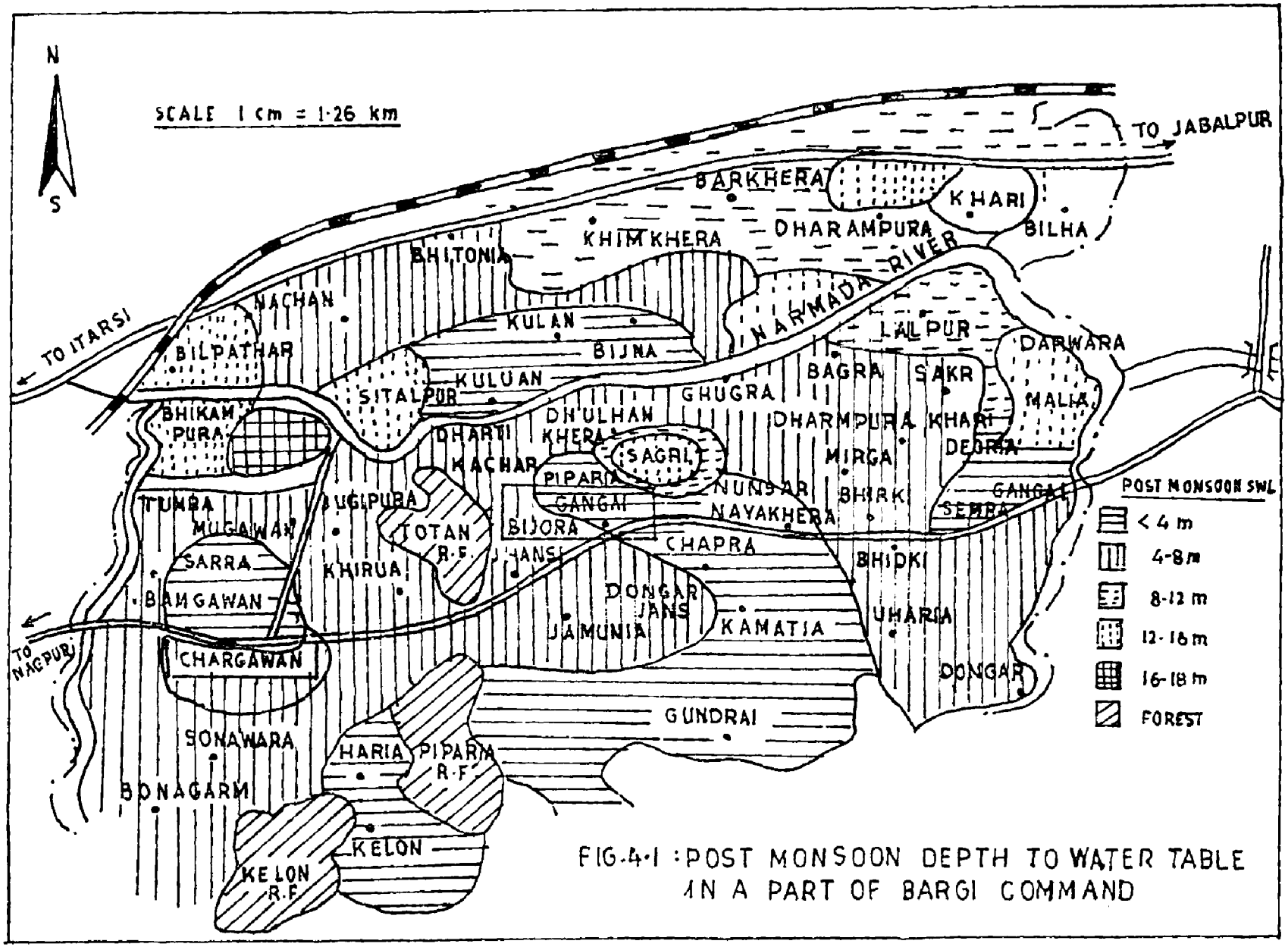


FIG.4·1 : POST MONSOON DEPTH TO WATER TABLE IN A PART OF BARGI COMMAND

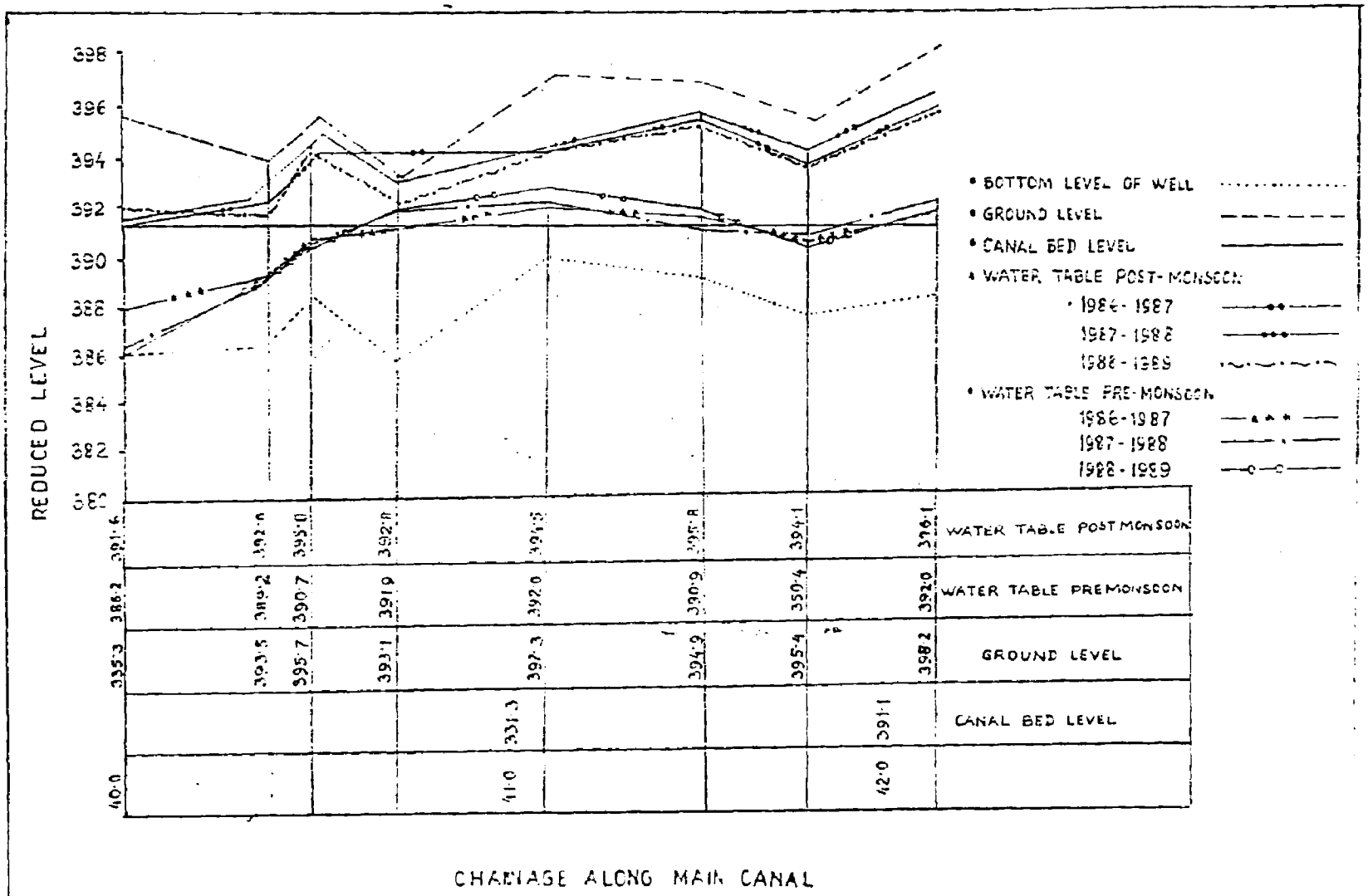


FIG.4-2 : WATER TABLE PROFILE ALONG LEFT BANK CANAL OF BARGI IRRIGATION PROJECT (CHAINAGE 40-42 Km)

Gangai minor and part of non command area in Semra and Bhidki villages have water table within 0.6 to 3.0 m from ground surface. Plate4'1 and Plate4'2 have been presented with the view to show the position of water table in the study area and the standing water in Haveli fields in the month of November 90. Khulri minor falls in the high water table region and hence was selected for the study. The project area is shown in Fig. 4.3. The Khulri minor is designed to irrigate 155 ha through a net work of 3 Km. At present the minor is constructed upto 2 Km. The total watershed comprises of 214.89 ha of land and has the main canal along the southern boundary and seasonal drains on either sides. The length of the drains is about 7.5 Km as observed in the field. It has a flat topography with average slope of 0.5% with elevation ranging between 384 m and 395 m above mean sea level.

4.2 Cropping Pattern

The area is mostly monocropped i.e either paddy in Kharif keeping fallow in rabi or following Haveli system for wheat cultivation. The present cropping pattern is presented in Table 4.1. The total area of cultivation in Kharif at present is 81.19 ha which is 38% of G.C.A. Paddy is the principal crop and 85% of the cropped area in Kharif is under paddy. About 60 ha is under Haveli system of cultivation where water is stored during monsoon and later drained out in the month of

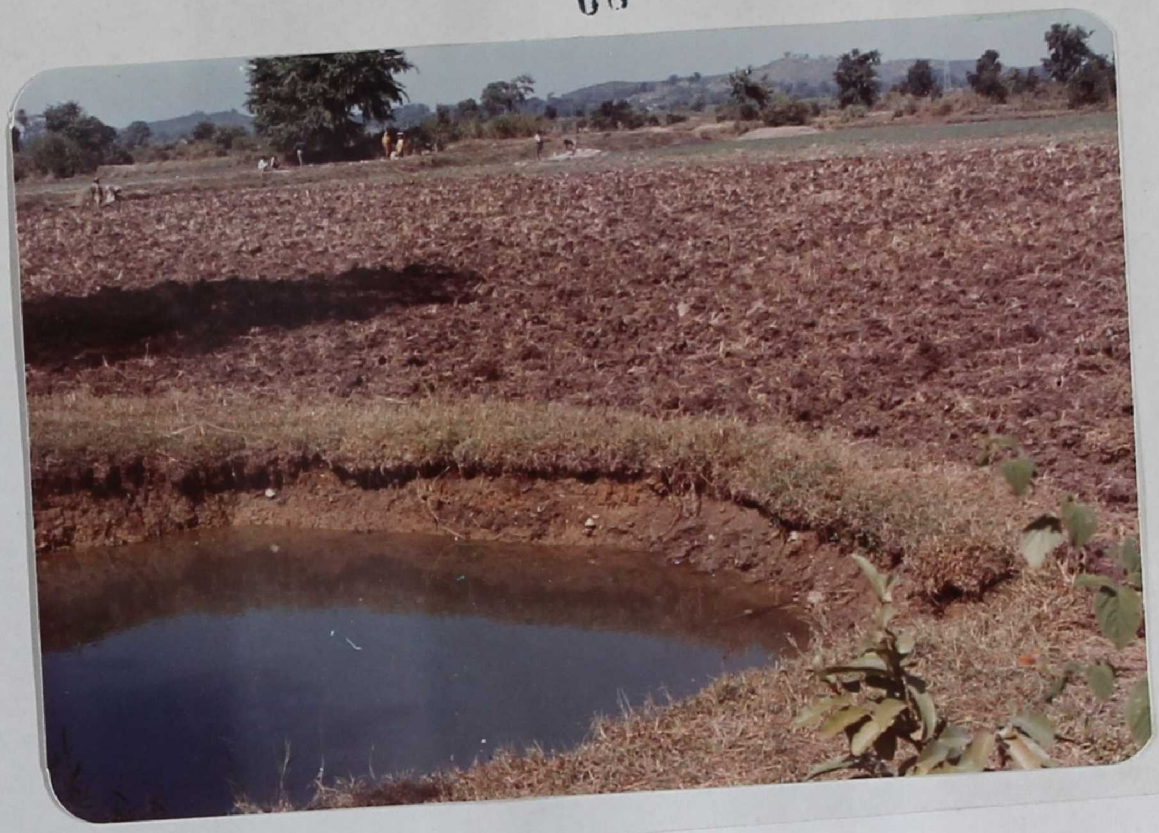


PLATE 4.1 DEPTH OF WATER TABLE IN AN OPEN WELL AT VILLAGEBARKHER

PLATE 4.2 PONDED WATER IN FIELDS.

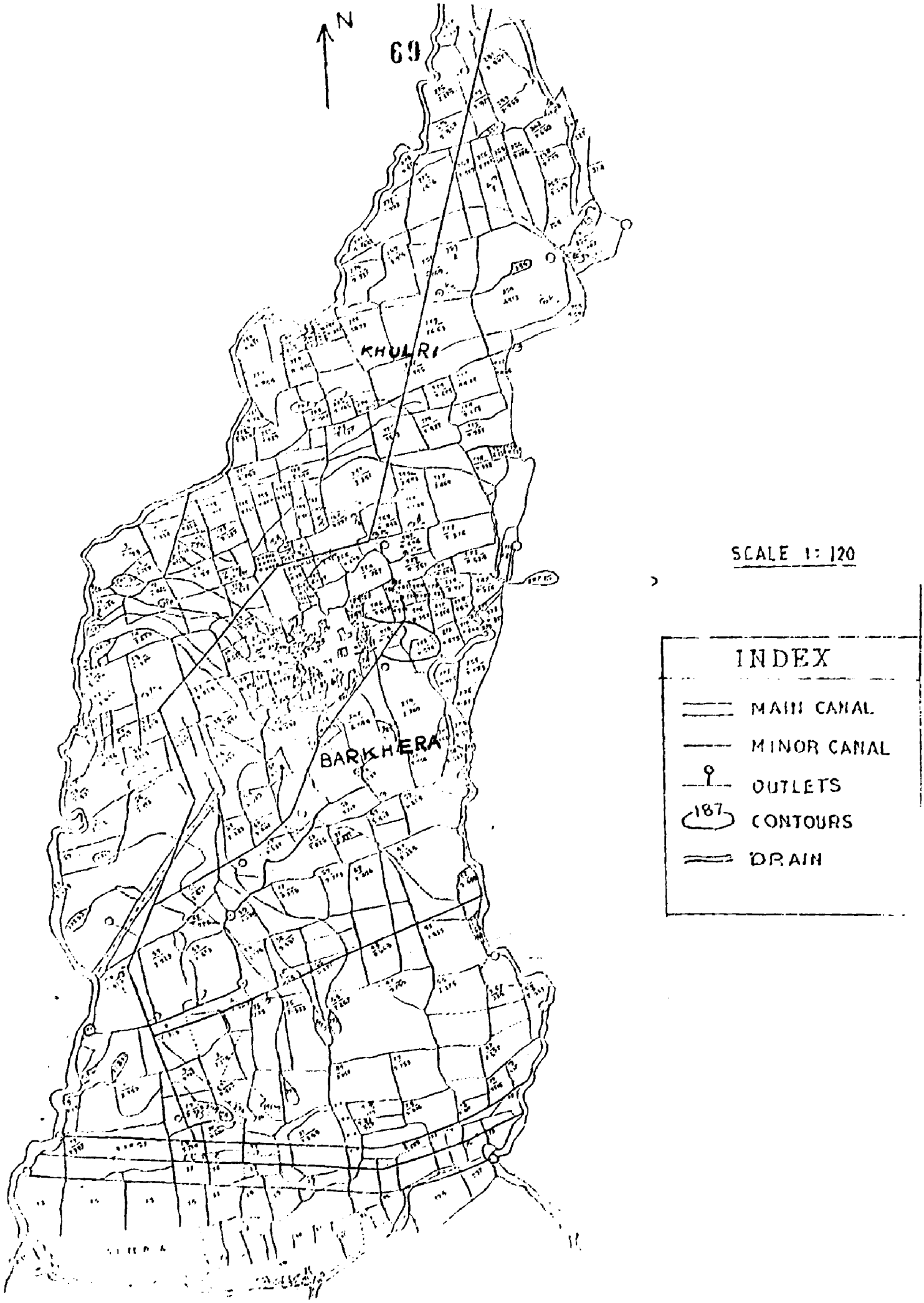


FIG. 4.3 : MAP OF PROJECT AREA

Table 4.1 Existing Cropping pattern of project area (1988-90)

S.No.	KHARIF		RABI	
	Crop	Area (ha)	Crop	Area (ha)
1.	Paddy	69.49	Wheat	83.32
2.	Soyabean	2.72	Gram	18.38
3.	Jowar	2.86	Lentile	9.47
4.	Arhar	4.52	Pea	8.56
5.	Vegetables & others	1.60	Vegetables & others	5.79
	Total	81.19	Total	125.52

Table 4.2 Proposed Cropping pattern of project area (1991-92)

S.No.	KHARIF		RABI	
	Crop	Area (ha)	Crop	Area (ha)
1.	Paddy	91.43	Wheat	128.38
2.	Soyabean	3.58	gram	28.32
3.	Jowar	3.76	Lentile	14.59
4.	Arhar	5.95	Pea	13.19
5.	Vegetables & others	2.11	Vegetables & others	8.92
	Total	106.83	Total	193.41

SOURCE - WAPCOS (1986)

8

October - November to bring it under cultivation. Total cultivated area in Rabi is 125.52 ha which is 58% of the G.C.A. Wheat covers the maximum area with 83 ha. Pulses and vegetables are grown in the rest of the area. There is no forest land and uncultivated land is mostly fallow.

After development of full irrigation potential cropping intensity of 140% is proposed through 50% during Kharif and followed by 90% in Rabi. The proposed cropping pattern is presented in Table 4.2. The area under Haveli is expected to reduce as there will be no necessity to store the water once irrigation water is assured in Rabi.

4.3 Soils

4.3.1 Physical and Chemical Properties

Textural analysis of the top soil profiles are given in Table 4.3. The clay content varies from 45% to 47% in profiles upto 1 m. The soil is classified as silty clay which is established by infiltration and hydraulic conductivity tests pH and electrical conductivity values as presented in the table are falling in safe limit. Moisture retention characteristics of different profiles ~~at~~ d~~ifferent~~ p~~ressures~~ ~~are~~ presented in Table 4.4. Soil Moisture ~~retaining~~ ~~capacity~~ content varies from 34% at field capacity i.e. 1/3 bar to 23% at 15 bar pressure i.e. at permanent wilting. point.

Table 4.3 Physical and Chemical properties of Soil.

S.No.	Depth from ground surface (cm)	% Sand	% Silt	% Clay	pH	Electrical conductivity E_c (m-mhos) cm
1.	0 - 20	10.9	41.6	47.4	7.5	0.37
2.	20 - 40	11.1	41.6	47.3	7.7	0.33
3.	40 - 60	10.0	42.2	47.7	7.8	0.29
4.	60 - 80	10.1	44.8	45.1	7.8	0.32
5.	80 - 100	9.8	43.9	46.3	7.7	0.33

Table 4.4 Water Retention Characteristics (Moisture content on volumetric basis)

Soil depth (cum)	Soil moisture tension (bar)						
	1/3	½	1	3	5	10	15
0 - 20	32.70	32.00	31.10	25.0	23.90	22.80	20.30
20 - 40	34.40	34.00	33.10	26.7	24.70	23.70	22.30
40 - 60	34.00	34.20	33.40	26.7	25.00	24.20	22.90
60 - 80	36.70	35.40	34.80	28.1	26.80	24.90	23.30
80 - 100	37.50	36.40	35.40	28.2	26.80	24.90	23.30

4.3.2 Infiltration

Infiltration test was carried out at 4 sites. Basic ~~Contant~~ infiltration rate varied between 0.4 cm/hr at village Barkhera to 2 cm/hr at village Semra. An average value of 1.25 cm/hr was adopted for the study. Fig. 4.4 to Fig. 4.7 shows the plot ~~relationship~~ between cumulative infiltration, ~~and~~ rate of infiltration and elapsed time. Observations recorded are in Appendix C-1 to C-4. The relationship of infiltration and elapsed time is expressed in a mathematical form by fitting the experimental data in the following equation..

$$I = Kt^n + C$$

Where

I = Infiltration rate in cm/hr

K = infiltration rate at unit time in cm/hr

n = exponent

C = constant rate of infiltration in cm/hr

t = elapsed time in min

The values of variables obtained are as follows -

Village	Site	K	n	C
Barkhera	1	10.196	-0.75	0.4
Barkhera	2	14.150	-0.72	0.5
Semra	3	24.530	-0.67	2.0
Semra	4	10.260	-0.73	1.6

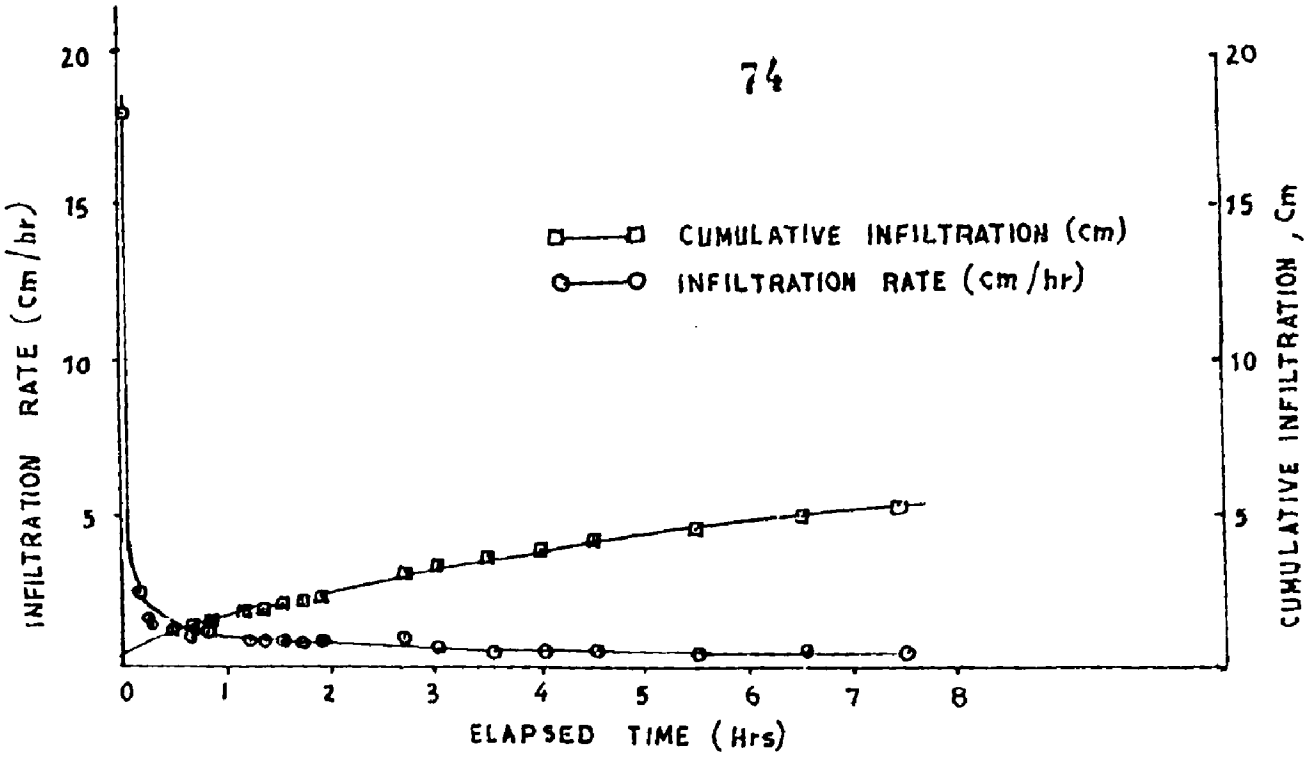


FIG. 4.4: RELATIONSHIP BETWEEN INFILTRATION RATE / CUMULATIVE INFILTRATION AND ELAPSED TIME AT VILLAGE BARKHERA SITE 1

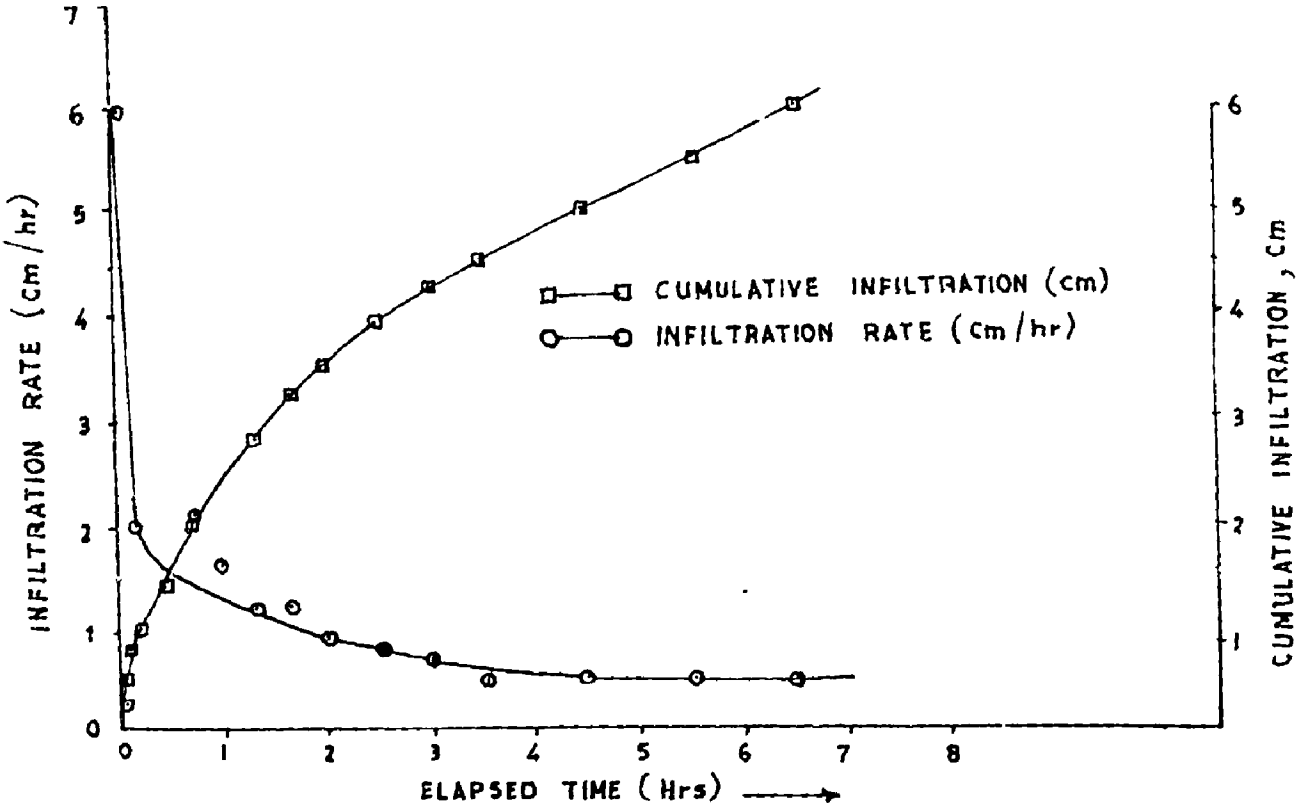


FIG. 4-5 : RELATIONSHIP BETWEEN INFILTRATION RATE / CUMULATIVE INFILTRATION AND ELAPSED TIME AT VILLAGE BARKHERA SITE 2

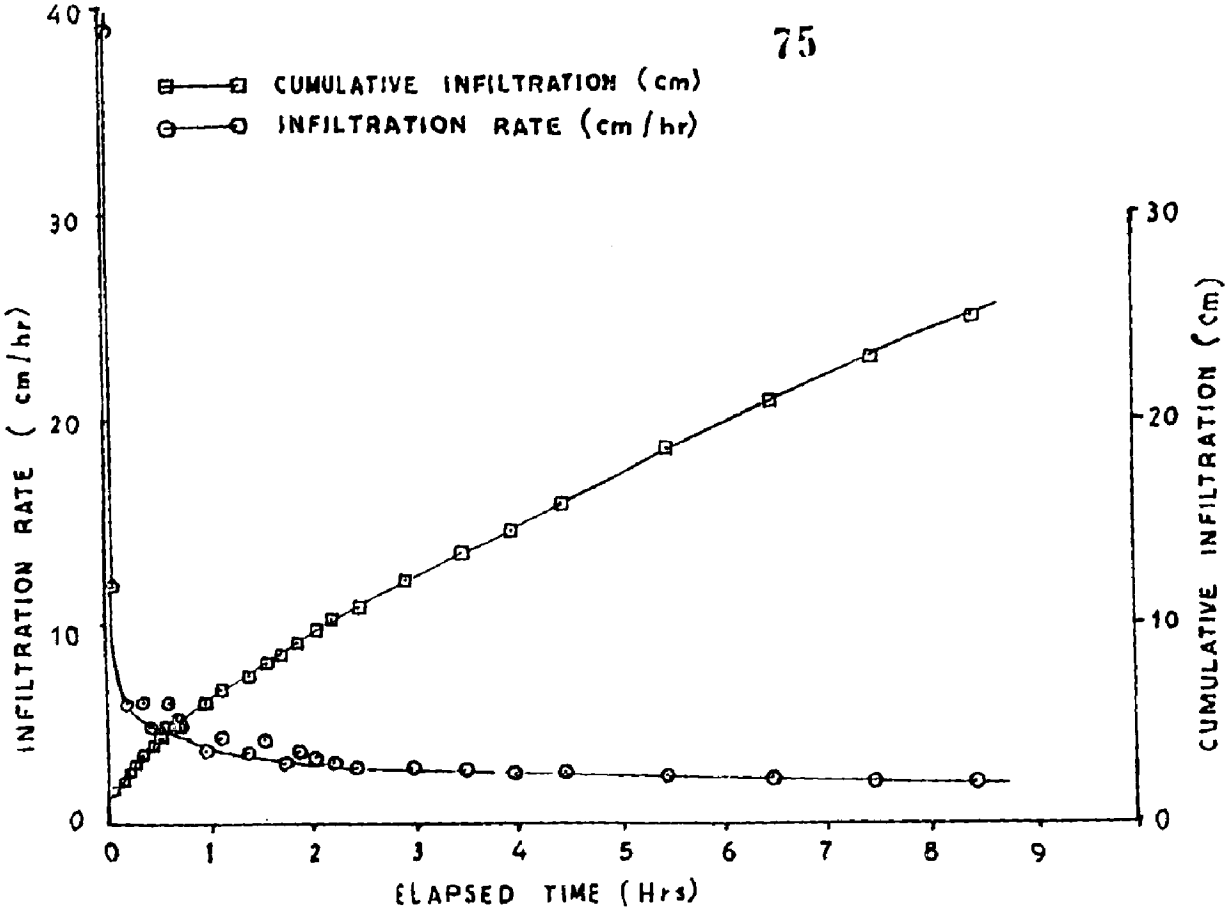


FIG.4.6 : RELATIONSHIP BETWEEN INFILTRATION RATE / CUMULATIVE INFILTRATION AND ELAPSED TIME AT VILLAGE SEMRA SITE 3

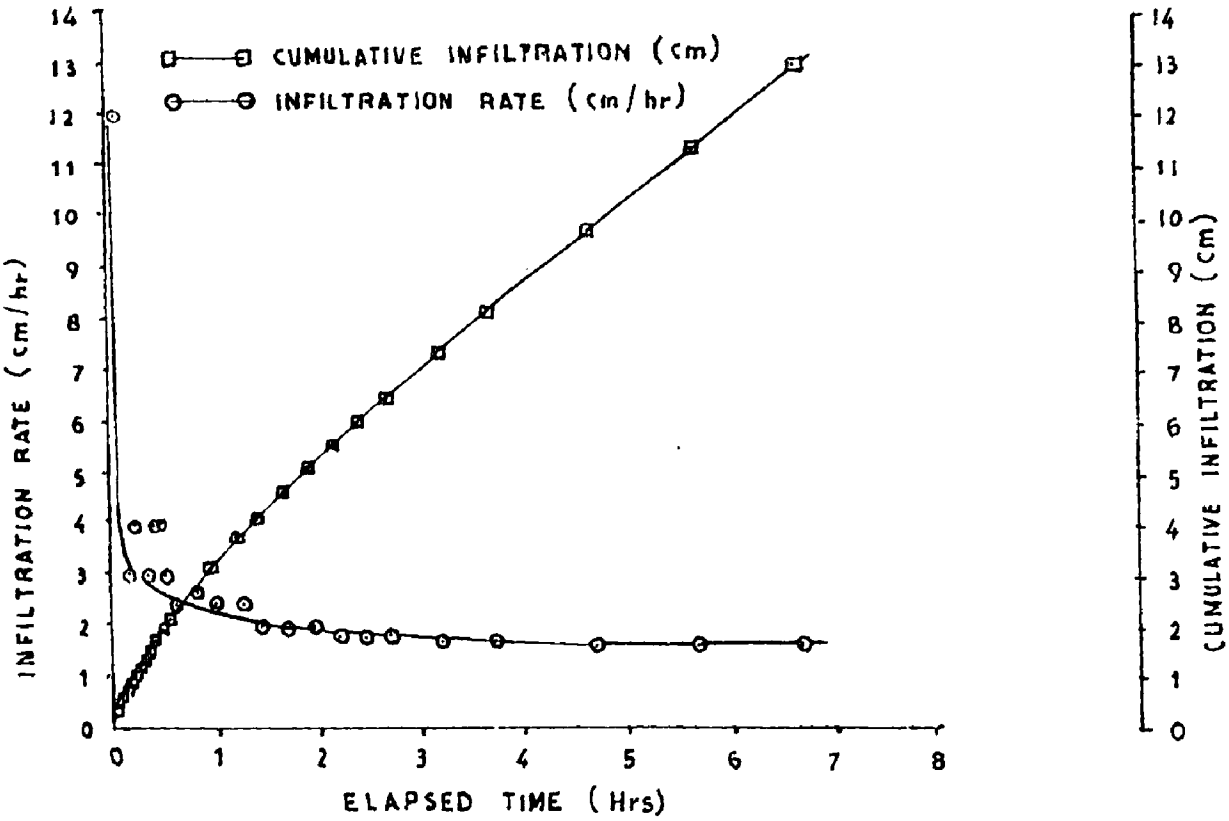


FIG.4.7 : RELATIONSHIP BETWEEN INFILTRATION RATE / CUMULATIVE INFILTRATION AND ELAPSED TIME AT VILLAGE SEMRA SITE 4

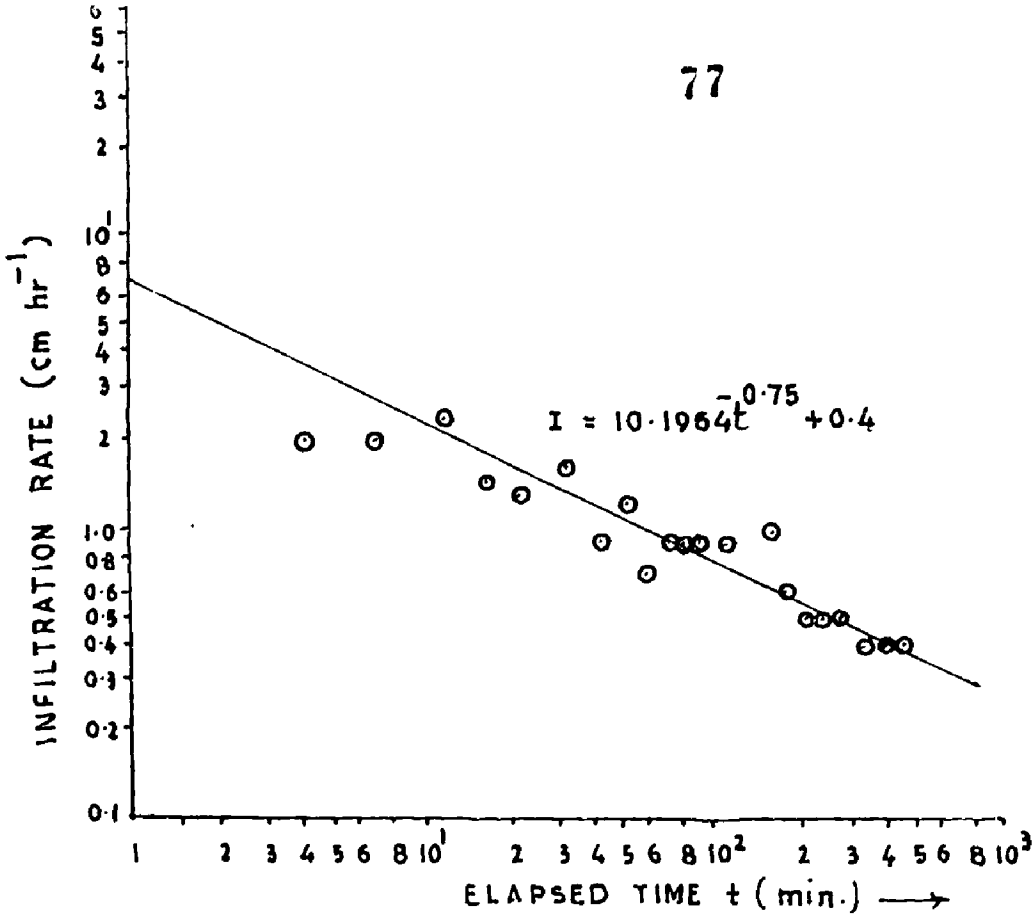


FIG. 4.8 : BEST FIT FOR INFILTRATION EQUATION FOR SITE 1

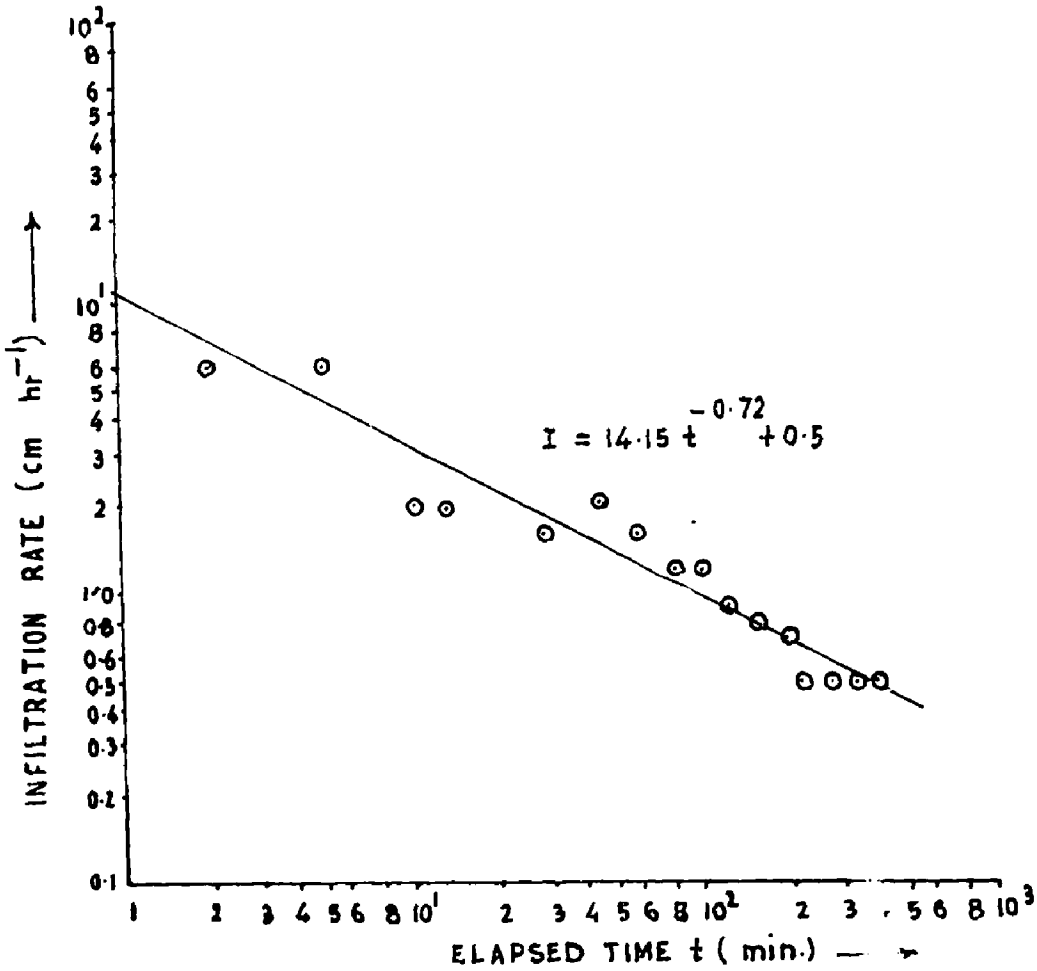


FIG. 4.9: BEST FIT FOR INFILTRATION EQUATION SITE 2

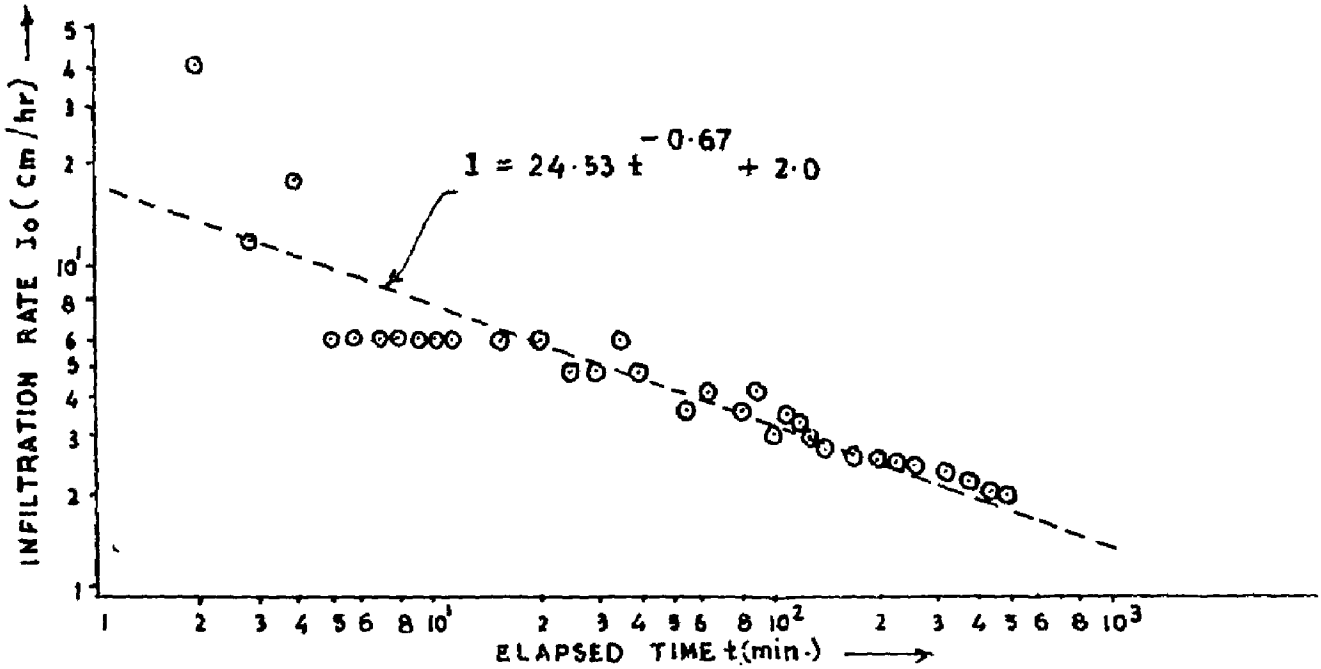


FIG. 4·10: BEST FIT FOR INFILTRATION EQUATION FOR SITE 3

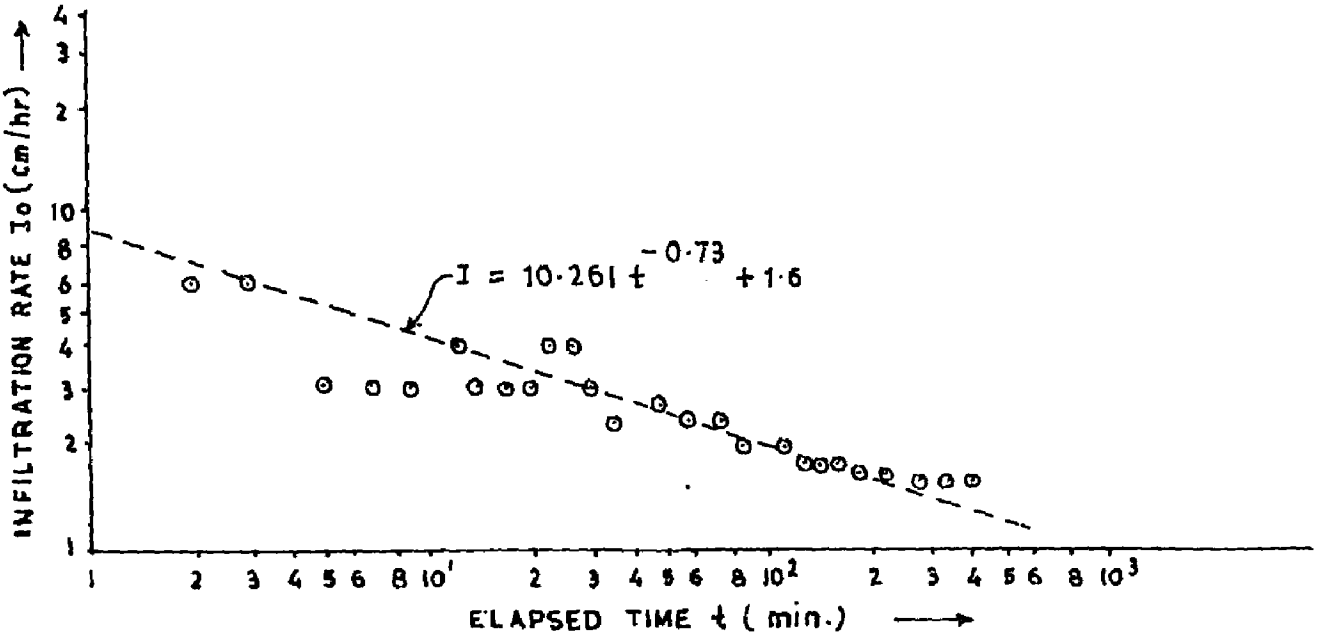


FIG. 4·11 : BEST FIT FOR INFILTRATION EQUATION FOR SITE 4

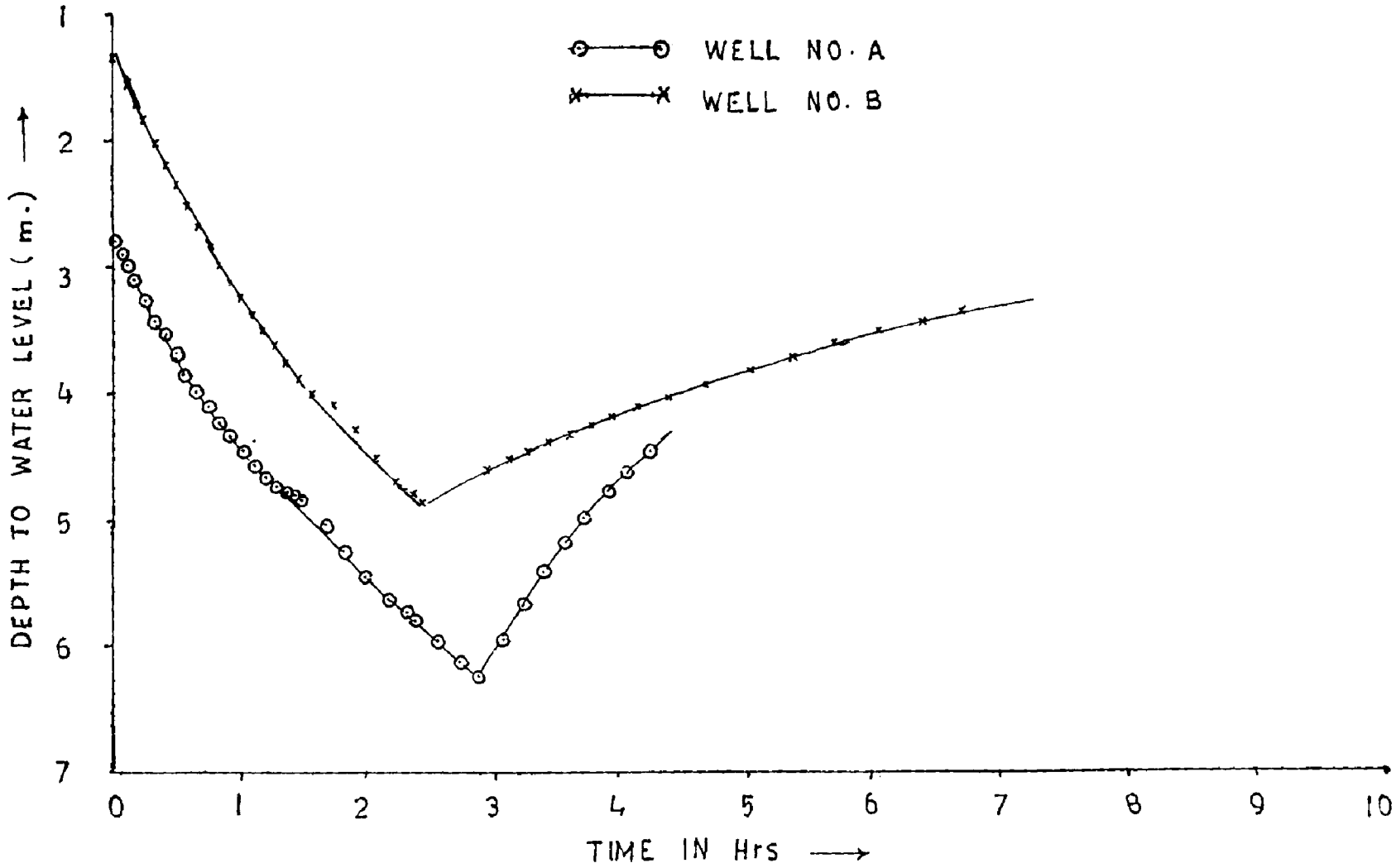


FIG. 4·12 : DRAWDOWN AND RECUPERATION CURVES OF WELL A AND B

Table 4.5 Specification of main canal (LBC) and Khulri minor.

Particulars	Length (m)	Bottom width (m)	Full supply depth(m)	Free board (m)	Side slope.	Discharge (cumec)
Existing main Canal	1120	9.14	3.96	1.20	1:1.5	77.17
Existing minor Canal	2000	0.30	0.30	0.50	1:1.5	0.125
Extended minor Canal	3000	0.30	0.30	0.50	1:1.5	0.125

Table 4.6 Details of Canal operation for different years (1989-91)

Particulars	Depth of supply (m)			Period of supply (hrs)		
	1989	1990	1991 (Proposed)	1989	1990	1991 (Proposed)
Main Canal	2.64	3.45	3.96	628	816	1098
Minor Canal	0.20	0.30	0.30	340	408	765

4.6.3 Irrigation

Since water courses are yet to be constructed, the total volume of water delivered at the head of the minor minus the seepage loss at minor was considered to be delivered at the field and taken as inflow. The volumes are 9.8, 17.47 and 31.82 ha-m for the year 1989, 1990 and 1991 respectively.

4.6.4 Surface runoff

Since there was no supporting experimental data for the project area to compute the surface runoff coefficient, the curve number technique was adopted to estimate the runoff from daily storms. Sample ~~calculations~~ results ~~is~~ are given in Appendix G-2. The maximum runoff to the extent of 58% was obtained during 1990 when the rainfall was 1315 mm. The rainfall for 1989 and 1991 was found to be 661 mm and 1035 mm where as the runoff was calculated to be 20% & 46% respectively.

Since Haveli and paddy fields retain the rainfall for longer duration and allow to flow off the excess, reasonable assumption were considered to account for runoff from these fields. The value of rainfall and runoff coefficient from haveli

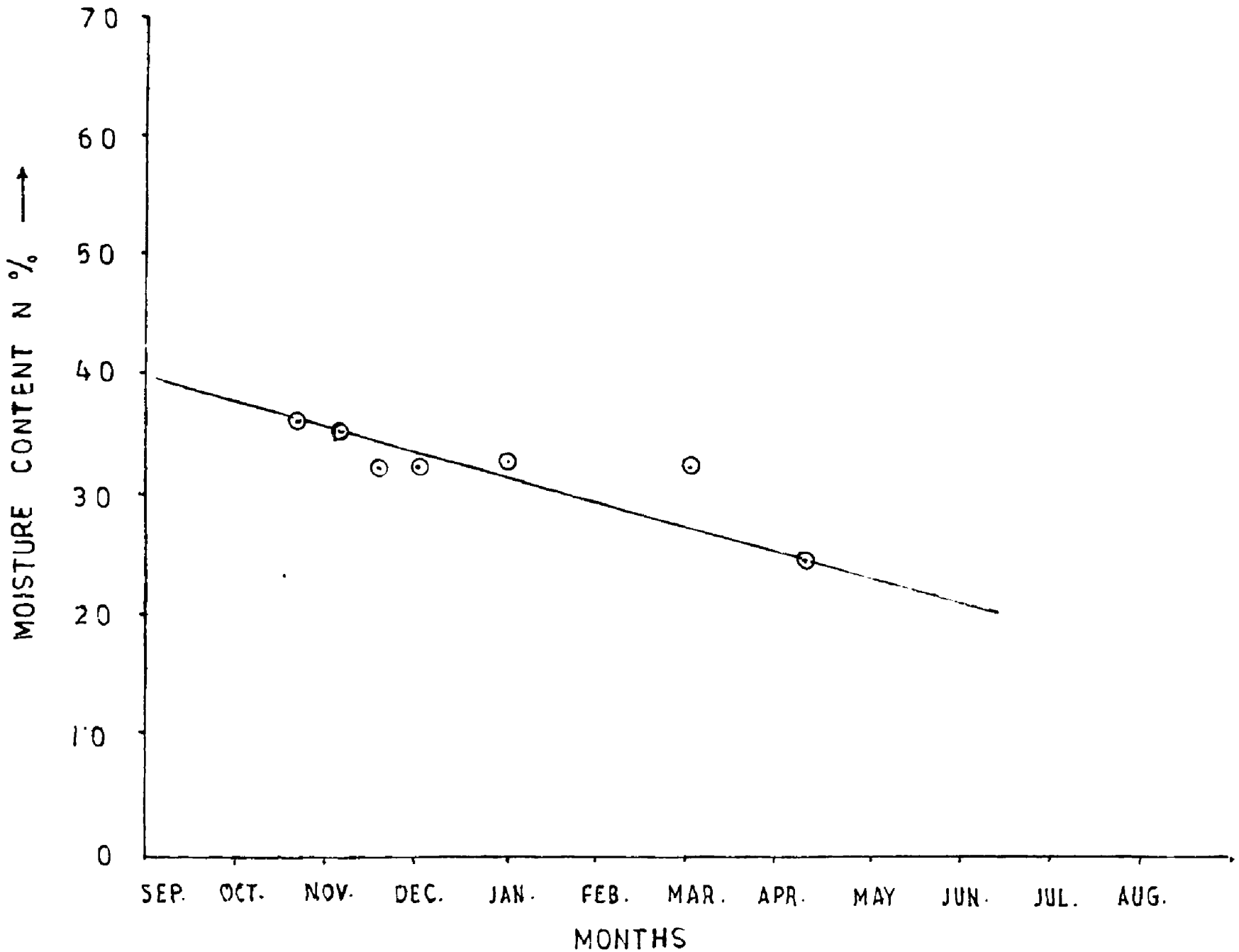


FIG. 4.13 : GRAPH SHOWING MOISTURE CONTENT IN DIFFERENT MONTHS (DRAWN FROM APPENDIX G3

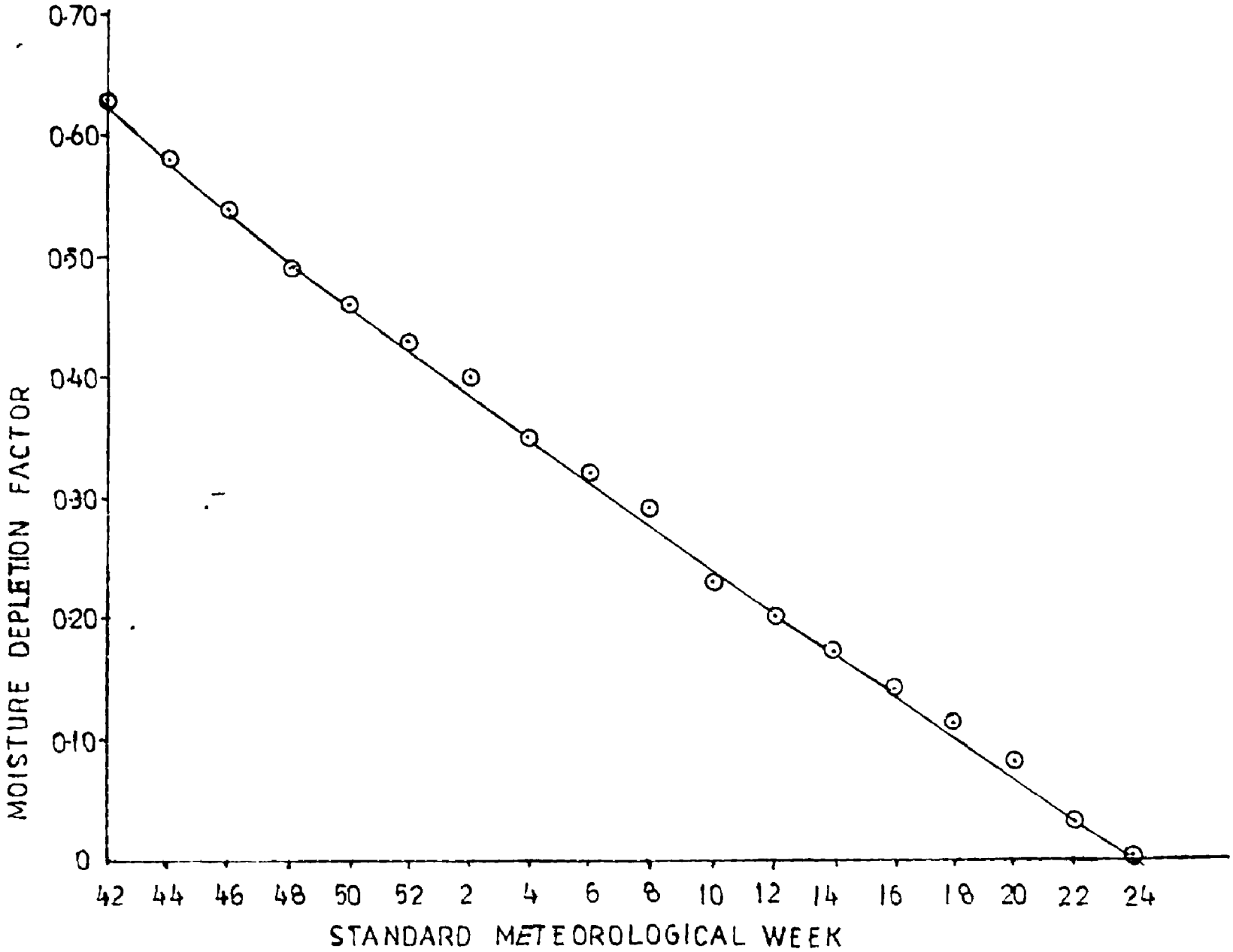


FIG. 4.14 = GRAPH SHOWING MOISTURE DEPLETION FACTOR IN DIFFERENT WEEKS

CHAPTER - V

SUMMARY AND CONCLUSION

BIBLIOGRAPHY

BIBLIOGRAPHY

Agrawal, M.C. and Malik, R.K. 1984. Study of water table behaviour in Haryana Agril. Engg. Today, I.S.A.E. 8 (i) 5 8.

Anonymous 1972. Lining of irrigation canals, water management division Ministry of Food and Agriculture, Govt. of India, Section 14, P 338-345.

Anonymous 1972. Drainage Manual. U.S. Department of Agriculture Soil Conservation Service, Engineering Division,

Anonymous 1982. Estimation of ground water resources of Bist Doab Tract. Progress Report of I.C.A.R. Co ordinated Research Scheme on O.G.W.U. through wells and pumps. Punjab Agril. University P. 61.

Anonymous 1982. Study of rising water table problem in canal irrigatied areas using a ground water simulation model. Progress report of I.C.A.R. Co-ordinated Research Scheme on O.G.W.U. through wells and pumps, Punjab Agril. University, P. 86.

Anonymous 1986. Management and optimization in development of surface and ground water system of Sarada River Basin, Andhra Pradesh, C.B.I.P. Annual Review.

Asthana, B.N. and Gupta D.K. 1988. Systems approach in Conjunctive development on water resources. Paper presented at National Symposium on Ground water and Conjunctive Irrigation.

Barona, D.F. 1957. Concrete lining of irrigation canal in Mexico. Third Congress on Irrigation and Drainage Vol. 2 P. 7-17.

Bhargava, G.P. 1982. Characteristics and extent of salt affected Soils. National Training Course on field drainage for the control of ground water table and soil salinity in irrigated agricultural lands of Semi arid RegionS, C.S.S.R.I., Karnal.

Brown, R. 1980. Ground Water Hydrologic Technique in Watershed Planning Trans. A.S.A.E. Vol.3 1984-1986.

Chauhan, H.S. 1983. Water table fluctuations in National Tarai and Nainital Bhaber. Annual Report of I.C.A.R. Co-ordinated Research Scheme on O.G.W.U. through wells and pumps. G.P. Pantnagar University of Agr. and Technology.

Doorenbos, J., Pruit, W.C. 1975. Guidelines for predicting crop water requirements. Irrigation and drainage paper 24, Food & Agricultural Organization, Rome, P. 197.

Grewal, S.S., Juneja, Dubey, M.L. and Chandrappa M. 1982. Effect of some soil and site properties on seepage losses from harvested runoff water in small storage reservoir. J. Agril. Engg.. I.S.A.E., Vol. 19 No.3, 38-46.

Gulshan, R., Hiran, K.S. and Singh, O.P. 1985. Salt and water balance analysis for evaluating the performance of vertical drainage system. Paper presented at Silver Jubilee Convention of I.S.A.E., Bhopal.

Gupta, P., Khepar S.D. and Kaushal, M.P. 1987. Conjunctive use approach for Management of Irrigated Agriculture, J. Agril. Engg., I.S.A.E., Vol. 24, No. 3.

Hrabovszky, J. 1971. Timing, sequence and strategy in the planning of irrigation system. Paper presented at the Farm Water Management Seminar, Manila.

Isao, M. 1975. On a modern irrigation project in Japan. Second World Congress on Water Resources, Vol. IV.

Kumar, A. and Arya, Y.C. 1972. Research needs for combating water logging. National Symposium on water logging causes and measures for its prevention Vol. II P 160-169.

Kushwah, S.S. 1986. Irrigation scheduling for major crops of Jabalpur and Indore Region. Unpublished M.Tech. thesis, S.W.E., C.A.E., J.N.K.V.V., Jabalpur.

Lauritzen C.W. 1955. Way to control losses from seepage water Year Book of Agriculture, U.S.A.E. Water, 311-320.

Lohan, H.S. and Kasyap, V.P.S. 1983. Ground Water Development in Haryana. Paper presented in XX Annual Convention of I.S.A.E., held at G.B. Pant Univ. of Agri. and Tech.

Mathur, S.K., Puntamkar, S.S. and Johri, J.N. 1982. Water management, soil salinity aspects in Rajasthan Canal Command Area. Proc. Workshop on problem of Water and Soil Management in Irrigation Command. All India Co-ordinated Project on Water Management C.S.S.R.I., Karnal.

Mehta, H.C., Joshi R.S. and Thomsie M.F. 1972. Effect of pumping and surface drainage in controlling water table, water logging and salinity conditions on Deep Black Cotton Soil area symposium on water logging causes and measures for its prevention C.B. I.P. Vol. II P 115.

Michal, A.M. 1978. Irrigation theory and practice. Vikas Publishing House Pvt. Ltd., 5, Ansari Road, New Delhi. P 525-530.

Molesworth and Yennidamia 1974. Survey and investigation.Drainage principles and application Vol. 3, 364-365.

Morachan, Y.B. and Rethinam P. 1972. Water logging in Tamil Nadu and measures suggested for improvement. Symposium on water logging causes and measures for its prevention. C.B.I.P. Vol. II P 72.

Naqvi Syed Naved 1987. Water table behaviour at Tawa Command Area. A case study of Powarkheda. An unpublished M.Tech. thesis, Deptt. of Soil & Water Engg., C.A.E., J.N.K.V.V., Jabalpur.

Nazir, P.N., Muzaffar A. and Shab S.L. 1957. Problem of canal lining in West Pakistan. Third Congress on Irrigation and Drainage, Vol. 2 P 7-17.

Offengenden 1979. Theories of field drainage and watershed runoff Vol. 2, DG 30, P 364.

Osborn, J.F. 1966. Prediction of piezometric ground water level in observation wells prior occurence. Water resource research 2 (1) P 139-144.

Pandey, R.P. 1988. Drainage investigations at Barna Command An unpublished M.Tech. thesis, Deptt. of Soil & Water Engg., C.A.E., J.N.K.V.V., Jabalpur.

Pandya, G.S. 1972. Water logging causes and measures for its prevention in Chambal Command of the Madhya Pradesh. Symposium on water logging causes and measures for its prevention C.B.I.P. Vol. II P 53.

Patel, R.M. and Nihalani, A.L. 1982. Comparison of hydraulic conductivity by Auger Hole Method using different formulae, Paper presented at the XIX Annual Convention of I.S.A.E. at College of Tech. and Agril. Engg., University of Udaipur.

Pathak, B.D. 1988. Groundwater and conjunctive irrigation. Paper presented at National Symposium on groundwater and conjunctive irrigation technical sesson IV.

Punamia, B.C. 1984. Irrigation and Water Power Engineering 8th Edition, Standard Publisher and Distibutor 1705-B Nai Sarak, Delhi-6, P 672-673.

Raghunath, H.M. 1982. Ground water Chapter 16. Ground water basin management and conjunctive use, Wiley Eastern Limited, Ansari Road, Daryaganj, New Delhi-110002.

Raj, P.A. and Bapat M.V. 1972. Problems of water logging remedied before canal inception. Symposium on water logging causes and measures for its prevention. Vol. II P 79.

Raj Singh 1988. Water table behaviour in canal command area- a case study An unpublished M.Tech. thesis, Deptt. of Soil & Water Engg. C.A.E., J.N.K.V.V., Jabalpur.

Rogers, J.S. and Carter C.E. 1987-. Auger hole hydraulic conductivity determination in layered soil. A.S.A.E. 30 (2) P 374-378.

Sahu Harilal 1983. Water logging problems in Tawa Command. Technical paper presented at National Seminar on integrated approach to water management in the Command Areas at IARI, New Delhi.

Samantrai, S.K., Mishra, B., Mohpatra, N. and Pandey S.C. 1987. Determination of different sources and their extent of contribution to rise in ground water table in Hirakund Command Area. Paper presented at XXIII Annual Convention of I.S.A.E, held at J.N.K.V.V.,Jabalpur.

Shakya, S.K., Singh S.R. and Verma R.S. 1987. Multiple well point system for water logged land and aquifer management. Paper presented at XXIII Annual Convention of I.S.A.E. held at J.N.K.V.V., Jabalpur.

Sharma, P.B.S., Rao. N.H. and Sondhi, S.K. 1987. Assessment of ground water resources of a Canal Command Area. Paper presented at XXIII Annual Convention of I.S.A.E., at J.N.K.V.V., Jabalpur.

Sharma, R.K. 1986. Rainfall runoff relationship in Indo, U.K. Project, Indore. An unpulished M.Tech. thesis Deptt. of Soil and Water Engg., C.A.E., J.N.K.V.V., Jabalpur.

Sims, D.A. 1973. Agricultural Engineering aspects of Command Area Development, United Nations Development Programme FAO of the United Nations, Kota.

Singh, J. and Singh R. 1972. Water logging in Punjab - its causes and remedies. Symposium on water logging causes and measures for its prevention C.B.I.P. Vol. II P 32.

Sinha, V.S. 1982. Problems of water management and soil salini in Ukai Kakrapar Command. Proceedings of workshop of problem of water and soil management in Irrigation Command. All India Co-ordinated Project on Water Management, C.S.S.R.I., Karnal.

Smille, D.E. and Towner G.D. 1968. The steady state measurements of the relation between hydraulic conductivity and moisture content in soils. Water resources 4 : P 1029-1030.

Sondhi, S.K. 1985. Study on water table behaviour and its effect on irrigation pumping system in Punjab. Paper presented at Silver Jubilee Convention of I.S.A.E. at Bhopal.

Taylor, R.L. 1973. Operation and maintenance of irrigation and drainage system. Proc. A.S.A.E., J. Irrigation and drainage division.

Todd, D.K. 1959. Ground water level and fluctuation. Ground water hydrology, John Wiley and Sons.

Tomar, Sahib Singh, 1989. Effect of soil hydrothermal regimes on the performance of safflower planted on different dates. An unpublished Ph.D. thesis, College of Agriculture, J.N.K.V.V., Jabalpur.

Uppal, H.L. 1972. Serious water logging in Punjab and Haryana - How cured and measures to prevent its recurrence. Symposium on water logging - causes and measures for its prevention Vol. II, C.B.I.P., P 1-32.

U.S.D.I.B.R. 1978. Design and construction of drains. Drainage mannual, a water resource technical publication. 2nd Edition. Published by Mohan Primlani. Oxford and LHH Publishing Co. 66, Janpath, New Delhi.

Walton, W.C. and Sehicht R.J. 1961. Hydrologic Budgets for three small watersheds in Illinois. Report of investigation 40. Illinois State Water Supply, State of Illinois.

WAPCOS 1986. Feasibility report of Bargi Left Bank Canal Project, Vol. I Main report.

...

APPENDICES

APPENDIX - A-1

Comparison of seepage estimation by different seepage formulae using modified value of constants, seepage loss in RBMC system (cusec/M sqm of wetted area)

Section No.	Distance from starting point(m)	Length section (m)	Direct measurement in flow out-flow method.	Mortiz formula estimated average value of e=0.677	Moles worth formula estimated average value of C=0.0018	USDIBR formula estimated average value of C=1.991	Formula UP estimated average value of C=1.197	Formula Punjab estimated average value of C=1.398	Offengenden formula estimated average value of e = 0.358
I	0 - 400	400	2.22	1.986	1.878	1.942	1.952	1.958	1.956
II	400 - 800	400	1.931	1.986	1.878	1.942	1.952	1.958	1.954
III	800 - 1200	400	1.78	1.984	1.878	1.942	1.952	1.958	1.954
IV	1200 - 1600	400	2.08	1.984	1.874	1.942	1.954	1.952	1.955
V	1600 - 2000	400	1.78	1.981	1.872	1.940	1.956	1.943	1.951

RBMC - Right Bank Main Canal of Bama Irrigation Project, Distt. Raisen, M.P.

Source - Pandey (1988)

APPENDIX A-2

BINNIES PERCENTAGE

Rainfall (mm)	500	625	750	875	1000	1125
Runoff %	15	24	27	35	38	40

APPENDIX C-1

Double cylinder infiltrometer test for determination of infiltration rate at village Barkhera Site 1

S.No.	Time interval (min)	Elapsed time t (min)	Depth of infiltration (cm)	Cumulative depth of infiltration (cm)	Rate of infiltration I_o (cm/hr)
1.	1	1	0.30	0.30	18.00
2.	3	4	0.10	0.40	2.00
3.	3	7	0.10	0.50	2.00
4.	5	12	0.20	0.70	2.40
5.	5	17	0.12	0.82	1.44
6.	5	22	0.11	0.93	1.32
7.	10	32	0.27	1.20	1.62
8.	10	42	0.15	1.35	0.90
9.	10	52	0.20	1.55	1.20
10.	10	62	0.10	1.65	0.60
11.	10	72	0.15	1.80	0.90
12.	10	82	0.15	1.95	0.90
13.	10	92	0.15	2.10	0.90
14.	10	102	0.12	2.22	0.72
15.	12	114	0.18	2.40	0.90
16.	48	162	0.80	3.20	1.00
17.	20	182	0.20	3.40	0.60
18.	30	212	0.25	3.65	0.50
19.	30	242	0.25	3.90	0.50
20.	30	272	0.25	4.15	0.50
21.	60	332	0.40	4.55	0.40
22.	60	392	0.40	4.95	0.40
23.	60	452	0.40	5.35	0.40

APPENDIX C-2

Double Cylinder infiltrometer for determination of infiltration rate at village Barkhera Site 2

S.No.	Time interval (min)	Elapsed time t (min)	Depth of infiltration (cm)	Cumulative depth of infiltration (cm)	Rate of infiltration I_o cm/hr
1.	2	2	0.20	0.20	6.00
2.	3	5	0.30	0.50	6.00
3.	2	7	0.30	0.80	9.00
4.	3	10	0.10	0.90	2.00
5.	3	13	0.10	1.00	2.00
6.	15	28	0.40	1.40	1.60
7.	17	45	0.60	2.00	2.10
8.	15	60	0.40	2.40	1.60
9.	20	80	0.40	2.80	1.20
10.	20	100	0.40	3.20	1.20
11.	20	120	0.30	3.50	0.90
12.	30	150	0.40	3.90	0.80
13.	30	180	0.35	4.25	0.70
14.	30	210	0.25	4.50	0.50
15.	60	270	0.50	5.00	0.50
16.	60	330	0.50	5.50	0.50
17.	60	390	0.50	6.00	0.50

APPENDIX C-3

Double cylinder infiltrometer test for determination of infiltration rate at Village Semra Site 3

S.No.	Time interval (min)	Elapsed time t (min)	Depth of infiltration (cm)	Cumulative depth of infiltration (cm)	Rate of infiltration I_o (cm/hr)
1.	2	2	1.30	1.30	39.00
2.	1	3	0.20	1.50	12.00
3.	1	4	0.30	1.80	18.00
4.	1	5	0.10	1.90	6.00
5.	1	6	0.10	2.00	6.00
7.	1	8	0.10	2.20	6.00
8.	1	9	0.10	2.30	6.00
9.	1	10	0.10	2.40	6.00
10.	1	11	0.10	2.50	6.00
11.	5	16	0.50	3.00	6.00
12.	5	21	0.50	3.50	6.00
13.	5	26	0.40	3.90	4.80
14.	5	31	0.40	4.30	4.80
15.	5	36	0.50	4.80	6.00
16.	5	41	0.40	5.20	4.80
17.	15	56	0.90	6.10	3.60
18.	10	66	0.70	6.80	4.20
19.	15	81	0.60	7.40	3.60
20.	10	91	0.70	8.10	4.20
21.	10	101	0.50	8.60	3.60
22.	10	111	0.60	9.20	3.60
23.	10	121	0.55	9.75	3.30
24.	10	131	0.50	10.25	3.00
25.	15	146	0.70	10.95	2.80
26.	30	176	1.35	12.30	2.70
27.	30	206	1.30	13.60	2.60
28.	30	236	1.28	14.88	2.56
29.	30	266	1.25	16.13	2.50
30.	60	326	2.40	18.53	2.40
31.	60	386	2.25	20.78	2.25
32.	60	446	2.00	22.78	2.00
33.	60	506	2.00	29.78	2.00

APPENDIX C-4

Double cylinder infiltrometer test for determination of infiltration rate at Village Semra Site 4

S.No.	Time interval (mins)	Elapsed time t (min)	Depth of infiltration (cm)	Comulative infiltration (cm)	Rate of infiltration I_o cm/hr
1.	1	1	0.20	0.20	12.00
2.	1	2	0.10	0.30	6.00
3.	1	3	0.10	0.40	6.00
4.	2	5	0.10	0.50	3.00
5.	2	7	0.10	0.60	3.00
6.	2	9	0.10	0.70	3.00
7.	3	12	0.20	0.90	4.00
8.	2	14	0.10	1.00	3.00
9.	3	17	0.15	1.15	3.00
10.	3	20	0.15	1.30	3.00
11.	3	23	0.20	1.50	4.00
12.	3	26	0.20	1.70	4.00
13.	4	30	0.20	1.90	3.00
14.	5	35	0.20	2.10	2.40
15.	13	48	0.60	2.70	2.70
16.	10	58	0.40	3.10	2.40
17.	15	73	0.60	3.70	2.40
18.	12	85	0.40	4.10	2.00
19.	15	100	0.50	4.60	2.00
20.	15	115	0.50	5.10	2.00
21.	15	130	0.45	5.55	1.80
22.	15	145	0.45	6.00	1.80
23.	15	160	0.45	6.45	1.80
24.	30	190	0.85	7.30	1.70
25.	30	220	0.85	8.15	1.70
26.	60	280	1.60	9.75	1.60
27.	60	340	1.60	11.35	1.60
28.	60	400	1.60	12.95	1.60

APPENDIX D-1

Observation and calculations for determination of hydraulic conductivity by single auger hole method at village Barkhera.

S.No.	Elapsed time after recuperation starts t (cm)	Depth of water level after an interval of time t $h_m(t_i)$(cm)
1.	0	108
2.	600	106
3.	900	105
4.	4500	93
5.	5100	89
6.	5700	87
7.	6300	85
8.	6900	83
9.	7500	81
10.	8100	79
11.	9000	77

Sample Calculation

From Serial 2 to 6

$\Delta t = t_6 - t_2$

$= 5700 - 600 = 5100$ secs.

$\Delta h = h_m(t_2) - h_m(t_6)$

$= 106 - 87 = 19$ cm

$h = h_m(t_2) - A_m - \Delta h/2$

$= 106 - 75 - 19/2 = 21.5$ cm.

$$K_{(2-6)} = \frac{4000 \quad r^2 \quad \Delta h}{(H_m + 20r)\ (2 - h/H_m)\ h\Delta t}$$

$$= \frac{4000 \times 3.75 \times 3.75 \times 19}{(33 + 2 \times 3.75)(2 - 21.5/33)21.5 \times 5100}$$

$= 0.0669$ m/day

Serial 3 to 7

$\Delta t = t_7 - t_3$

$= 6300 - 900 = 5400$ secs.

$\Delta h = h_m(t_3) - h_m(t_7)$

$= 105 - 85 = 20$ cm

$h = h_m(t_3) - A_m - \Delta h/2$

$= 105 - 75 - 20/2 = 20$ cm

$$K_{(3-7)} = \frac{4000 \times 3.75 \times 3.75 \times 20}{(33 + 20 \times 3.75)(2 - 20/33)20 \times 5400}$$

$= 0.0692$ m/day

$$K_{(4-8)} = \frac{4000 \times 3.75 \times 3.75 \times 8}{(33 \times 20 \times 3.75)(2 - 10/33) \times 10 \times 2400}$$

$= 0.102$ m/day

K = Average = 0.085 m/day

= 0.355 cm/hr

APPENDIX D-2

Observation for determination of hydraulic conductivity by single auger hole method at village Semra.

S.No.	Elapsed time after recuperation starts t (sec)	Depth of water level after an interval of time t $h_m(t_i)$ (cm)
1.	0	99.0
2.	120	98.5
3.	240	98.0
4.	480	97.0
5.	780	96.0
6.	960	95.5
7.	1080	95.0
8.	1440	94.5
9.	1560	94.0
10.	1860	93.5
11.	2100	93.0

SAMPLE CALCULATION

r = radius of auger hole = 3.75cm

$H_m = D_m - A_m$

$= 105 - 74 = 31$ cm

Serial 2-9

$\Delta t = t_q - t_2 = 1560 - 120 = 1440$

$\Delta h = h_m(t_2) - h_m(t_q)$

$= 98.5 - 74 - 4.5/2 = 22.25$

$$K_{(2-9)} = \frac{4000\, r^2\, \Delta h}{(H_m + 20r)\,(2-h/H_m)h\; t} \text{ m/day}$$

$$= \frac{4000 \times 3.75 \times 3.75 \times 4.5}{(31+20\times3.75)(2-22.25/31)(22.25\times1440)}$$

$= 0.0581$ m/day

Serial 3.10

$t = t_{10} - t_3 = 1860 - 240 = 1620$

$h = 98 - 93.5 = 4.5$

$h = 98 - 74-4 - 4.5/2 = 21.75$

$$K_{(3-9)} = \frac{4000\times3.75\times3.75\times4.5}{(31+20\times3.75)(2-21.75/31)21.75\times1620}$$

$= 0.0522$ m/day

$$K_{(4-11)} = \frac{4000\times3.75\times3.75\times4.0}{(31 + 20 \times 3.75)\,(2-21/31)21\times1620}$$

$= 0.0472$ m/day

K (Average) = 0.0525 m/day
= 0.22 cm/hr.

APPENDIX E-1

Observations for pumping and recuperation test at village Barkhera Well A

S.No.	Pumping Test	
	Time (mins)	Depth to water level (m)
1.	0	2.80
2.	4	2.90
3.	7	2.98
4.	9	3.11
5.	14	3.28
6.	19	3.46
7.	24	3.58
8.	29	3.72
9.	34	3.85
10.	39	3.98
11.	44	4.11
12r.	49	4.23
13.	54	4.33
14.	56	4.37
15.	61	4.47
16.	66	4.56
17.	71	4.66
18.	76	4.74
19.	81	4.79
20.	84	4.80
21.	89	4.86
22.	99	5.07
23.	109	5.27
24.	119	5.46
25.	129	5.65
26.	139	5.76
27.	143	5.82
28.	153	5.99
29.	163	6.16
30.	173	6.26
Recuperation Test		
31.	183	5.99
32.	193	5.71
33.	203	5.45
34.	213	5.20
35.	223	5.03
36.	233	4.81
37.	243	4.66
38.	253	4.49

Calculation for specific capacity at Village Barkhera well A

Dia of well = 4.20 m
Initial depth to water table = 2.80 m
Total depth = 6.50 m

Slitcher's formula for specific capacity of well, well No.A

$$C = \frac{A}{t} \; 2.3 \; \log \frac{S_1}{S_2}$$

Where,
C = Specific capacity (cum/hr/m dd)
A = Area of well in (m^2)
t = time of about 50% recovery in hrs.
S_1 = Draw down in m.
S_2 = Residual drawn down.

$$A = \pi R^2$$
$$= \pi (2.1)^2$$
$$= 13.85 \; m^2$$

S_1 = 3.46 m
S_2 = 1.69 m
t = 1.33 hr.

i.e. $C = \frac{13.85}{1.33} \times 2.3 \log \frac{3.46}{1.69}$

= 7.45 cum/hr/m draw down.

APPENDIX E-2

Observation for pumping and recuperation test at Village Barkhera well No.B

S.No.	Pumping Test	
	Time (mins)	Depth to water level (m)
1.	0	1.35
2.	6	1.56
3.	10	1.72
4.	15	1.87
5.	20	2.03
6.	25	2.21
7.	30	2.35
8.	35	2.51
9.	40	2.68
10.	45	2.85
11.	50	2.99
12.	55	3.13
13.	60	3.25
14.	65	3.38
15.	70	3.50
16.	75	3.64
17.	80	3.76
18.	87	3.93
19.	94	4.01
20.	104	4.10
21.	114	4.30
22.	124	4.51
23.	134	4.71
24.	141	4.80
25.	146	4.89
	Recuperation Test	
26.	177	4.64
27.	186	4.55
28.	196	4.48
29.	206	4.42
30.	216	4.35
31.	226	4.28
33.	246	4.14
34.	261	4.07
35.	281	3.96
36.	301	3.86
37.	321	3.75
38.	341	3.64
39.	361	3.55
40.	381	3.49
41.	401	3.39

Calculation for specific capacity at Barkhera Well B

Dia. of well = 4.40 m
Initial depth to WL = 1.35 m
Total depth = 5.62 m

Slichter's formula for specific capacity of well.

$$C = \frac{A}{t} \quad 2.3 \quad \log \frac{S_1}{S_2}$$

Where
C = specific capacity (cu.m./hr/m.dd)
A = area of well (m^2)
t = time of about 50% recovery in hrs.
S_1 = Draw down in m

S_2 = Residual draw down, m

$$A = \pi r^2$$

$$= \pi (2.2)^2 = 15.21 \ m^2$$

S_1 = 3.54 m

S_2 = 2.01 m

t = 4.50 hrs.

$$C = \frac{15.21}{4.50} \times 2.3 \times \log \frac{3.54}{2.01}$$

= 1.91 cu.m/hr./m dd

APPENDIX E-4

Determination of hydraulic conductivity using Ernst equation from the recuperation test data at Village Barkhera Well No. B

Hm = 427 cm r = 220 cm Am = 135 cm)

S.No.	Elapsed time after recuperation starts t' (sec)	Time interval between consective observation t' (sec)	Depth of recuperation of water level after an interval of time h_m (t_i) (cm)	Change in depth of ruperation of water level after time interval. (h) (cm)	Distances from the static water level to the centre of h h = h (t_i) A_m - h/2	Hydraulic Conductivity $K = \frac{4000\,r^2}{(H_m - 20r)(2-h/H_m)h}\,\frac{\Delta h}{\Delta t}$ (m/day)
1.	0		464			
		540		9	324.5	1.66
2.	540		455			
		600		7	316.5	1.17
3.	1140		448			
		600		6	310.0	1.02
4.	1740		442			
		600		7	303.5	1.02
5.	2340		435			
		600		7	296.5	1.21
6.	2940		428			
		600		7	289.5	1.22
7.	3540		421			
		600		7	282.5	1.24
8.	4140		414			
		900		7	275.5	0.84
9.	5040		407			
		1200		11	266.5	1.00
10.	6240		396			
		1200		10	256.0	0.93
11.	7440		386			
		1200		11	245.5	1.05
12.	8640		375			
		1200		11	234.5	1.08
13.	9840		364			
		1200		9	224.5	0.91
14.	11040		355			
		1200		6	217.0	0.62
15.	12240		349			
		1200		10	209.0	1.05
16.	13440		339			

Average = 1.08 m/day

APPENDIX - F

COMPUTER PROGRAMME (BASIC)

```
10      READ R, ETC, EU, GWD, WC, WI, DSM, FO
20      INPUT "S =";S$
30      READ AP, AH
40      INPUT "C ="; C
50      INPUT "C1 ="; C1
60      K = 2.7
70      D = 10
80      R = R/1000
90      INPUT "T ="; T
100     INPUT "GI ="; GI
110     INPUT "GO ="; GO
120     Q1 = K * GI * 1840 * D * T/10000
130     SR = C * R * (214.89 - AH - AP) + (R * C1 * AP) + (R * C1 * AH)
140     QO = K * GO * 3520 * D * T/10000
150     QN = (QO - Q1)
160     NI = R * 214.89 + WC + WI
170     NO = ETC + EU + GWD + SR - DSM + QN
180     NR = NI - NO
190     F = NR/ (214.89 * 0.06)
200     FVAR = FO - F
```

APPENDIX G-I

Daily Rainfall at Patan

Year	Date	Rainfall (mm)	Year	Date	Rainfall (mm)
1987	18.6.87	32.0	1987	11.9.87	15.0
	25.6.87	3.0		15.9.87	10.0
	3.7.87	9.03		16.9.87	109.0
	6.7.87	92.02		17.9.87	40.0
	9.7.87	5.0		17.10.87	22.4
	10.7.87	8.0		19.10.87	12.2
	11.7.87	11.0	1988	16.6.88	13.01
	12.7.87	12.0		23.6.88	6.01
	19.7.87	12.3		24.6.88	20.0
	26.7.87	39.3		26.6.88	57.0
	27.7.87	38.4		27.6.88	93.0
	28.7.87	6.4		28.6.88	33.0
	29.7.87	3.4		29.6.88	11.0
	3.8.87	8.0		4.7.88	70.0
	4.8.87	7.3		5.7.88	10.0
	5.8.87	55.3		7.7.88	5.0
	7.8.87	2.0		9.7.88	95.0
	13.8.87	10.2		10.7.88	13.0
	17.8.87	0.4		12.7.88	6.0
	19.8.87	20.3		13.7.88	9.0
	24.8.87	100.3		14.7.88	40.0
	25.8.87	101.2		18.7.88	16.0
	26.8.87	4.2		19.7.88	14.0
	27.8.87	4.4		21.7.88	2.0
	28.8.87	16.4		22.7.88	4.0
	29.8.87	100.2		26.7.88	15.0
	30.8.87	3.2		27.7.88	0.8
	6.9.87	2.2		1.8.88	19.0
	7.9.87	24.2		2.8.88	50.0
	8.9.87	11.0		3.8.88	40.0
	9.9.87	56.0		4.8.88	220.0
	10.9.87	28.2		5.8.88	20.0

APPENDIX G-1

Daily Rainfall in Patan

Year	Date	Rainfall (mm)	Year	Date	Rainfall (mm)
1988	11.8.88	4.0		6.7.89	22.0
	12.8.88	10.0		10.7.89	0.2
	19.8.88	75.0		13.7.89	14.0
	22.8.88	81.0		14.7.89	25.0
	23.8.88	37.0		15.7.89	5.3
	24.8.88	7.0		21.7.89	79.0
	25.8.88	3.0		6.8.89	106.00
	26.8.88	25.0		9.8.89	22.0
	27.8.88	8.0		11.8.89	15.0
	10.9.88	5.0		12.8.89	6.0
	13.9.88	6.0		14.8.89	21.0
	15.9.88	18.0		15.8.89	8.0
	16.9.88	12.0		19.8.89	2.0
	17.9.88	10.0		22.8.89	6.0
	18.9.88	15.0		25.8.89	54.0/
	2.10.88	11.0		26.8.89	6.0
	5.10.88	4.0		27.8.89	18.0
1989	27.3.89	0.05		1.9.89	50.0
	6.6.89	9.0		4.9.89	20.0
	11.6.89	35.0		5.9.89	3.0
	13.6.89	3.2		25.9.89	29.0
	18.6.89	10.3		1.10.89	19.0
	19.6.89	9.0	1990	3.6.90	10.0
	20.6.89	10.3		15.6.90	5.0
	21.6.89	8.0		18.6.90	65.0
	22.6.89	35.0		19.6.90	20.0
	23.6.89	12.0		20.6.90	16.0
	28.6.89	20.2		21.6.90	12.0
	1.7.89	20.3		22.6.90	10.0
	2.7.89	6.2		23.6.90	19.0
				24.6.90	18.0

APPENDIX G-1

Rainfall at Patan Tehsil

Year	Date	Rainfall (mm)	Year	Date	Rainfall (mm)
1990	25.6.90	15.0	1990	12.8.90	16.0
	26.6.90	13.0		13.8.90	6.0
	27.6.90	74.0		14.8.90	15.0
	28.6.90	24.0		19.8.90	4.0
	30.6.90	5.0		21.8.90	21.0
	1.7.90	90.0		28.8.90	4.0
	2.7.90	39.0		30.8.90	7.0
	3.7.90	4.2		31.8.90	9.0
	4.7.90	10.0		3.9.90	9.0
	12.7.90	0.5		4.9.90	21.0
	13.7.90	16.0		5.9.90	33.0
	14.7.90	87.0		11.9.90	0.3
	15.7.90	19.0		13.9.90	12.0
	19.7.90	13.0		14.9.90	29.0
	20.7.90	6.0		15.9.90	9.0
	21.7.90	16.0		16.9.90	11.0
	22.7.90	79.0		18.9.90	14.0
	23.7.90	43.0		19.9.90	21.0
	24.7.90	53.0		20.9.90	12.0
	30.7.90	21.0		24.9.90	19.0
	31.7.90	63.0		25.9.90	39.0
	2.8.90	33.0		29.9.90	12.0
	3.8.90	9.0		30.9.90	16.0
	6.8.90	4.0		3.10.90	3.0
	7.8.90	9.0		6.10.90	21.0
	8.8.90	41.0			

APPENDIX G-2

Runoff from Daily Rainfall data, 1990

S.No.	Date	Rainfall (mm)	Runoff (mm)
1.	15.6.90	5	0.0
2.	18.6.90	65	40.5
3.	19.6.90	20	5.5
4.	20.6.90	16	6.0
5.	21.6.90	16	3.25
6.	22.6.90	10	2.5
7.	23.6.90	19	8.25
8.	24.6.90	18	8.00
9.	25.6.90	15	5.75
10.	26.6.90	13	4.50
11.	27.6.90	74	58.25
12.	28.6.90	24	13.00
13.	30.6.90	5	1.00
14.	1.7.90	90	74.5
15.	2.7.90	39	25.75
16.	3.7.90	4.2	0.00
17.	4.7.90	10.0	2.75
18.	12.7.90	0.50	0.00
19.	13.7.90	16	6.00
20.	14.7.90	87	70.75
21.	15.7.90	19	8.25
22.	19.7.90	13	4.50
23.	20.7.90	6	1.25
24.	21.7.90	16	6.00
25.	22.7.90	79	63.50
26.	23.7.90	43	30.50
27.	24.7.90	53	40.50
28.	30.7.90	21	10.75
29.	31.7.90	63	48.25
30.	2.8.90	33	20.75

S.No.	Date	Rainfall (mm)	Runoff (mm)
31.	3.8.90	9	2.25
32.	6.8.90	4	0.00
33.	7.8.90	9	2.25
34.	8.8.90	41	25.75
35.	12.8.90	16	6.00
36.	13.8.90	6	1.25
37.	14.8.90	15	5.75
38.	19.8.90	4	0.00
39.	21.8.90	21	10.75
40.	28.8.90	4	0.00
41.	30.8.90	7	1.50
42.	31.8.90	9	2.25
43.	3.9.90	9	2.25
44.	4.9.90	21	10.75
45.	5.9.90	33	20.75
46.	11.9.90	0.3	0.00
47.	13.9.90	12	3.25
48.	14.9.90	29	17.00
49.	15.9.90	9	2.25
50.	16.9.90	11	3.00
51.	18.9.90	14	5.00
52.	19.9.90	21	10.75
53.	20.9.90	12	3.25
54.	24.9.90	19	8.25
55.	25.9.90	39	25.75
56.	29.9.90	12	3.25
57.	30.9.90	16	5.75
58.	3.10.90	3	0.00
59.	6.10.90	21	10.75
			760.25

Total Runoff = 760.25 mm

Total Rainfall = 1315.00 mm

$$\% \text{ Run off} = \frac{760.25}{1315.00} \times 100 = 57.8 = 58\%$$

APPENDIX G-3

Soil Moisture depletion in fallow land of black cotton soil

S.No.	Depth of soil (cm)	% Soil moisture deplection for different date of observation						
		20.11.85	4.12.85	17.12.85	30.12.85	31.1.86	30.3.86	7.5.86
1.	0 - 10	29.30	27.43	24.81	20.60	16.92	24.97	9.19
2.	10 - 20	30.71	32.04	27.27	24.57	25.13	27.46	19.01
3.	20 - 30	32.64	34.23	32.34	29.76	30.73	33.30	22.15
4.	30 - 40	33.88	33.14	31.20	31.15	34.03	34.83	22.87
5.	40 - 50	37.37	36.53	32.44	33.55	35.23	37.44	26.89
6.	50 - 60	40.46	37.21	33.60	34.46	35.83	39.55	27.12
7.	60 - 70	38.93	38.30	35.19	35.14	37.32	32.60	29.46
8.	70 - 80	38.01	39.27	37.20	37.42	37.55	30.59	30.14
9.	80 - 90	4 1·29	37.39	33.43	37.85	37.86	30.94	31.20
10.	90 - 100	40.08	37.55	36.81	37.88	38.82	32.36	31.44
	Total	362.67	353.09	324.29	322.38	329.42	324.04	248.47
	Average	36.267%	35.309%	32.429%	32.238%	32.942%	32.404%	24.847%

(Source : Tomar, 1985)

APPENDIX G-4

Moisture depletion factor with respect to standard mateorlogical week

Standard Mateorlogical week	Moisture depletion factor $\frac{(Mc\% - 20)}{(50 - 20)}$
42	0.63
44	0.58
46	0.54
48	0.49
50	0.46
52	0.43
2	0.40
4	0.35
6	0.32
8	0.28
10	0.23
12	0.20
14	0.17
16	0.14
18	0.11
20	0.08
22	0.03
24	0.00

VITA

The author was born on 1st March, 1965 at Imphal, Manipur. He passed the Indian Certificate of Secondary Education Examination conducted by the Council for the Indian School Certificate Examination, New Delhi with 72.3% from St. Joseph's College, Darjeeling in Nov. 1979. He then joined St. Joseph's College, Bangalore for 2 years of Pre-university Education in Science. He secured a first class with 71.16% in the Pre-university Examination conducted by Board of Pre-university Educastion, Govt. of Karnataka in June 1982. He was nominated by I.C.A.R. to undergo B.Tech. course in Agril. Engineering at College of Agril. Engg., J.N.K.V.V., Jabalpur in 1983. He completed the course with a first class securing 72.7%. in '87 He was also the winner of the Chandrakant Shah Memorial Inter-college Debate Competition at J.N.K.V.V. in 1986.

He was then appointed as Section Officer in the Department of Agriculture, Govt. of Manipur in 1988 and was actively involved in establishing Regional Foundation Seed Farm for major field crops at Kharungpat, Manipur. He was then deputed for Post-graduation in College of Agril. Engg., J.N.K.V.V., Jabalpur in November 1988.

J.N.K.V.V. LIBRARY 33786 JABALPUR