OPTIMAL WATER RESOURCE MANAGEMENT IN UPPER GANGA CANAL COMMAND - A CASE STUDY

A DISSERTATION

submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF ENGINEERING
in
IRRIGATION WATER MANAGEMENT

By
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CANDIDATE'S DECLARATION

I hereby declare that the work, which is being presented in this dissertation entitled, **"OPTIMAL WATER RESOURCE MANAGEMENT IN UPPER GANGA CANAL COMMAND – A CASE STUDY"**, in partial fulfillment of the requirement for the award of the Degree of Master of Engineering in Irrigation Water Management of the University of Roorkee, is an authentic record of my own work carried out from July, 2000 to January, 2001 under the supervision of **Dr. G.C. Mishra**, Professor, WRDTC and **Prof. R.P. Singh**, WRDTC, University of Roorkee, Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

Dated: 31-01-2001 **(YOGENDRA PRASAD YADAV)**

CERTIFICATE

This is to certify that the above statement made by the candidate is true to the best of our knowledge.

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SYNOPSIS

To meet the growing food-grain demands of the country, a higher level of food-grain production is required. The meaning of Optimal Water Resource Management is to get the maximum return without imbalancing the ecological system. The Optimal Water Resource Management in the command of Right Main Distributary (in the command of UGC) has been undertaken for study. The objectives of the study is to estimate Crop Water Requirement, Canal Water Supply, Water Deficit and to optimize Cropping Intensity and Net Return.

It has been found that rainfall is not sufficient to meet the evapotranspiration demand of the crops. Similarly canal water supply is also not sufficient to meet the crop water requirement. There is substantial quantity of groundwater available to meet the crop water requirement. Favourable and adequate availability of groundwater and its conjunctive use with surface water may show good response to equitable distribution of water which is a pressing and basic need in Irrigation Water Management.

The irrigated agriculture of the command area is beneficial and also sustainable. There is no substantial salinity or alkalinity problem in the study area. The water quality is also good and soil is well irrigable.

There is substantial scope for increase of Cropping Intensity and Net Return.

ABBREVIATIONS AND ACRONYMS

1.	AE	:	Assistant Engineer
2.	AV	:	Average
3.	CA	:	Command Area
4.	CCA	:	Culturable Command Area
5.	CE	:	Chief Engineer
6.	CH	:	Channel
7.	C.I.	:	Cropping Intensity
8.	CSSRI	:	Central Soil Salinity Research Institute
9.	Cu	:	Consumptive use
10.	CWR	:	Crop Water Requirement
11.	D	:	Day
12.	DA	:	Diagnostic Analysis
13.	DEL	:	Delivery
14.	EC	:	Electrical Conductivity
15.	EE	:	Executive Engineer
16.	ETc	:	Reference Crop Evapotranspiration
17.	ETo	:	Evapotranspiration
18.	etc	:	et cetra
19.	FAE	:	Field Application Efficiency
20.	FAO	:	Food and Agriculture Organization
21.	Fig	:	Figure
22.	FIR	:	Field Irrigation Requirement
23.	GCA	:	Gross Command Area
24.	GIR	:	Gross Irrigation Requirement
25.	Govt	:	Government
26.	GW	:	Ground Water
27.	ha	:	hectare
28.	ha-m	:	hectare- meter
29.	ICAR	:	Indian Council of Agricultural Research
30.	i.e	:	id est
31.	IQR	:	Inter-Quartile Ratio
32.	IRF	:	Irrigation Return Flow
33.	IRI	:	Irrigation Research Institute.
34.	JE	:	Junior Engineer
35.	Kc	:	Crop Coefficient
36.	Km	:	Kilometer

37.	LAI	:	Leaf Area Index
38.	Lit	:	Liter
39.	L.P.Model	:	Linear Programming Model
40.	LPS	:	Liter Per Second
41.	M	:	Million
42.	mgl	:	miligram per liter
43.	ml	:	mili liter
44.	mm	:	mili meter
45.	NIR	:	Net Irrigation Requirement
46.	O & M	:	Operation and Maintenance
47.	OR	:	Operation Research
48.	P	:	Precipitation
49.	Pe	:	Effective rainfall
50.	PET	:	Potential Evapotranspiration
51.	P.W.P	:	Permanent Wilting Point
52.	RMD	:	Right Main Distributary
53.	RWS	:	Relative Water Supply
54.	SE	:	Superintending Engineer
55.	SW	:	Surface Water
56.	UGC	:	Upper Ganga Canal
57.	U.P.	:	Uttar Pradesh
58.	U.O.R	:	University of Roorkee
59.	WAPCO	:	Water And Power Consultancy Services (India) Limited
60.	WRDTC	:	Water Resources Development Training Centre
61.	WT	:	Water Table

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INTRODUCTION

1.1 GENERAL

One of the basic conditions for life on earth is the availability of water in liquid form. Sea is believed to be the origin of all life on earth. Water, like air, is bound up with man's evolution. Water medium is essential for the occurrence of every organic process. The embryo floats in a liquid form from conception to birth. Besides sustenance of human life and activities, water is also essential for the quality of life. Life in plants and animals too depends on water. Water is a prime natural resource, a basic human need and a precious national asset. It has varied uses in human life. The total quantum of water available for use, however, bountiful at present, is more or less a fixed quantity. With the increase in population, more and more water is needed. Modern civilization has placed heavy demand on water on account of urbanization, modernization of agriculture and industrial development. As a consequence, the quantity of water available per capita is dwindling correspondingly. It is, therefore, essential that water resources should be developed at a faster rate on a rational basis.

1.2 INDIA'S POPULATION AND GEOGRAPHICAL AREA

India's population is 16% of the world population but water resources available is only about 4%. India has probably the largest irrigation network. Total geographical area of country is 328 million ha, out of which 305.5 million ha are counted for land use, the balance 22.5 million ha consists of mountains, deserts and forests.

1.3 INDIA'S POPULATION AND FOOD REQUIREMENT

India's population has reached 100 crores mark and is projected to be 150 and 164 crores by 2020 and 2050 respectively. The food production at present is 200 million tonnes and requirement is projected to be 350 and 450 million tonnes in 2020 and 2050 respectively. Water demand has grown globally by 2.4% per year. Land per capita availability in 2020 AD will be only 800 m^2.

The graphical representation of food production scenario: population, food production, and per capita cultivated land (India) is shown in Fig. 1.1 (Dr. Anil Kumar Srivastva, Sr. Scientist, Agronomy, Central Soil Water Conservation Research and Trg Institute, Dehradun –248195, India)

1.4 WATER BALANCE OF INDIA

The National Commission on Agriculture (1976) has estimated water balance of India to be 400 million hactaremetres on the basis of average annual precipitation of 120 cm. The geographical area of India is 328 million ha and depth of average annual precipitation is 1.20 m. Thus 328 x 1.20 = 400 mham is the average annual precipitation input. The distribution of fresh water is given below in Table 1.1 (Sharma, 1987).

Table 1.1: Distribution of Fresh Water

1	Evaporation loss, 18%	70 mham
2	Surface run-off, 29%	115 mham
3	Soil infiltration, 53%	215 mham
	Total	400 mham

Out of 215 million ham infiltrating into the soil, about 23 percent of it i.e. 50 million ham moves downward to replenish the permanent water table and the remaining 77 percent i.e. 165 million ham is held by soil capillaries. Two-third of this capillary water is available to the growing plants in India.

1.5 RESOURCES OF IRRIGATION WATER IN INDIA

Precipitation is the primary resource of irrigation water. Sources of irrigation water are broadly classified as (i) surface water and (ii) ground water.

An outline of the water resources is shown in Fig. 1.2.

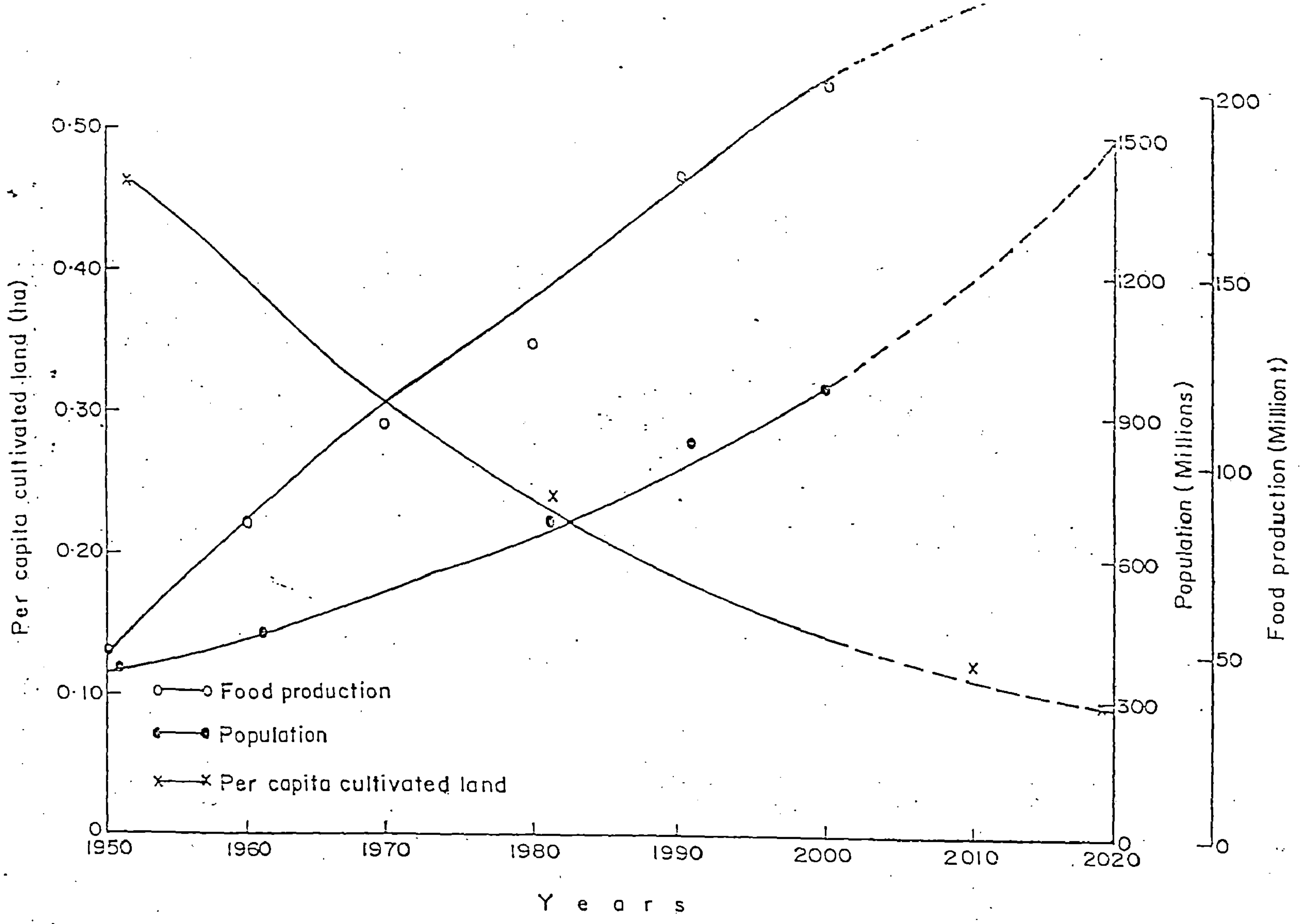


Fig.1·1- Food production scenario : Population, Food production, Per capita cultivated land. (India)

Sources of Irrigation Water

Surface water

- Rivers and streams
- Tanks
- Lakes
- Percolation Tanks

Ground water

- Open wells
- Tubewells
- Artesian wells
- Springs

Fig. 1.2

1.6 GROUND WATER

The Geological environments control the occurrence of groundwater and the physical laws control the flow of ground water.

Classical Definition of Ground Water

The subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated, is called groundwater.

Groundwater flow also influences the near-surface, unsaturated; soil moisture regime that plays an important role in the hydrologic cycle. The study of groundwater is interdisciplinary in nature. Its study is important to geologists, hydrologists, soil scientists, agricultural engineers, foresters, geographers, ecologists, geotechnical engineers, mining engineers, sanitary engineers, petroleum reservoir analysts and probably others.

1.6.1 Groundwater Resources of India

The groundwater resources are dynamic in nature as they grow with the expansion of irrigation. The groundwater is one of the earth's most widely distributed and one of the important resources. The distribution of groundwater resources is mainly dependent on two factors, namely the rainfall and the nature of the geological formations. The alluvial plains, namely, the Indus, the Ganga, the Brahmaputra and their tributaries, the inland valleys of the rivers Narmada, Tapti and the coastal alluvial are the richest in groundwater. These formations comprise about one third of the total land area in the country but account for about 50% to 60% of the total usable ground water resource. Semi consolidated sandstone formations are next in importance with regard to the groundwater availability but these cover only 5% of total land area. The annual replenishable groundwater resource is about 43 mham (Groundwater Resource Estimation Committee, 1977, Ministry of Water Resources, Government of India).

1.7 MEANING OF OPTIMAL WATER RESOURCE MANAGEMENT

The meaning is explained under management, water resources management and optimal water resources management.

1.7.1 Management

It is defined as the process by which actions are directed towards achieving common goals.

Function of management

There are several functions of management (as decision making, organizing, staffing, planning, controlling, communicating, directing etc.) but one of them is planning, and meaning of planning is to anticipate the future problem and discover alternative course of action.

1.7.2 Water Resource Management

It is the management of water resources for maximum return without imbalancing the ecological system.

Here the goal is to get maximum return without impairing the natural resources (land, water etc) and without degrading environment. Water-logging, overdrafts of ground water, and deterioration of ground water quality are the subjects of anticipation for future problem.

1.7.3 Optimal Water Resource Management

Its aim is to yield optimum benefits with least costs on a sustained basis over a large possible time horizon.

1.8 OBJECTIVES OF IRRIGATION WATER MANAGEMENT

There is growing realization in the country of the need to improve the quality of the supplies and services from irrigation, particularly from existing large and medium projects.

The main objectives are outlined as below:

1. To increase the productivity per unit of water or land;
2. To improve equity of water distribution among users;
3. To increase reliability of supplies and
4. To improve environmental stability and sustainability of land and water productivity over time.

In brief, the main aim of irrigation management is to maintain the system in proper shape to yield optimum benefits with least costs on a sustained basis over the largest possible time horizon.

1.9 OBJECTIVES OF STUDY

Following are the objectives of study:

1. **To determine Crop Water Requirement in the study area.**
2. **To determine Availability of Surface Water in the study area.**
3. **To determine Water Deficit.**
4. **To determine Availability of Ground Water.**
5. **To optimize Cropping Intensity and**
6. **To optimize Net Return.**

1.9.1 Crop Water Requirement (CWR) :

The evapotranspiration demand of existing cropping pattern is to be determined. Modified Penman Method is one of the most suitable methods for its determination. Water is one of the critical input for crop production. Crops need water for carrying its physiological process, and for other purposes. Crop water requirement takes into account the evapotranspiration demand of the crops and any other needs, if any, as leaching requirement, field application loss, conveyance loss, etc. There are several methods for determination of Reference Evapotranspiration but Modified Penman Method gives more precise value.

The study of CWR is needed to know the situation that canal supply is meeting the demand of crop water or not.

1.9.2 Assessment of Surface Water

It is supply water by canal to the crops in a year. Its study is required to know the situation that surface water is meeting the crop water requirement or not. If surface water available is not meeting the CWR, then conjunctive use of surface and groundwater is planned accordingly.

1.9.3 Deficit of Water

It is differences between CWR and canal supply in a year. If CWR is more than Canal Supply in a year, then there is deficit of water. If Such a case occurs, then planning is made to supplement the surface water with groundwater.

1.9.4 Ground Water

The water beneath water table is ground water. The study of groundwater is required to know the groundwater balance in a year so that a planning for conjunctive use of surface water and groundwater can be made accordingly. Numerical modeling method is one of the most powerful technique for groundwater balance determination.

1.9.5 Cropping Intensity

It is the percentage of cropping area over the cultural area in a year. To meet the growing needs of food-grain production in a country, a high cropping intensity is required. High cropping intensity requires assured irrigation. Only surface water is not meeting the demand of high cropping intensity, so its supplementation with groundwater is needed.

1.9.6 Crop Yield

It is yield of crop per hectare of land in a year. Crop production is the function of types of crop, viability of seeds, soil fertility, water availability, management, time, use of fertilizer and pesticides.

1.9.7 Net Return

It is the net return from irrigated agriculture. Agriculture consists of cost of seed, fertilizer, pesticides, human labour, bullock labour, irrigation water etc. Production of crop per hectare gives crop yield. The market price of food-grain gives gross return and gross return after subtraction of input cost gives the net return.

1.10 CONJUNCTIVE USE OF SURFACE AND GROUND WATER

Conjunctive use of water is the supplementation of ground water to surface water for irrigation. Growing needs of food-grain production requires sustainable irrigated agriculture. Conjunctive use of water establishes a hydrological equilibrium of water table. There are other advantages also which are shown below.

Advantages of conjunctive use of water

Following are the advantages:

1. Congenial Agro-climate
2. C.I. upto 200-250%
3. More reliable water supply
4. Sustainable irrigated agriculture and
5. Hydrological equilibrium of water table.

1.11 STUDY AREA

The study area for optimal water resource management is the command area of Right Main Distributory. Right main distributory takes off from Deoband branch canal at 7.26 km and Deoband Branch canal itself takes off from the Upper Ganga canal at km 35. The Upper Ganga Canal takes off at Hardwar from the Ganga River. The map of study area is shown is Fig. 1.3 below.

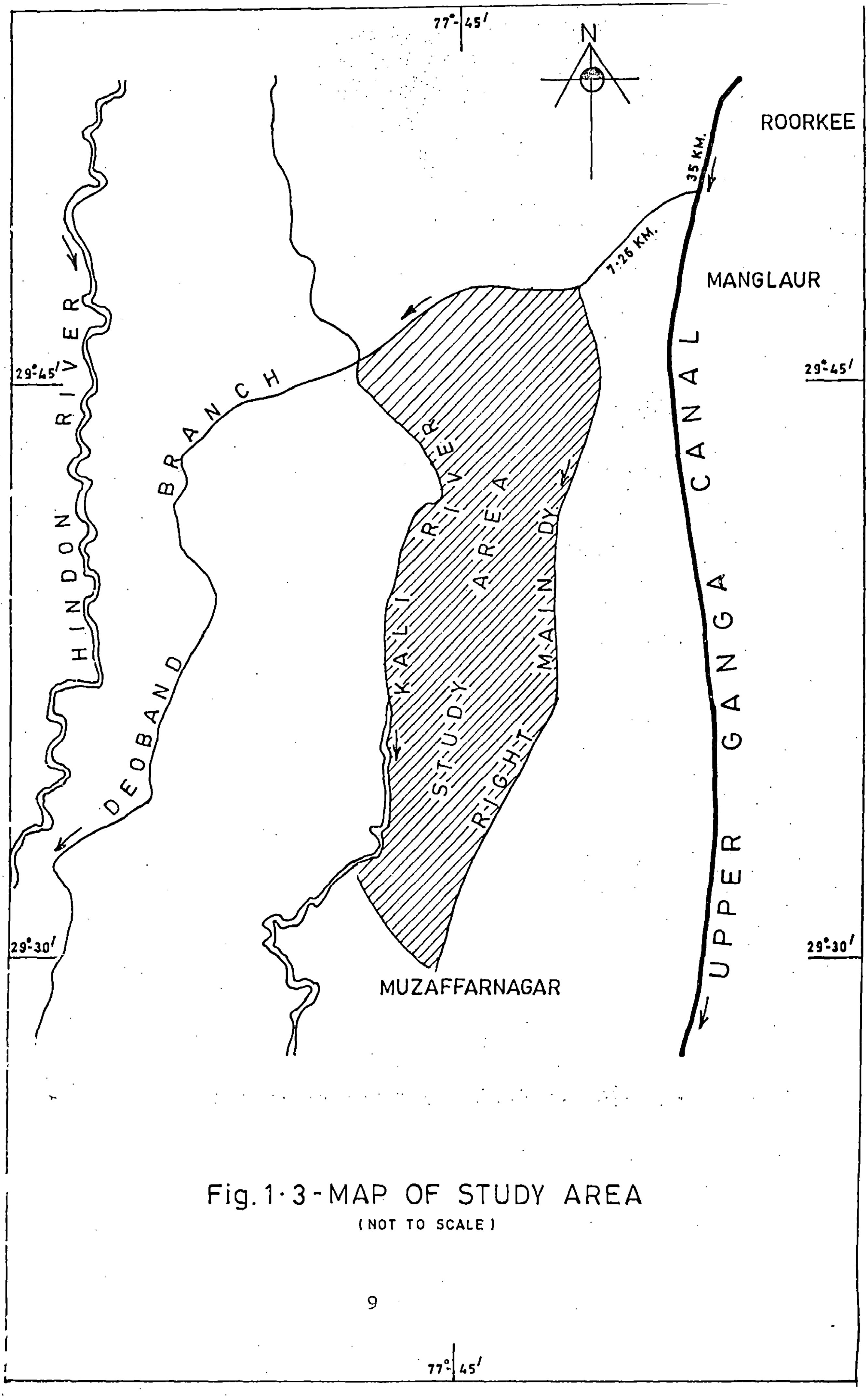


Fig. 1·3 - MAP OF STUDY AREA
(NOT TO SCALE)

SURVEY OF LITERATURE

2.0 GENERAL

Relevant literature regarding the study of optimal water resource management in Right Main Distributary of Upper Ganga Canal Command has been surveyed and some of the important features are presented here.

2.1 INTRODUCTION TO UPPER GANGA CANAL (UGC) SYSTEM

Historical development of Upper Ganga Canal System has been given in TECHNICAL REPORT under "FIELD RESEARCH"-FORD FOUNDATION PROJECT (GRANT NO. 900-1463) by JITENDRA PRASAD SINGH.

The severe famine of 1837 in Ganga-Yamuna Doab drew the attention of Biritsh Canal Engineers to protect the agricultural land from recurring droughts. CaptainP.Thomas Cautley, a Royal Artillery Officer, came forward and first of all prepared the project of UGC in 1838 with a proposal to take out a canal from Ganga river near Hardwar, and feasibility report was approved in 1841.

Captin Cautley was a visionary person. He used his engineering skill in producing simple and bold designs with locally available material (brick, lime and surkhi) at the time when there was no inception of soil mechanics and knowledge of hydraulic engineering too was in primitive stage.

In spite of several constraints, the project was ultimately taken up with full swing in 1848 and canal was commissioned on 8thc April 1854 with a head discharge of 189 cumecs at Mayapur, Hardwar. When it became operational, it was a first major and large canal system of the country and also a remarkable major irrigation system in world in mid of 19th century.

The major objective behind the construction of UGC was protective irrigation during Rabi season. Every year a temporary diversion bund was constructed after the monsoon period and it happened to be washed away by flood in the beginning of monsoon. Gradually the concept of irrigated agriculture developed and a gradual demand for kharif agriculture was began to rise. Keeping in view the irrigated kharif crops, a permanent weir known as BHIMGODA WEIR was constructed across the sacred river Ganga at Hardwar in 1920 to direct the water flow in UGC. During modernization, the capacity of UGC has now been raised to 297.00 cumecs and Bhimgoda weir was replaced by a modern BARRAGE in 1985-86.

2.2 OPERATION OF MAIN CANAL

The above mentioned TECHNICAL REPORT deals with Operation of main canal under two headings: operation of main canal during monsoon period and during non-monsoon period.

2.2.1 Operation of Main Canal During Monsoon Period

Flow during monsoon period is loaded with silt and floating debris which requires control structures to check the silt and debris from entering into the canal. But at Mayapur, where discharge is received, there is no control structure, flow enters are through old supply channel, so operation of main canal during monsoon requires great vigil. The religious sanctity and commitments do not permit construction of a gated regulator on the old supply channel which feeds the Har-Ki-Pauri sacred Pond of Hardwar.

Following precautionary measures are to be adopted in operation during monsoon period:

(i). Main canal should not be allowed to run when silt content below silt ejector (Constructed in 1975 at 2.2 km) exceeds 7.5 gms/liter (7500 ppm) or continue to remain above 5.00 gms/liter for more than 24 hours.

(ii) the UGC should be closed whenever flood discharge in the Ganga river exceeds 5667.33 cumecs (2,00,000 cusecs).

(iii) Main canal should not be run with less than 184.19 cumecs (6500 cusecs) from head during monsoon when silt content in water is high because it is likely to deposit silt in canal bed at less than this discharge.

(iv) Checking cross section of canal in the head reaches should be practiced.

2.2.2 Operation of Main Canal During Non-Monsoon Period

The monsoon rainfall in catchment area of Ganga River is generally over by the end of August and in September. By that time the silt content falls below 1000 ppm. After that available supplies fall below the canal capacity, so naturally all available supply is directed into main canal for irrigation and other purposes.

The weekly regulation day at the head of UGC at Bhimgoda is fixed as Wednesday and the regulation is carried out between 6 A.M and 8 A.M.. All gauges at the head are read at 6 A.M., 12.00 noon and at 6 P.M.. The gauges are recorded in a guage register by the signaler-in-charge and reported by canal telegraph to JE/AE/ EE/ SE and to others as per special instructions. The length of main canal being 291.91 km, the effect of head regulation reaches the tail end in about 3 days.

2.2.3. Lowering and Raising Water Levels in UGC

The Technical Report also mentions this practice. When an unlined canal is opened after a long closure, sudden increase in the gauge and discharge causes high velocity which is likely to cause scours in bed particularly when any type of obstruction is encountered. Hence, the gauge is never allowed to raise more than 6 inches in every half hour. Likewise, at closure of UGC, the reduction in gauge is not allowed to be more then 6 inches in every half an hour.

2.3 OPERATION OF BRANCHES, DISTRIBUTARIES AND MINORS

MANUAL FOR OPERATION AND MAINTENANCE FOR UGC SYSTEM OF IRRIGATION DEPARTMENT, GOVERNMENT OF UTTAR PRADESH BY WAPCOS (1990) presents the operation of branches, distributaries and minors.

The UGC has a head design discharge of 297.00 cumecs but between mid-May and mid-Novermber the river supply is in excess of 311.70 cumecs and river discharge goes down to about 127.15 cumecs in the month of February/March when river supplies dwindle. In these circumstances, while the main canal runs continuously, the branches and distributaries have to run in rotation.

2.3.1 Allocation of Supplies

The S.E., I.W. circle-I (Ganga), Meerut has been authorised to manage the inter Circel and inter Divisional distribution of water on the principles laid down in CE's orders, who convenes meetings of the concerned SE's in October/November to assess and decide the likely availability of water for utilisation in UGC as per its share and makes weekly allocations to each SE. Who in turn decides the plan of operation of Branches/ Distributaries in his Circle.

The Executive Engineer, after knowing the anticipated share of water in each week, prepares a plan of running the different Distributaries in the Division. These plans have to be prepared in such a way that there is equitable distribution of water with regard to quantity and timing of supplies in different channels according to the developed cropping pattern. Since the water available is less than requirement, a rotational running of various distributaries has to be planned. There are weekly Osrabandi on outlets and hence the channels are run for one week or multiples at a time. The system of planned and rotational running to match the availability of water with the requirement in a most equitable manner is called the 'Rostering' of the channels.

2.3.2 Preparation Of Rosters and their Publicity

While the total weekly availability of water in a division is fixed according to the share, the roster of running of different channels is prepared in consultation with District Agriculture officer. After finalisation of the roster the same is got printed in the form of a weekly running chart for the entire crop season for all Distributaries and minors in the division and is supplied to district and block level officials, Gaon Sabhas etc. for information and wide publicity so that the farmers may be able to know as to when water will be available to their outlets and they plan accordingly the supplementation of irrigation requirements and agricultural operations.

2.3.3. Adjustment in Allocation and Rosters

While planning the Roster an attempt is made to run the channels with full supply discharge and if necessary, with a little higher gauge to utilise and distribute the allocated share of discharge in selected channels without having to surrender the share or run any channel with partial discharge.

In actual practice the river supply may be in excess of or less than that assumed in the planning stage for each week. If any Division/Circle does not need the allotted supplies due to slack demand or any other reason, the distributary authority has to decide whether the quantity of water surrendered could be reallocated to this division in subsequent weeks or not. The quantity so surrendered or not utilised may be allowed to be used by other Divisions or disposed; if not required. Normally all available water is used during Rabi Period, when the supplies are much shorter than the demand.

2.3.4 Operation of Outlets

The distribution of water from the outlet amongst the beneficiaries of the outlet command is done by enforcing weekly Osrabandi in which time and sequence are allocated to each land holder prorata in the command area. Outflow is fixed on the basis of requirement of water for various crops proposed for irrigation.

The outlets are ungated and they are designed to run continuously so long as the channel runs in the roster. Thus there is no operational control on the outlets.

2.3.5 Emergency Operation

There will be situations such as breach of a major canal or serious accident causing damage to important structures which may endanger public life and property. There may be some distress conditions where failure is not imminent but the situation may lead to failure. In such case closure of canal at the earliest may be called for. In such situation emergency operation is needed.

2.4 PROBLEMS AND CONSTRAINTS IN UGC SYSTEM

The above mentioned TECHNICAL REPORT also points out the problems and constraints of UGC system.

2.4.1 Problem

UGC is an old canal system and there are multiplicity of regulation points. Due to this, the problems in UGC specially in Upper reaches of the system are quite troublesome and pose a challenge to the maintenance staff. The major problems are pointed here.

(i) Sediment entry
(ii) Reduction in carrying capacity
(iii) Dhanauri Level crossing
(iv) Drainage problem
(v) Escapes
(vi) Problem in communication
(vii) On farm problems
(viii) Monitoring and Evaluation problems
(ix) Problems on giving incentive to irrigators
(x) Scope for malpractice etc.

2.4.2 Constraints

Constraints prevailing in UGC system are pointed as below:

2.4.2.1 Engineering Infrastructure Constraint

Ranipur Super-passage: subject to uplift pressure, Pathri Super-passage: accretion problem, Dhanauri Ratmau Rao Level Crossing: retrogression in d/s of dam and damage, and Solani Aqueduct: not more than 255.0 cumecs (9000 cusecs) can pass through aqueduct safely.

2.4.2.2 Agricultural Constraint

Cultivation of sugarcane in larger area in head reach and taking more than fair share of water.

2.4.2.3 Availability of Water Constraints

There is ample water available in Kharif season to meet the irrigation requirements of Paddy from July to mid-September but there is shortage in June, in 2^{nd} fortnight of September and in Ist fortnight of October. In Rabi season, there is always shortage of available water.

2.4.2.4 Social Constraints

Unfortunately, the spirit of Co-operation and self-discipline has not been fully generated till now among the farmers in the command area. Malpractice e.g. taking water out of turns, dismantling water courses, enlarging the size of outlets, cutting banks etc are still observed.

2.4.2.5 Administrative Constraints

There is no restriction on area and types of crops to be cultivated in water use policy at present. Rabi irrigation should get priority over Sugarcane. Existing canal laws need to be reviewed and amended.

2.4.2.6 Financial Constraints

Continued reduction in the maintenance grants has resulted into the deterioration of canal and its structures to such an extent that efficient running of UGC canal has become difficult as their carrying capacity has gone down.

2.5 RIGHT MAIN DISTRIBUTARY

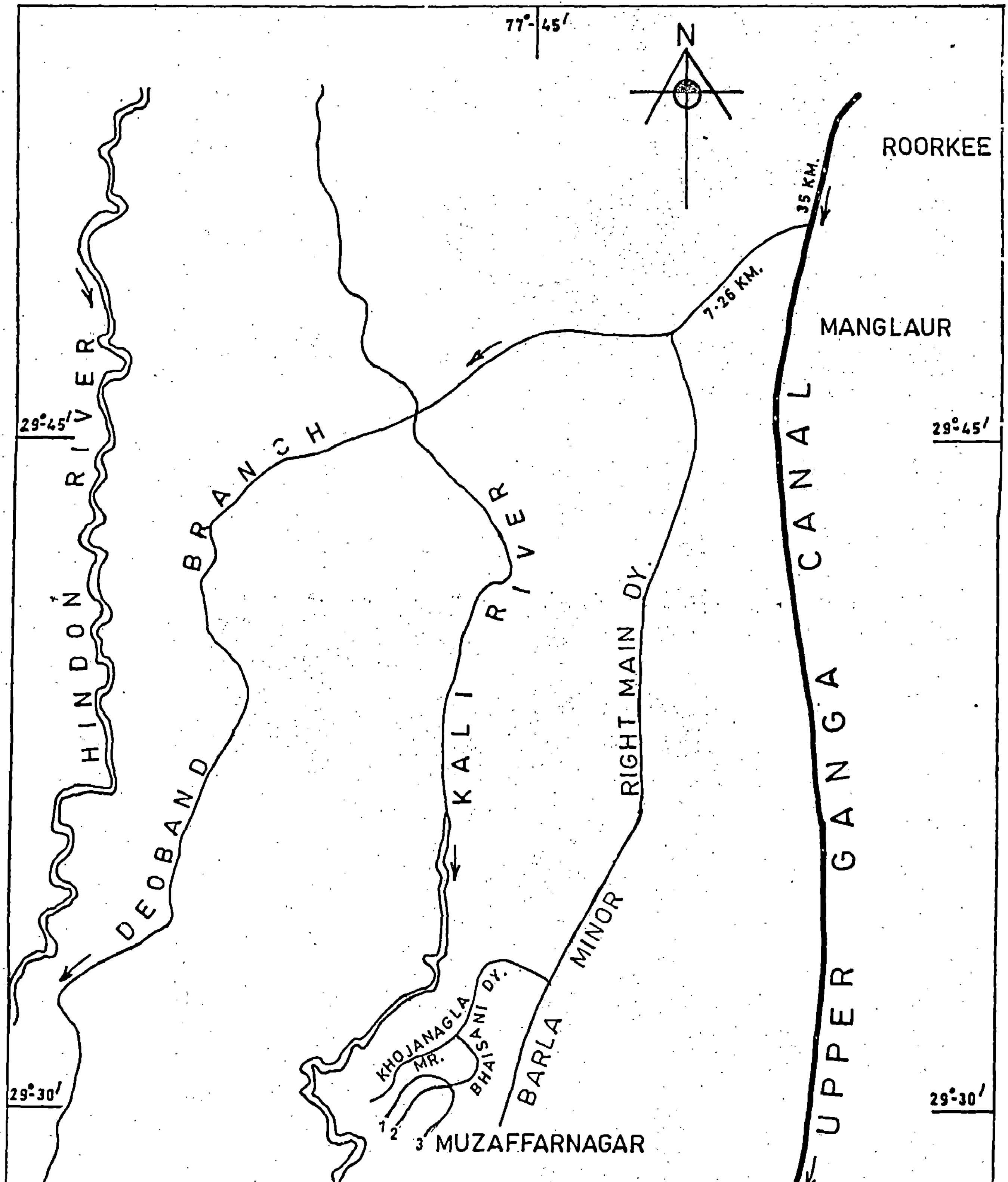
REPORT ON DIAGNOSTIC ANALYSIS (1987) conducted by WRDTC, UOR, Roorkee –247667, (India) presents the detailed study of Right Main Distributary.

The Right Main Distributory, which has been chosen for the study, takes off from Deoband Branch at Km 7.26. The Deoband branch itself takes off from UGC at km.35. The head regulator for this distributary is located on the left bank of Deoband Branch. The length of the distributory is 17.60 km. The total C.C.A. of this distributory is 5890 ha. The total number of outlets is 176. The average size of chak is 33 ha. The sizes of the outlets are 4 inch (10 cm) and 6 inch (15.0 cm). The Index plan and particulars are given in Fig. 2.1 and Table 2.1 respectively.

2.5.1 Soil and Climate

The Upper Ganga canal command area is more or less level with gentle slopes. The soils are deep alluvial, sandy to clay loams deposited by Ganga River.

The area has a monsoonic climate characterised by dry hot summers followed by about three months of monsoon rainfall from July to September, which accounts for about 75% of the annual rainfall. The winters are cool and generally dry. The average annual rainfall in the command is about 105.0 cm. The maximum temperatures in summer goes upto 43^0C while minimum in winter may comes down to 5^0C.



1. KHAMPUR MINOR
2. BIJOPUR MINOR (RIGHT)
3. BIJOPUR MINOR (LEFT)

Fig. 2·1- INDEX PLAN
(not to scale)

Table- 2.1 Features of Right Main Distributary

Sl. No.	Name of Canal	Offtake point (km.)	Tail point (km)	Authorised discharge (m^3/sec)	C.C.A. (Ha)
1.	Right Main Distributary	7.26 of Deoband Branch	17.702	2.69	2111 Direct Irrigation
2	Bhaisani Distributary	16.40 of Right Main Disty.	13.60	1.22	2237
	(a) Khoja Nagla Minor	5.60 of Bhaisani Disty.	4.00	0.25	568
	(b) Bijopura Minor	10.32 of Bhaisani Disty.	1.72	0.84	138
	(c) Khampur Minor	10.69 of Bhaisani Disty.	2.60	0.056	128
3.	Barla Minor	17.70 km of Right Main Disty.	7.25	0.339	708
	Total		46.87		5890 Ha

Total No. of outlets = 176

Average size of the Chak on outlet = 33 Ha.

2.5.2 Water Regulation

Water is supplied for irrigation through network of irrigation channel, adopting rotational water supply System which is locally known as "OSRABANDI" or "WARABANDI". This practice is reported to have been in operation for several decades and has been functioning satisfactorily without giving rise to major problems. The rotation of supplies is fixed on weekly basis considering 166 hours out of 168 hours that comprise a week. The remaining two hours are meant to take care of transmission time. The roster for the channel is fixed by the Executive Engineer well in advance of the crop period and communicated to all concerned including the farmers. Normally channels run for two weeks and are closed for one week during Kharif while during Rabi they run for one week out of three remaining closed for the other two. The predetermined roster is normally adhered to reasonably well.

2.5.3 The Hydraulic Structures

The hydraulic structures on the Right Main Distributory Comprise Head Regulators, Falls and Bridges. There are no cross regulators on the channels. The Head Regulator comprises of screw gear operated vertical gates and has two bays of 1.60 m each.

2.5.4 Channel Sections

Presently all the channels are running with higher discharge than the design discharges and have assumed larger dimensions. The designed and existing sections are shown in Table 2.2.

Table 2.2 : Designed and Existing Channel Sections

Channel	Designed			Existing		
	Bed width m	Water surface width m	F. S. D m	Bed width m	Water surface width m	F. S. D m
R.M. Distributory 0.1 km. 1.8 km.	 5.4 5.10	 6.30 5.97	 0.90 0.87	 7.80 6.70	 8.30 7.30	 1.00 1.00
Bhaisani Distributory 9.88 km.	1.22	1.95	0.73	1.70	2.60	0.66
Barla Distributory 0.24 km	0.65	1.19	0.54	1.90	3.0	0.56
Bijopura Disty	0.305	0.77	0.46	0.90	1.6	0.40

2.5.5 Hydraulic Roughness

On the basis of measured velocities, cross-sections and slopes, values of n in Manning's equation have been calculated on various channels. The measured values are tabulated below in Table 2.3

Table 2.3: Hydraulic Roughness

Channel Reach1	Slope	Mean velocity m/s	Computed value of n
R. M. D. (200 to 400 m)	1/2222	0.62	0.026
R. M. D. (900 to 1090 m)	1/3167	0.67	0.020
R. M. D. (9656 to 16490 m)	1/4456	0.414	0.029
Bhaisani Disty. (2972 to 3686 m)	1/3300	0.44	0.025
Barla distributory	1/2500	0.404	0.022
Bijopura Minor head to tail (1350 m)	1/1755	0.33	0.026

The Manning's n values are in the range normally expected in sediment transporting channels of this size in which resistance due to grain roughness is almost doubled due to form resistance of bed ripples or dunes. The values in R.M.D in the first and third rows of the above table are on the high side and indicated irregular berms. Berm cutting in these reaches has improved the conveyance capacity of the channel.

2.5.6 Seepage Losses

Seepage losses in the various channels of the system were measured by Inflow-Outflow and /or by Ponding methods. The results are tabulated below in Table 2.4.

Table 2.4: Seepage Losses

Channel Reach	Method of Measurement	Loss (cumecs/million sq m of wetted perimeter)
1.R. M. D. from km. 0.4 to km. 4.265	Inflow outflow	2.42m^3/s/mil. Sq. m. of perimeter
2. Barla minor at km . 3.758	Ponding	1.12 to 0.97
3. Bhaisani Disty., head to km. 3.686	Inflow-outflow	2.48
4. Bijopura minor Reach 50-550 800-1100 1100-1350	Inflow- outflow	5.60 6.66 6.52
5. Bijopura minor	Ponding	5.2 to 3.7

The measured losses in the head reach of R.M.D. and in Bhaisani distributary correspond to those expected in average loam soils, while those in lower reach of R.M.D. and in Barla minor would correspond to clay loam soil. The measurements in Bijopura minor suffer from certain short-comings-the accuracy of surface float method is not such as to give a relibale measure of flow difference in a short reach of 250 to 300 m, while in ponding method the ponding depth (30 cms and 22 cms) as well as observation period are too small. Even so, it is likely that the Bijopura minor runs in more sandy soil.

2.5.7 Conjunctive Use of Surface and Ground Water

The present canal supplies fall short of the peak requirement of highly intensive agriculture in the area. Canal irrigation is supplemented through privately owned tubewells by many farmers. Groundwater is available at a depth of 6 to 9 m below the ground surface. Shallow bores of 10 cm/ 12.5 cm diameter to a depth of 20 to 30 m are made at a moderate cost and which yield 16 to 18 liters/ sec. With this flow it takes about 15 hours to irrigate one ha. The tubewells in the area are generally operated by diesel engines. Tubewell irrigation is 4 to 5 times more expensive than canal irrigation, but is found worthwhile by the farmers as an insurance and for supplementing the deficiency of canal supplies.

2.5.8 Irrigation Efficiency

It has been estimated that Field Application Efficiency (FAE) varies from 97.2% for sugarcane in RMD to 34.2% in sugarcane in Bijopur minor. Similarly storage efficiency has been estimated to be 100% in above command and deep percolation efficiency same as FAE. Uniformity of distribution is found to vary from 84% to 99.4%.

2.5.9 Land Drainage

The soils are medium to sandy loam and drainage is needed only for expeditious removal of runoff resulting from rainfall. The available surface drainage is found generally adequate. There is very little area affected by water logging, as water table rise is controlled by pumping from tubewells.

2.5.10 Practice of Irrigation Method

It has been found that Border, Furrows and Check basin methods of irrigation are practiced. MANUAL ON AGRONOMY FOR ENGINEERS (1994) WRDTC, UOR, ROORKEE-247667 (U.P.) INDIA deals with suitable irrigation procedure on the basis of infiltration rate after one hour. This is shown in Table 2.5 below.

According to above mention DA Report, Infiltration rate equation is $z = 15\,t^{0.25}$ to $z = 3.0\,t^{0.375}$ where z is mm per hour, t in minutes. At t = 60 minutes, value of z comes 41.7 mm/hr to 14 mm/hr. So the area comes under high to medium infilterability class and flooding in short strips is a suitable method of irrigation.

Table 2.5 Infiltration and Irrigation Method

S.N.	Infilterability class	Infiltration after 1 hr. (mm/hr)	Suitable irrigation procedure
1.	Very low	<5	Flood irrigation
2.	Slow	5-15	Sprinkler
3.	**Medium**	**15-25**	**Flooding in short strips**
4.	High	25-50	Flooding impossible
5.	Very high	50	No. irrigation possible

2.5.11 Soil Characteristics

Soil characteristics of C.A. are shown in Table 2.6 below.

Table 2.6: Soil Characteristics

Properties	Values
Soil Texture	Sandy/ silty loam, silty clay loam
Soil pH	7.2 to 7.6
EC of Soil mmho/cm	0.09 to 1.9
Porosity (%)	40.5 to 47
Bulk density (gms/ cm^3)	1.39 to 1.7
Field capacity (%)	18.5 to 26.7
P.W.P (assessed)	5.2 to 8
Water Holding Capacity (cm/m)	19.4 to 27.4

2.5.12 Socio-Economic System

They irrigation system, which was initially designed as a protective irrigation command has got converted into a market oriented intensive system. The demand for water is extremely keen and that puts the system under stress and gives rise to irregular practices. Better control and better information to the farmers are needed to keep the abuses under control.

Majority of the farmers in the area have more than 2 ha land and are literate. They have ownership and use machinery and implements. There is widespread indulgence in irregular withdrawals from main channels.

2.5.13 Performance Evaluation

Major objective of irrigation water management is to deliver water in sufficient quantities, according to time schedule that matches the requirements for healthy plant growth, and with fair distribution among many users.

ABERNETHY CHARLES L. has given following parameters for evaluation of performance of irrigation system:

1. Adequacy
2. Equity
3. Timeliness
4. Sustainability and
5. Reliability

Adequacy, equity and timeliness are primary parameters while sustainability and Reliability are secondary parameters.

Abernethy (1984, 1986) has also indicated another parameter in terms of output i.e. potential productivity. Potential productivity is the ratio between the output that can be achieved under water regime, and the output that would have been achieved if the water supply had been ideally matched to the needs of the crop.

Here productivity means productivity per unit of input. So we may have land productivity (tonnes/hectare), which is usually called yield or we may have water productivity (kg of crop/m^3 of water).

2.5.13.1 Adequacy

The indicator of adequacy is RWS (Relative Water Supply): in the physical sense, RWS is the ratio of water supplied to an irrigation unit and the demand for water in that unit over a period of time.

$$RWS = \frac{(IR + RN)}{(ET + S\,\&\,P)} \qquad (2.1)$$

where

IR = Mean irrigation application mm/day

RN = Mean rainfall mm/day

ET = Mean evapotranspiration mm/day

S&P = Seepage and deep percolation mm/day.

2.5.13.2. Equity

It means the fair share of water to users at different points in the system. Equity parameter is Inter- Quartile Ratio (IQR).

IQR (Inter-Quartile Ratio)

Abernethy (1990) proposed the use of IQR. IQR is defined as the ratio of volume delivered respectively, to the most favoured upper 25% and the least favoured lowest 25% of the units. It is more than one in the study area.

2.5.13.3 Dependability, Reliability and Timeliness

Dependability is defined as the delivery of a relatively uniform amount of water over time (Molden, 1988). There are two aspects of dependability: reliability which relates to a fairly constant rate of supply and the predictability which relates to the timing of water supply.

In the study area, there is scarcity of water in Rabi period, so uniform amount of water is not supplied in Rabi period. Dependability is affected although the users get predicated (time) water supply at constant rate.

2.5.13.4 Water Quality

The characteristics of irrigation water itself have bearing on the performance of water delivery system. Temperature, Sediment and dissolved salts affect the performance of irrigation system. Temperature of irrigation water through its effect on soil can affect the plant growth.

Sediment in water can have both positive and negative effects. The positive effect is in its soil building role in sandy soil and supply of nutrients for crops. The negative effects can be the sealing of soil surface, raised field elevations relative to canal outlets and thereby reduced water supplies.

In study area, water quality is fairly good.

2.5.13.5 Sustainability

Dissolved constituents in water particularly salts are important indicators of irrigation system performance. Salinity problem is one of the major problems in irrigated agriculture. The study area has neither salinity nor waterlogging problem. So, the area has sustainable agriculture.

2.6.0 GROUND WATER RESOURCES OF UGC COMMAND

THE REPORT OF UPPER GANGA MODERNIZATION PROJECT, based on the findings of WORLD BANK MISSIONS (1984), accounts for the ground water resources of the command.

2.6.1 General

The Upper Ganga Canal (UGC) irrigation system is located between the Ganga and Yamuna Rivers and extends on this doab form just below the foothills of the Himalaya.

Land elevations on the doab range from about 280 m MSL in the north to 150m MSL in the south. The climate is monsoonal and 90% of rainfall occurs in mid-June to mid-September and rainfall ranges from 600 mm in southwestern part of the area to about 1050mm in the north. The inter and intra-annual variation in rainfall distribution is large, particularly in the drier part of the area. February with mean temperatures in the range of 7 to 10^0C. May- June is the hottest months when daily maximum exceeds 40^0C. Potential Evopranstranspiration (Calculated by the penman method) ranges from about 1330 mm/annum (Roorkee) to 1530 mm/annum (Aligarh).

2.6.2 The Aquifer System

The command area forms part of the Ganga alluvial basin and is entirely underlain by alluvial deposits to depths which may exceed 1000 m. The alluvial sediments consists of gravel, sand of varying grades, silt, clay and Kankar.

2.6.3 Flow Dynamics

The regional hydraulic gradient is in accord with the regional topographical gradient and is from north to south at about 1:3000.

2.6.4 Depth to Water Table

Depth to water table ranges from near land surface to more than 30m in some localised areas (these are usually associated with relatively high land in relation to surrounding areas). In general, water levels at the end of dry season are less than 10m below land surface.

2.6.5 Aquifer Characteristics

Permeability ranges 27 to 41 m/d, with a median value of 38 m/d. With the help of specific capacity data and screened length information, value of permeability can be calculated by applying Logan approximation of the Thiem steady state formula.

$$K = \frac{Q \times C}{S \times h} = \frac{SC \times C}{h} \qquad (2.2)$$

Here Q/S = SC = Specific Capacity

K = Permeability in m/d

Q = Well discharge in cub m/d

s = Drawdown in meters

h = Screen length in meters

SC = Specific Capacity in Sqmetre per day (m^2/d)

C = A constant taken as 1.22.

2.6.6 Specific Yield

Its value is expected to be 12%.

2.6.7 Recharge-Discharge Relationship

The main sources of recharge to the aquifer system are infiltration of rain falling on the area, deep percolation of canal and channel seepage losses, and on field losses from the surface water irrigation system. Discharge is by effluent seepage to the natural surface water drainage system, evaporation from shallow water tables, transpiration by vegetation rooted within the capillary fringe and abstraction by wells.

2.6.8 Recharge From Rainfall

$$R = S(1.6P-0.27) \quad (2.3)$$

Where R = recharge from monsoon rainfall in metres.

S = specific yield as a decimal fraction

P = monsoon precipitation in metes.

At S = 0.12, this formula reduces to

$$R = 0.192P-0.032 \quad (2.4)$$

This formula implies that recharge represents about 19% of monsoon rainfall minus 32 mm. Recharge from non-monsoon rainfall is regarded as negligible.

2.6.9 Recharge From the Canal System

From the unlined UGC system, estimates of conveyance losses have been made by inflow-outflow measurements on major canal system (main and branch) and by ponding method in minor canals. Seepage losses are estimated as 2.3 cumecs per m sq meter (8 cusecs per million square feet) of wetted surface (200 mm/day), all of which goes to deep percolation. Seepage losses from fully wetted minor canals are lower and are estimated to be 100 mm/day on the wetted surface.

2.6.10 Recharge From Watercourses and Field Channels

Channel seepage losses are 24% of the water delivered at the chak outlet.

2.6.11 Effect Of Canal Lining on Seepage Losses

Seepage loss from lined canal will be about 25% of the losses from unlined channel.

2.6.12 On Field Seepage Losses

The element of recharge will vary according to the soil type, crop and water application procedures. Literature review and field experience indicate that average on-field losses and probably about 30% of the water applied to the crop, measured at the field gate.

2.6.13 Effluent Flows to the Drainage System

Ground water outflows maintain dry weather base flows in the Ganga below Bhimgoda weir, the Yamuna below Tajiwala weir and on Hindon river. Relationships between ground water levels and river stage indicate effluent groundwater flows which also contribute to river discharges during the wet season, albeit only a very small proportion. Analysis of the available average about 11 Mm^3/annum/km of reach on the Ganga river from Bhimgoda to Narora and 9 Mm^3/annum/Km of reach on the Yamuna from Tajiwala to Okhla.

2.6.14 Evaporation from Shallow Watertable Areas

The water table has at a depth less than 3m below land surface at the end of the monsoon over quite a large part of the gross command area of UGC. Direct evaporation from the water table via the capillary fringe would be significant with such depths, and approach the potential evaporation rates with depths of less than 1 .m. At water table depth below 3m, direct evaporation from the water table is negligible. Crops grown in areas of shallow watertable will derive part of their dry season water supply from the capillary fringe and thus, part of this discharge element will be transpiration by cultivated crops.

Evaporation form shallow water tables is extremely difficult to quantify. However, it is considered that this element of discharge is significant in water balance. Such losses could be controlled in many areas by lowering the water table by pumping for irrigation and thus more beneficial use of the groundwater could be achieved without much affecting the water balance.

2.6.15 Transpiration by Trees

A rough estimate of the quantity of water withdrawn by scattered trees is in the order of 500 Mm^3 over the dry season.

2.6.16 Abstraction by Wells

Private tubewells have been installed in large numbers in the area served by surface water irrigation through the UGC system and in the area which is not in outlet commands. Similarly a large no of open wells, Persian wheels (decreasing trends) and pubic tubewells serve the area. Estimates of annual draft by various types of abstraction wells are as below in Table 2.7

Table 2.7 : Annual Draft (Mm^3/Annum)

Type of wells	year			
	1975-76	1976-77	1977-78	1978-79
1. Private tubewells	1639	1793	1958	2113
2. Private pumpsets	443	472	479	516
3. Traditional lifting devices	539	447	447	453
4. public tubewells	515	526	521	514
Total	3136	3238	3405	3596

The above estimate refers to gross draft but part of the water pumped will be recycled to groundwater as deep percolation from seepage losses in water courses and field channels, and from on-field application losses. It is estimated that about 40% of the water delivered at the well head is recycled as return flow of groundwater.

2.6.17 Water Quality

The ground water is generally of good quality. Total dissolved solids are generally less than 700 ppm and chloride content is less than 250 ppm.

Cherry (1973) recommend limits of solute concentration for water use for Drinking, Livestock and Irrigation crop production.

The recommended limits are shown below

Table 2.8: Recommended Concentration Limits for Water Used for Livestock And Irrigation Crop Production

S.N.	Constituent	Livestock: Recommended limits (mg/l)	Irrigation crops recommended limits (mg/l)
1	2	3	4
1	Total dissolved solids: small animals, poultry, other animals	3000 5000 7000	700
2.	Nitrate	45	-
3.	Arsenic	0.2	0.1
4.	Boron	5	0.75
5.	Cadmium	0.05	0.01
6.	Chromium	1	0.1
7.	Fluoride	2	1.0
8.	Lead	0.1	5
9.	Mercury	0.01	-
10.	Selenium	0.05	0.02
Sources : U.S. Environmental Agency, 1973 b.			

Concentration limits for drinking water is shown in Table 2.9 below.

Table 2.9: Drinking Water Standards

Constituent	Recommended concentration limit (mg/l)
Inorganic	
Total dissolved solids	500
Chloride (Cl)	250
Sulfate (SO_4^{2-})	250
Nitrate (NO_3^-)	45
Iron (Fe)	0.3
Manganese (Mn)	0.05
Copper (Cu)	1.0
Zinc (Zn)	5.0
Boron (B)	1.0
Hydrogen sulfide (H_2S)	0.05
	Maximum permissible concentration:
Arsenic (As)	0.05
Barium (Br)	1.0
Cadmium (Cd)	0.01
Chromium (Cr)	0.05
Selenium	0.01
Antimony (Sb)	0.01
Lead (Pb)	0.05
Mercury (Hg)	0.002
Silver(Ag)	0.05
Fluoride (F)	1.4 –2.4
Organic	
Cyanide	0.05
Endrine	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
2,4-D	0.1
2,4,5,-TP silvex	0.01
Phenols	0.001
Carbon chloroform extract	0.2
Synthetic detergents	0.5
Radionuclides and radioactivity	Maximum permissible activity (pCi/l)
Radium 226	5
Strontium 90	10
Plutonium	50,000
Gross beta activity	30
Gross alpha activity	3
Bacteriological	
Total coliform bacteria	1per 100ml

Sources: U.S. Environmental protection agency, 1975 and World Health Organization, European Standards, 1970.

Recommended concentration limits for these constituents are mainly to provide acceptable esthetic and taste characteristics.

Limit for NO_3^- expressed as N is 10 mg/l according to U.S and Canadian standards: according to WHO European standards, it is 11.3 mg/l as N 50 mg/l as NO_3^-

From observation of Table 2.8, it is obvious that dissolved solids and chloride content is within permissible limits.

2.7 GROUNDWATER RESOURCES IN SAHARANPUR DISTRICT AND MUZAFFARNAGAR DISTRICT

MASTER PLAN FOR CENT-PER-CENT IRRIGATION (SEPTEMBER 1976) BY IRRIGATION CIRCLE, MEERUT, IRRIGATION DEPARTMENT, UTTAR PRADESH (INDIA) has taken into account the ground water resources of Saharanput, Muzaffarnager, Meerut, Bulandshahr and Aligarh district.

This document mentions the policy matter for ground water abstraction. It states very clearly that there will be state tubewell for deep aquifer and private tubewells in shallow water table position. Only in some part of Saharanpur district (northern part) water table is deep otherwise position of water table is shallow, so private tubewell is preferred.

There are 10, 833 private tubewells in Saharanpur district and 24, 642 number of tubewells in Muzaffarnagar district.

Discharge of one private tubewell is 10,000 gellons per hour (50,000 liters per hour or 50 m^3/hr or 13.88 say 14 lit/sec). A tubewell of this discharge running 10 hrs a day can irrigate for 10 hac rabi or paddy or 6 hac sugarcane.

In canal command also, there are very large nos. of private tubewells supplementing the nos. of watering in canal irrigated fields. This ground water irrigates as half of the command.

The availability of ground water excluding ghar area wher WT is very deep is as below.

1. Saharanpur district : 2399×10^6 cum.
2. Muzaffarnagar district: 723×10^6 cum.

The above mentioned Diagnostic Analysis Report expresses that yield of one Private Tubewell is 16 to 18 lit/sec. With this flow it takes about 15 hours to irrigate one hac.. Tubewell irrigation is 4 to 5 times more expensive than canal irrigation but is found worthwhile by the farmers as an insurance and for supplementing the deficiency of canal supplies.

2.7.1 Annual O & M Cost of Tubewell

Dissertation thesis submitted by Mr Raj Kumar Aborl (1993) for his M.E. Degree presents the equation of annual o & m cost of tubewell.

$$A = 456.535 + 97.94\,X \qquad (2.5)$$

where A = annual o & m cost (Rs/ha-m) for 500 annual working hours of a tubewell of 10 lps capacity.

X = depth of WT(in meter) below ground level.

Equation 2.5 is the best line of fit.

A Report on Aquifer Response Modeling for evaluation of conjunctive use of surface and ground water in Hindon-Kali Nadi Doab by I.R.I., Roorkee- 247667 (India) points out the cost of tubewell charge and surface water.

A state Tubewell charge : Rs.4.80 per 1000 gallon in Rabi season.

: Rs 2.40 per 1000 gallon in Kharif season.

It works out to be Rs. 1056.0 per ha-m for Rabi season and Rs. 528.00 per ha-m for Kharif season.

But 90% of groundwater pumping is done by private tubewells and pumping sets. Cost of surface water

(i) Kharif Season : Rs 440.0 per ham.

(ii) Rabi season : Rs 630.0 per ham.

2.8 CROPPING PATTERN

The main crops grown in the area are sugarcane, wheat, paddy and fodder like berseem, oats etc. The predominant crop in the area is sugarcane.

The above mentioned DIAGNOSTIC ANALYSIS REPORT (1987) presents percentage of sugarcane as 30 to 60% and accounts average value 45%. The total cropping intensity was 131% in which total Kharif was 86% and total Rabi 45%, taking sugarcane as single crop.

The MASTER PLAN FOR CENT-PER-CENT IRRIGATION (1976), IRRIGATION DEPARTMENT, U.P. accounts for 177% cropping intensity in Saharanpur District by taking double weightage of sugarcane. The intensity of sugarcane was taken as 30%. The intensity of Rabi, Rice and other Kharif were taken as 60%, 25% and 32% respectively.

The REPORT ON AQUIFER RESPONSE MODELING points out 140% cropping intensity, taking sugarcane as single crop of 64.3% intensity.

YADAV (2000) states 144% cropping intensity by taking intensity of sugarcane as 60% (single weightage).

2.9 AGROCLIMATIC REQUIREMENTS FOR CROPS

FAo publication –33 deals with the crop and its climatic suitability.

2.9.1 Rice (Oryza Sativa)

It is believed to originate from southeast Asia. The growing period normally is 90 to 150 days depending on variety. The optimum temperature range in 22 to 30^{0}C at all stages but during flowering and yield formation small difference between day and night temperatures are required for good yield. Heavier soils are preferable due to low percolation losses.

2.9.2 Sorghum (Sorghum Vulgare)

It is a drought-resistant crop. It is grown for grain and forage production. Its optimum temperature is 25^{0}C. Growing time is 90 to 110 days. Soil most suitable is light to medium textured.

2.9.3 Wheat (Triticum Aestivum)

The crop is grown in the temperate climates. Its growing period is 100-130 days. Mean daily temperature for optimum growth and tillering is between 15 and 20^{0}C. Medium textured soils are preferable.

2.9.4 Sugarcane (Saccarum Officinarum)

Sugarcane originated in Asia. Optimum temperature for its germination is 32 to 38^{0}C. optimum and optimum growth is achieved with mean daily temperatures between 22 and 30^{0}C. It is an annual crop. Deep soil of any texture is suitable.

2.10 SOIL IRRIGABILITY CLASSIFICATION

On January 22-24, 1969, a workshop on soil and land irrigability Class was held in Delhi under the auspices of the Ministry of food, Agriculture, Community Development and Co-operation and in collaboration with the Central Water and Power Commission of the Ministry of Irrigation and Power. At this workshop the soil properties and criteria for grouping of soils into irrigability classes were discussed. On the basis of present knowledge of behavior of soil to water application, the system of technical grouping of soils into soil irrigability classes was decided upon and was presented in Table 2.1. Similarly Land Irrigability Classes was decided and was presented in Table 2.2

The above Table 2.1 and 2.2 has been enclosed in Appendix 3 as Table 9 and 10 respectively.

2.11 AGRO-CLIMATOLOGY

AGRICULTURAL CLIMATOLOGY, A BOOK BY J.K. KAKDE, METROPOLITAN BOOK CO(P) LTD, NEW DELHI throws sufficient light on agro-climatology.

Agriculture :

Agriculture is an exploitation of solar energy into various biological products for the welfare of mankind with the help of adequate supplies of water and nutrients.

Solar energy utilisation :

Solar energy is available on earth at the rate of 2 gm cal/cm^2 / minute on a calendar normal day. For proper utilisation of solar energy, LAI should at least be 1.

LAI: It is leaf Area Index. It is the ratio of areas of leaf (one side only) to the total surface area. In short, LAI is leaf area per unit area of land.

2.12 GROUND WATER MODELING

NUMERICAL MODELING OF GROUND WATER BY J. BOONSTRA AND N.A RIDDER presents introduction of ground water modeling.

The ground water in a basin is not at rest but is in a state of continuous movement. Its volume is increasing by the downward percolation of rain and surface water, causing the water table to rise. At the same time its volume is decreasing by evapotranspiration, by discharge to springs, and by outflow into streams and other natural drainage channels, causing the water table to fall. When considered over a long period, the average recharge equals the average discharge and a state of hydrological equilibrium exists.

If man interferes in this hydrological equilibrium, he may create undesirable side-effects. The abstraction of groundwater from wells, for example will lower the water table, allow the natural recharge to increase, and cause the natural discharge to decrease. If the abstraction is kept within certain limits, the increase in recharge and decrease in discharge will balance the abstraction and a new hydrological equilibrium will be established. The water table will again be almost stationery, although at a deeper level than before, if this level is too deep, it may affect agriculture and the eco-systems in the area. Excessive abstraction from wells can cause a continuous decline in the water table, which means that the ground water reserves are being depleted. Introduction of irrigation causes the water table to rise.

Solution of the problems of grounds water flow is obtained by combining Darcy's equation and the equation of continuity. The resulting differential equation or set of differential equations describes the hydraulic relations within an aquifer. To solve the equation (s), the aquifer's geometry, hydraulic characteristics and initial and boundary conditions must be known. Only when equations, characteristics and conditions (initial and boundary) are simple then an exact analytical solution is obtained otherwise analytical solution become difficult to obtain. The reason is that these problems are complex, possessing non-linear features that can't be included in analytical solutions. Such non-liner features involve variations in an aquifer's hydraulic conductivity, boundary conditions that change with time and other long-term time-dependent effects. Owing to the difficulties of obtaining analytical solutions to complex groundwater flow problems, there has long been a need for techniques that enable meaningful solutions to be found. Such techniques exist now a days in the form of mathematical or numerical modeling.

Of the great variety of numerical techniques, all of them have in common that an approximate solution is obtained by replacing the basic differential equations that describe the flow system by another set of equations that can be easily solved by a digital computer. The present model uses finite difference technique.

The finite difference method (of approximating the solution of differential equations) replaces the partial differential equations for two-dimensional flow in an aquifer by an equivalent system of finite difference equations which are solved by the computer. Unlike the analytical method, which gives a solution to a continuous boundary-value problem, the finite difference method provides a set of watertable elevations at a finite number of points in the aquifer.

One method to solve the finite-difference equations is gauss-seided which is stable. It is an iterative calculation process that is continued as long as is necessary to obtain watertable elevations that are sufficiently accurate. This method requires little computer memory.

As an alternative to the iteration method, there is Gauss-Jordan elimination method, which is a modification of the Gaussian elimination method. This method requires more computer memory than the iteration method, but the solution is exact within the accuracy of the computer use.

Groundwater basin modeling is, in essence, the art and science of applying various investigatory methods, checking their results against one another and representing the complexity of nature in a simplified form that allows mathematical treatment.

2.13 AQUIFER CHARACTERISTICS

THE ABOVE MENTIONED BOOK OF NUMERICAL MODELLING OF GROUNDWATER BASINS states the practical difficulties in obtaining aquifer data and its solution.

For a large basin extending over hundreds or even thousands of square kilometers), it is not possible to conduct aquifer tests in unlimited numbers because the costs would be prohibitive. Less costly methods, approximating the aquifer characteristics, are then a valuable addition. It is also important to mention that even that aquifer tests do not yield precise values due to heterogeneity of the aquifer material and limited number of observation wells.

2.14 AQUIFER BOUNDARIES

THE ABOVE MENTIONED BOOK OF NUMERICAL MODELING OF GROUNDWATER BASINS also expresses the types of aquifer boundaries.

The conditions at the boundaries of the aquifer must be properly defined. Different types of boundaries exist, which ,may or may not be a function of time. They are

1. Zero-flow (no flow) boundaries.
2. Head- controlled boundaries and
3. Flow-controlled boundaries.

2.14.1 Zero-Flow Boundary

A zero-flow boundary is a boundary through which no flow occurs. Examples are (i) thick tight compacted clay layers, unweathered massive rock, a fault that isolates the aquifer from other permeable strata, or a groundwater divide, mountain etc.

2.14.2 Head-Controlled Boundary

A head-controlled boundary is a boundary with a known hydraulic head which may or may not be a function of time. Examples are large water bodies like lakes and oceans whose water levels are not affected by the events within the groudwater basin. Irrigation canals with fixed water levels is other example. River and stream is a boundary whose head is a function of space and time. Its water level is high in rainy season and low in dry season.

2.14.3 Flow-Controlled Boundary

It is also called a recharge boundary. Certain volume of groundwater enters the aquifer per unit of time from adjacent strata whose hydraulic head and/or transmissivity are not known. Example is the sharp contact with another geological formation of low transmissivity. Such a contact may be a fault.

LITERATURE OF TRAINING COURSE OF SOFTWARE FOR GROUND WATER DATA MANAGEMENT by N.I.H. ROORKEE- 247667 (INDIA) also points out three types of boundary as non zero i.e. no flow boundary, zero flux i.e. flow boundary and semipervious i.e. flow-controlled boundary.

2.15 OPTIMIZATION

OPERATION RESEARCH - AN INTRODUCTION BY H.A TAHA, MCMILLAN PUBLISHING COMPANY, NEW YORK, 1992, presents Linear Programming Techniques.

An OR (Operation Research) model is defined as an idealized (simplified) representation of a real life system.

2.15.1 Structure Of Mathematical Models

1. Decision Variable: They are unknown parameters to be determined from the solution of the model.
2. Constraints: it limit the decision variables to their feasible values.
3. Objective function: This defines the measure of effectiveness of the system as a mathematical function of its decision variables.

2.15.2 Phases of OR Study

Following are phases of the OR study

1. Definition of the problem
2. Construction of the model
3. Solution of the model
4. Validation of the model and
5. Implementation of the final result.

2.15.3 Linear Programming (LP)

Linear programming is a class of mathematical programming models concerned with the efficient allocation of limited resources to known activities with the objective of meeting a desired goal (such as maximizing profit or minimizing cost). The distinct characteristic of linear programming models is that the functions representing the objective and constraints are linear.

The real-life problem shows that a linear program may be of the maximization or minimization type. The constraints may be of the type (≤), (=), or (≥) and the variables may be nonnegative or unrestricted in sign. A general linear programming model is usually defined as follows:

Maximize/minimize $x_0 = c_1x_1+c_2x_2+....c_nx_n$

Subject to $a_{11}x_1+a_{12}x_2+...+a_nx_n(\leq \text{ or } = \text{ or } \geq)b_1$

$a_{21}x_1+a_{22}x_2 +...+a_{2n}x_n (\leq \text{or} = \text{or} \geq)b_2$

....

....

$a_{m1}x_1+a_{m2}x_2+.......+a_{mn}x_n (\leq \text{ or } = \text{ or } \geq) b_m$.

where c_j,b_i and a_{ij} $\begin{pmatrix} i = 1,2...m \\ j = 1,2...n \end{pmatrix}$

are constraints and x_j are the decision variables.

PHYSICAL FEATURES OF COMMAND AREA

3.1 GENERAL

The Upper Ganga Canal (UGC) irrigation system is located in the Ganga Yamuna Doab and Command Area of Right Main Distributary (study area) is located between Right Main Distributary and Kali river. The coordinates of the area is as below :

Latitude : 29° 30′ N to 29° 50′ N

Longitude : 77° 40′ E to 77° 50′ E.

The altitude of the area is about 260 m. The location of study area has been shown in Fig. 1.3. The location of UGC and index map of study area are shown in Fig.1 and 2 respectively in Appendix 1.

3.2 RIGHT MAIN DISTRIBUTARY

The Right Main Distributary (RMD) takes off from Deoband Branch at 7.26 km. The Deoband branch itself takes-off from UGC at 35 km. The location plan has been shown in Fig. 1.3 and 2.1. The details of this distributary has been shown in Table 2.1. The command area has slope of 1 in 3000. The soil is deep alluvial sandy to clay loam deposited by the Ganges river. The soil characteristics has been shown in Table 2.6.The salient features of UGC, Deoband Branch, RMD and command area is shown in Table 3.1, 3.2, 3.3 and 3.4 respectively.

Table 3.1 : Salient Features of Upper Ganga Canal

Sl. No.	Particulars	Features
1.	Formulation of the project and preliminary arrangements	1838-1842
2.	Main construction period	1842-54
3.	Initial GCA	0.607 Mha
4.	Present GCA	1.95 Mha
5.	Present CCA	0.925 Mha
6.	Initial head discharge	189 cumecs (6750 cusecs)
7.	Present head discharge	297 cumecs (10,500 cusecs)
8.	Initial capital investment	Rs. 140 lacs
9.	Initial length of the canal and branches in the system	1400 km (878 miles)
10.	Total length of channels in present system	6540 km (unlined)
11.	Important major structures	Solani aquaduct and three other major cross drainage works.
12.	Design concepts of system : (Maximum insurance against drought to maximum area and the largest number of users)	Protective rabi irrigation
13.	Design concept for major works	Massive structures with simple and bold designs mainly brick arches in lime-Surkhi mortar.
14.	Other important features	First major and large canal system of the country as well as a remarkable major irrigation system in whole of the world in mid of nineteenth century.

Source : Technical Report (January, 1998).

Table 3.2 : Salient Features of Deoband Branch

Sl. No.	Particulars	Features
1.	Off-take point	35 km from right bank of UGC
2.	Discharge (Q)	24.78 cumecs (875 cusecs)
3.	Length (L)	82.40 km
4.	C.A.	54,985 Ha.
5.	Lining	Nil
6.	Bed width (B)	9.143 m
7.	F.S.D.	1.524 m

Source : Diagnostic Analysis Report (1987).

Table 3.3 : Salient Features of Right Main Disty

Sl. No.	Particulars	Features
1.	Latitutde	29° 30′ to 29° 50′ N
2.	Longitude	77° 40′ to 77° 50′ E
3.	Off-take point	7.26 km from left bank of Deoband branch
4.	Discharge (Q)	2.69 cumecs (95 cusecs) designed (3.40 cumes actual)
5.	Length (L)	17.60km
6.	CCA	5890 ha
7.	'n' (rugosity coefficient)	0.02 to 0.029 (avg. 0.026)
8.	Longitudinal slope (S)	1 in 3000 (average)
9.	Silt factor (F)	0.96
10.	Mean velocity (V)	0.62 m/s

Source: Diagnostic Analysis Report (1987).

Table 3.4 : Salient Features of Study Area

Sl. No.	Particulars	Value
1.	Location	Latitude 29°30′ N to 29°50′ N Longitude 77°40′ E to 77°50′ E
2.	Block	Gurukul Narsan, Deoband and Purkazi
3.	District	Haridwar, Saharanpur and Muzaffar Nagar
4.	Average altitude	260.0 m
5.	CCA	5890 ha
6.	Topography of CA	Gentle slope : 1 in 3000
7.	Existing CI	144%
8.	Average rainfall in CA	107.5 cm
9.	Average ETo (Evapotranspiration)	179.0 cm
10.	Agro-climatic zone	Slightly dry
11.	Crop water requirement (CWR)	7460.0 ham
12.	Surface water available	4670.0 ham
13.	Water deficit	3370.0 ham
14.	Soil type	Sandy loam to clay loam
15.	Aquifer type	Unconfined
16.	W.T. position	1.4 to 2.3 m.
17.	Specific yield	Av. 16%
18.	Storage coefficient	Av.1.50 x 10^{-3}
19.	Transmissivity	Av.843m^2/day
20.	Seepage loss	2.4 cumecs/million m^2 of wetted perimeter in RMD
21.	Infiltration rate	21 mm/hr
22.	Irrigation method	Furrow, border and basin
23.	Present net profit	Rs. 11,812.00 per ha.

Source : (1) Diagnostic Analysis Report (1987)

(2) Ground Water Investigation Division, Roorkee.

AGROCLIMATOLOGY, CROPPING SYSTEM AND CROP WATER REQUIREMENT

4.1 AGROCLIMATOLOGY

The study of climate with reference to cultivation of crops is called AGROCLIMATOLOGY.

There is a definite relationship between the crop plants and their environment. Each crop has its own set of environmental condition under which it grows most effectively. Knowledge of a weather pattern of an area is helpful in interpreting the crop harvests. We know the fact that each crop plant has its own definite optimal requirements of light, temperature (of soil and air) and atmospheric and soil moisture. Without these desired limits of weather elements, plant cannot proceed at an economically desirable rate to flowering and seed formation.

The day-today occurrences of atmosphere are called weather. Its elements are temperature, humidity, sunshine, rainfall, wind, evaporation etc.

4.1.1 Climatological Data of Command Area

From the observation of climatological data it is clear that maximum temperature is 39.4°C in the month of May and minimum temperature is 6.6°C in the month of January. Mean value of humidity ranges from 79% in the month of August to 35% in the month of May. Wind velocity ranges from 121 km/day to 52 km/day. Actual sunshine hour is maximum in the month of May i.e. 10.80 hours and minimum in the month of August i.e. 6.10 hours (due to cloud cover). Similarly value of rainfall is 354.90 mm in the month of August. Rainfall in monsoon period (June to September) is 837.80 mm out of 1075 mm. It means 77.9% i.e. say 78% rainfall occurs in the monsoon period only. Annual mean rainfall is 1075 mm. The details of data has been shown in Table 11 in Appendix –4.

The weather parameters has been observed by Meteorological Department at Station Roorkee and it is averageof 30 years value.

But rainfall data has been taken from Groundwater Investigation Division, Roorkee, Groundwater Department, U.P. (India). Data of four station of C.A. has been taken and arithemtic mean has been calculated. The details of rainfall is shown in Table 1 to 5 and Fig. 3 in Appendix – 2.

4.1.2 Effective Rainfall

It is that part of rainfall which is easily utilized by the crops to meet its evapotranspiration demand. It has been calculated cropwise and monthwise and has been found 647.00 mm annual out of annual average rainfall of 1075 mm. The details has been shown in Appendix – 4 in Table 14 to 20 and value of average rainfall and effective rainfall is shown in Table 4.1 here.

Table 4.1 : Rainfall and Effective Rainfall

Sl. No.	Name of months	Average rainfall (mm)	Effective rainfall (mm)	Remarks
1.	January	24.60	-	1. Effective rainfall has been calculated from FAO Table 3.8. for Sugarcane crop. 2. In June, 100% of rainfall is effective. The reason is that c_u (consumptive use) is high (291mm). So all rainfall becomes effective as per FAO Table 3.8. 3. Similarly, in July at 289mm rainfall, effective rainfall is 215.60 mm while in August rainfall is 354.90 i.e. higher than July but effective rainfall is only 158.1 mm i.e. less than July. The reason is that consumptive use in August is less than July (230.95mm).
2.	February	37.50	25	
3.	March	29.85	23	
4.	April	28.50	22	
5.	May	19.65	-	
6.	June	67.0	67.0	
7.	July	289.90	215.60	
8.	August	354.90	158.1	
9.	September	126.0	86.1	
10.	October	69.80	50.26	
11.	November	6.60	-	
12.	December	19.40	-	
	Total	1073.70 say 1075.00	647.06 say 647.00	

4.1.3 Comparative Study of Rainfall from Isohyetal Map of India

Isohyetal map is that map which shows lines of equal rainfall. From Isohyetal map of India, it is clear that command area (latitude 29° 45′ N and longitude 77° 30′ N) receives annual rainfall about 1000 mm. Actual observation is 1075 mm which is consistent with the isohyetal value.

4.1.4 Agroclimatic Zone

The Planning Commission, Government of India, after examining the earlier studies at the regionalization of the agricultural economy has recommended that agricultural planning be done on the basis of agroclimatic regions. For resource development, the country has been divided into fifteen agricultural regions based on agroclimatic features, particularly soil type, climate including temperature and rainfall and its variation and water resources availability. The study area comes under agro-climatic zones V, i.e. Upper Gangetic Region.

4.1.5 Evapotranspiration

Maximum value of evapotranspiration 281.48 mm (9.08 mm/day) cames in the month of May and minimum value 60.14 mm (1.94 mm/day) comes in January. The annual evapotranspiration value comes 1790 mm. The details of evapotranspiration has been shown in Table 12 in Appendix –4.

4.1.6 Agroclimatic Classification

According to ICAR classification, the study area comes under slightly dry zone. The details of classification has been shown in Table 6, 7 and 8 in Apendix-2.

4.1.7 Agroclimatic Requirement for Crops

It has already been mentioned earlier that crops require a set of environment features. These features have been described in section 2.9.

4.2 CROPPING SYSTEM

Patterns of world crop have developed which are based on natural principles of biological evolution and ecology. But it may be influenced greatly by man's ambition and ingenuity.

The modern cropping pattern is the result of both evolution and ambition of the people. Here ecology means crop ecology. Crop ecology is the study of relationship between crop plants and their environment.

The success of an irrigation system depends largely upon the cropping system which includes the cropping pattern and cultural practices adopted by the farmers in the command area. Soil, land, climate and irrigation are major constraints of a particular cropping pattern. Our objective is to maximize the crop production with efficient management of soil, climate, water, and fertilizer.

Elements of cultural practices are: field preparation, selection of seed variety, fertilizer application, irrigation, plants protection measure, harvesting, thrashing, grain storage etc.

4.2.1 Crop Plan

Crop plan of study area is shown below

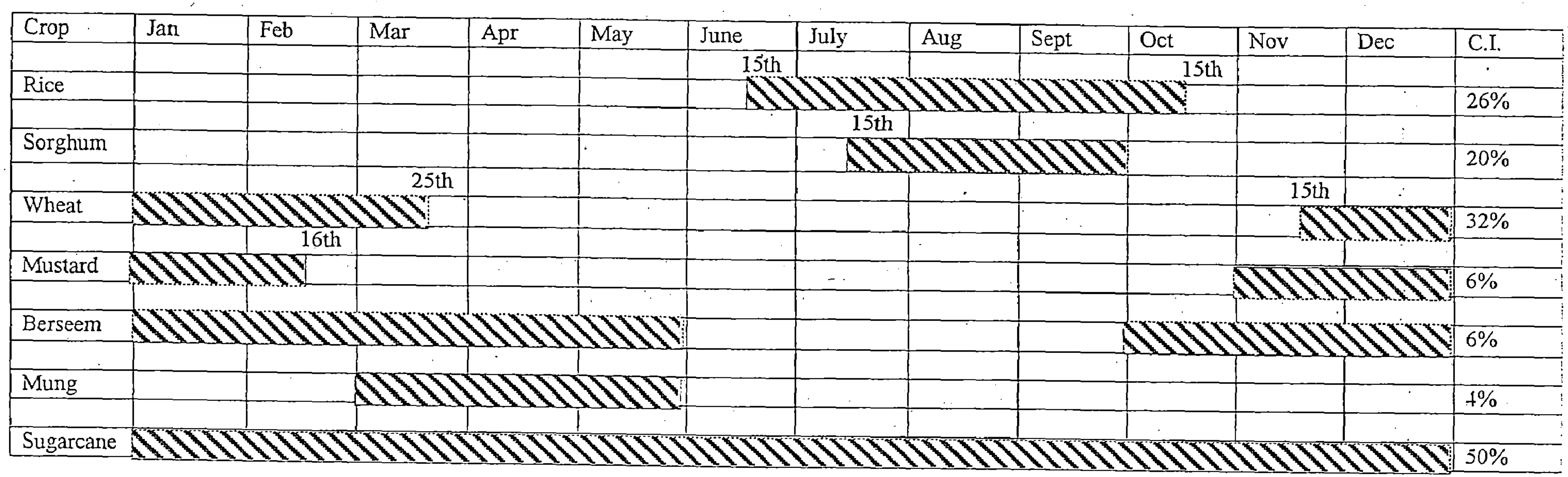
Table 4.2 Crop Plan

Sl.No.	Name of crop	Biological name.
1.	Rice	Oryza sativa
2.	Sorghum (Bajra)	Sorghum vulgare
3.	Wheat	Triticum aestivum
4.	Mustard (oilseed)	Brassice spp.
5.	Berseem	Trifolium alexandrinum
6.	Mung (pulse)	Phaseolus aureus
7.	Sugarcane	Saccharum officinarum

4.2.2 Crop Calendar

A crop calendar showing date of sowing and harvesting has been prepared cropwise and monthwise which is shown in Fig 4.1.

Fig. 4.1 CROP CALENDAR (EXISTING)



4.2.3 Existing Cropping Pattern

Rice, Sorghum, Wheat, Mustard, Berseem, Mung and Sugarcane are the crops which are mainly practiced by the farmers in the command area. Sugarcane is the predominant crop in the C.A. Taking single weightage of Sugarcane, C.I. is 144%.

Cropping Intensity (C.I.). It is the ratio of cropping area to total area. It is expressed in percentage.

$$\text{C.I.} = \frac{\text{Cropping Area}}{\text{Total Area}} \times 100$$

Weighted Cropping Intensity:

It is also expressed in percentage. It is the ratio of weighted cropping area to total area.

$$\text{Weighted Cropping Intensity} = \frac{\text{Weighted Cropping Area}}{\text{Total Area}} \times 100$$

Sugarcane is an annual crop, so it takes time of 3 crops. But generally its weightage is taken as 2.

The existing cropping pattern in the study area is shown below in Table 4.3

Table 4.3 : Existing Cropping Pattern

S.N.	Name of crop	Cropping intensity (%)
1.	Rice	26
2.	Sorghum (kharif fodder)	20
3.	Wheat	32
4.	Mustard (oilseed)	6
5.	Berseem (Rabi fodder)	6
6.	Mung (green gram-pulse)	4
7.	Sugarcane	50
	Total	144

The season of crop and growing period, growing days etc are shown in Table 13 of Appendix 4.

4.2.4 Cropping Pattern

It is distribution of crops on land surface.

Factors of Cropping Patterns:

The governing factors on which cropping pattern develops are climate, geography and economic and social condition of the people. For knowing cropping pattern, bioclimatics is required. Bioclimatics is the body of knowledge dealing with the effects of climatic factors including geography and elevation, upon plant response.

There is change in flowering time of the same species of plants with the change of latitude, longitude and altitude.

1. For each degree of latitude N or S of the equator, the flowering is retarded by 4 calendar days.
2. For each 5^0 of longitude E or W on land areas flowering is advanced by 4 calendar days.
3. For each 122 m (400 feet) increase in altitude, flowering is retarded by 4 calendar days.

Similarly, temperature (minimum and maximum) affects the cropping pattern. There is threshold temperature (minimum temperature below which growth of plant practically ceases) for every crop.

Von't Hoff states that there is a linear relationship between the logarithm of the yield and the mean temperature during the growing period of a crop.

4.2.5 Physico-Chemical Properties of Soil

Soil is one of the major inputs of agriculture. Its physical properties like-texture, soil moisture content, bulk density, etc and chemical properties as pH value, salt content etc have been dealt in section 2.5.11in Table 2.6.

4.2.6 Soil Irrigability Classification

During January 22-24, 1969, a workshop on Soil and Land Irrigability Classes was held in Delhi under the auspices of the Ministry of Food, Agriculture, Community Development and Co-operation and in collaboration with the Central Water and Power Commission of the Ministry of Irrigation and Power. At this workshop the soil properties and criteria for grouping of soils into soil irrigability classes were discussed. On the basis of present knowledge of behaviour of soil to water application, the system of technical grouping of soils into soil irrigability classes was decided upon and was presented in Table 2.1. Similarly Land Irrigability Classes was decided and was presented in Table 2.2.

Table 2.1 and 2.2 is presented here as Table 9 and 10 respectively in Appendix 3.

Definitions of the five soil irrigability classes are as follows:

Class A - None to slight soil limitations for sustained use under irrigation

Class B - Moderate soil limitations for sustained use under irrigation

Class C - Severe soil limitations for sustained use under irrigation

Class D - Very severe soil limitations for sustained use under irrigation

Class E - Not suitable for irrigation (or non-irrigable soil class).

4.2.7 Soil Irrigability Class

Soil irrigability class of the study area is studied under Table 4.4 as below based on Table 9, Appendix -3 .

Table 4.4: Soil Irrigability Classification

S.N.	Soil Properties	Value	Soil Irrigability Class (as per Table 9)	Index Value	Remarks
1.	Effective Soil Depth	>90 cm	A	4	Here, A = 4, B = 3, C = 2, D = 1, E = nil
2.	Texture of soil surface	Sandy loam to clay loam	A	4	
3.	Water holding capacity	19.4 to 27.4cm i.e. >12 cm	A	4	
4.	Ece (salinity)	0.09 to 1.9 i.e. <4 mmhos	A	4	
5.	PH	7.2 to 7.6 < 8.5	A	4	
6.	Slope	<1%	A	4	
7.	Soil erosion status	Nil	A	4	
			Total =	28	

Soil properties has been shown in Table 2.6 and effective soil depth has been taken as > 90 cm.

Rating = 28 / 7 = 4

Soil class is A i.e. soil has none to slight limitations for sustained use.

[Here > 3.5 = A, < 3.5 =B]

4.2.8 Land Irrigability Class

The slope of study area is 1in 3000 i.e. 1/3000 = 0.00033 < 1%. So land irrigability class is A (Please refer to Table 10, Appendix 3).

4.2.9 Soil Drainability Class

Depth of water Table is 1.4 m to 2.3 m (please refer Fig. 6.6). Its range is 1.5 to 3.0 m, so drainage of area is not very good. It is C class drainability
(Table 10 of Appendix 3).

4.3 CROP WATER REQUIREMENT

Water is the prime input in crop production. Besides its own importance in crop growth, it ensures the efficiency of other inputs like seeds, fertilizer and pesticides. There are several methods for determination of Crop Water Requirement but Modified Penman Method, though complex, has been suggested by FAO-24 as it gives more precise value of evapotranspiration. It is a climatolgoical method and takes into account all the weather parameters. The other methods are: Radiation method, Pan-evaporation method, Blaney-Criddle method etc.

4.3.1 Modified Penman Method

In this method, climatic factors as sunshine hour, temperature, humidity, and wind speed are taken into account.

$$ETo = c\,[W.Rn + (1-W).f(U).(ea-ed)] \quad (4.1)$$

Where ETo = Reference Evapotranspiration (mm/day).

PART A: (1-W). f(U). (ea - ed) is called aerodynamic term.

PART B: W.Rn is called radiation term.

PART C: c is called adjustment factor.

Where;

ea = saturated vapour pressure at mean temperature in mbar. Its value is read from FAO, Table - 9.

ed = actual vapour pressure

$$= ea.\, R_H\, mean / 100 \quad (4.2)$$

ea-ed = vapour pressure deficit

f(U) = wind function = 0.27 (1+U/100)

where, U is wind velocity in km/day measured at 2m height.

Rn = total net radiation in mm/day

$$= 0.75\, Rs - Rnl \quad (4.3)$$

where Rs is incoming short wave radiation in mm/day.

$$Rs = (0.25 + 0.50\, n/N)\, Ra \quad (4.4)$$

Where Ra is extra-terrestrial radiation in mm/day (Table 10) n is the mean actual sunshine duration in hour per day and N is maximum possible sunshine duration in hour/day (Table –11).

Rnl = net long wave radiation in mm/day and is a function of temperature f (T) of actual vapour pressure f(ed) and sunshine duration f(n/N)

$$= f(T).\ f(n/N).\ f(ed) \quad (4.5)$$

(Table 12,13,14 respectively)

W = temperature and altitude dependent weights factor (Table 15).

C = adjustment factor for ratio U day/ U night, for Rhmax and for Rs. (Table 16)

Also $f(T) = \sigma(TK)^4$ where (4.6)

σ = 2.00×10^{-9} for practical purposes

TK = temperature in Kelvin

$$f(ed) = 0.34 - 0.044\sqrt{ed} \quad (4.7)$$

$$f(n/N) = 0.10 + 0.9\ n/N \quad (4.8)$$

4.3.1 Crop Evapotranspiration (ETc)

$$ET_C = K_C \times ET_O \quad (4.9)$$

Where ET_C = crop evapotranspiration

K_C = crop coefficient.

4.3.2 Net Irrigation Requirement (NIR)

$$NIR = ET_C + \text{special needs (if any)} - \text{effective rainfall} \quad (4.10)$$

For calculation of effective rainfall, Table 34 of FAO-24 has been used.

For paddy following formula has been used for effective rainfall

$$P_e = 0.8\ P - 25 \text{ if } P > 75 \text{ mm/month} \quad (4.11)$$

$$P_e = 0.6\ P - 10 \text{ if } P < 75 \text{ mm/month} \quad (4.12)$$

Where P_e = effective rainfall and

P = precipitation

4.3.3 FIELD IRRIGATION REQUIREMENT (FIR)

$$FIR = \frac{N.I.R.}{\text{Field Application Efficiency (FAE)}} \quad (4.13)$$

4.3.5 Gross Irrigation Requirement (G.I.R.)

$$GIR = \frac{\text{F.I.R.}}{\text{Conveyance Efficiency (CE)}} \tag{4.14}$$

FAE and CE has been adopted as 80% here.

4.3.6 Value of ETo And CWR

Annual value of ET_O comes 1790 mm (Table 12, Appendix-4) and CWR comes 7460 ham (Table : 21).

WATER BUDGET

5.1 GENERAL

Here water budget means budget of canal water supply and crop water requirement. Right Main Distributary (RMD) runs on the roster basis in both kharif and rabi season. There is 2:4 roster in kharif and 1:4 in rabi season. The proposed running days of RMD in a year is 118 days and actual running days is 159 days. The proposed running days of RMD is shown in Table 5.1 and actual running days is presented in Table 5.2 below. The design discharge of channel is 2.69 cumecs while actual discharge is 3.40 cumecs. Due to stressed running of channel, section increases and hence discharge also increases. Here, availability of water is estimated on the actual running days of channel and on actual discharge basis.

Thesis of Yadav, (2000) also states actual running days of RMD as 159 days in a year while D.A. Report of RMD (1987) express proposed running days as 179 days and actual running days as 208 days, on the basis of operation of RMD for 1986-87. Here it is important to state that operation schedule of channel varies year to year. For study purposes 159 days of channel running in a year for availability of surface water is being considered.

5.2 DEFICIT OF WATER

The total availability of canal water is 4670.79 ham, say 4670 ham. (Row 4, column 15 of table 5.3) and net delivery = 4670 - 579 = 4091 ham (equation 5.1 and 5.2). Total CWR in a year is 7483.20 ham, say 7480 ham (please refer to row 1, column 15 of Table 5.3). Total Water deficit in a year is 3370.0 ham. (row 5, column 15 of Table 5.3).

Table 5.1: Proposed Running Days of Channel

S.N.	Month	Running Days
1.	January	6
2.	February	7
3.	March	6
4.	April	14
5.	May	12
6.	June	16
7.	July	14
8.	August	14
9.	September	14
10.	October	7
11.	November	7
12.	December	1
	Total	118 days

Soruce: Muzaffarnagar Divn., Ganga Canal, Muzaffarnagar

Table - 5.2: Actual Running Days of Channel

S.N.	Month	Running Days
1.	January	7
2.	February	7
3.	March	7
4.	April	13
5.	May	16
6.	June	14
7.	July	21
8.	August	21
9.	September	20
10.	October	17
11.	November	7
12.	December	9
	Total	**159 days**

Source: Muzaffarnagar Division, Ganga Canal, Muzaffarnagar

Table 5.3: Deficit of water in Right Main Distributory Command Area in ham

CCA = 5890 ha.

S.N	Particular	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Total GIR (ham)	394.43	217.14	544.50	884.63	1403.23	1416.97	669.30	172.24	677.11	365	380.09	333.78	7458.50 $\simeq$ 7460.0
2	Running days of canal	7	7	7	13	16	14	21	21	20	17	7	9	159
3	Discharge of canal (cumees)	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	3.40	
4	Delivery of canal (ham)	205.632	205.632	205.632	381.888	470.016	411.264	616.896	616.896	587.52	499.392	205.632	264.384	4670.784 $\simeq$ 4670.0
5	Deficit of water (ha.m) (1-4)	188.798	12.00	338.868	502.742	933.214	1005.706	52.404	-	89.59	-	174.418	69.396	3367.176 $\simeq$ 3370.0

Note: - There is surplus of canal delivery in the month of August and October. Surplus water is not taken into account.

1. Delivery = 4670 ham., Surplus supply = 579.048 ham (Aug. 444.656 + Oct. 134.392), Say 579 ham. (5.1)

2. Net Delivery = 4670 – 579 = 4091 ham. (5.2)

3. Deficit of Water = 7460 – 4091 = 3369 ham, say 3370 ham. (5.3)

GROUND WATER MODELLING

6.1 GENERAL

The governing differential equation for two-dimensional ground water flow in an isotropic unconfined aquifer can be written as (Freeze and Cherry, 1979).

$$\frac{\partial}{\partial x}\left[kh\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[kh\frac{\partial h}{\partial y}\right]=s_y\frac{\partial h}{\partial t}-Q_R+Q_P \qquad (6.1)$$

where, h = hydraulic head; S_y= specific yield; K = saturated hydraulic conductivity; Q_R = recharge to the ground water; and Q_p = ground water withdrawal rate per unit area. The above nonlinear parabolic partial differential equation can be linearised and solved using a finite-difference (Implicit) scheme and matrix inversion.

The finite difference form of the linearised Boussinesq's equation can be derived thorough mass balance and application of Darcy's law as given below:

The harmonic mean of transmissivity values at interfaces 2,3,4,5 of node i,j (Fig 6.1) are respectively given by

$$T_{hm2}(i,j)=\frac{\Delta x_j+\Delta x_{j+1}}{\dfrac{\Delta x_j}{T(i,j)}+\dfrac{\Delta x_{j+1}}{T(i,j+1)}}\ ;\ T_{hm3}(i,j)=\frac{\Delta y_i+\Delta y_{i+1}}{\dfrac{\Delta y_i}{T(i,j)}+\dfrac{\Delta y_{i+1}}{T(i+1,j)}}$$

$$T_{hm4}(i,j)=\frac{\Delta x_j+\Delta x_{j-1}}{\dfrac{\Delta x_j}{T(i,j)}+\dfrac{\Delta x_{j-1}}{T(i,j-1)}}\ ;T_{hm5}(i,j)=\frac{\Delta y_i+\Delta y_{i-1}}{\dfrac{\Delta y_i}{T(i,j)}+\dfrac{\Delta y_{i-1}}{T(i-1,j)}}$$

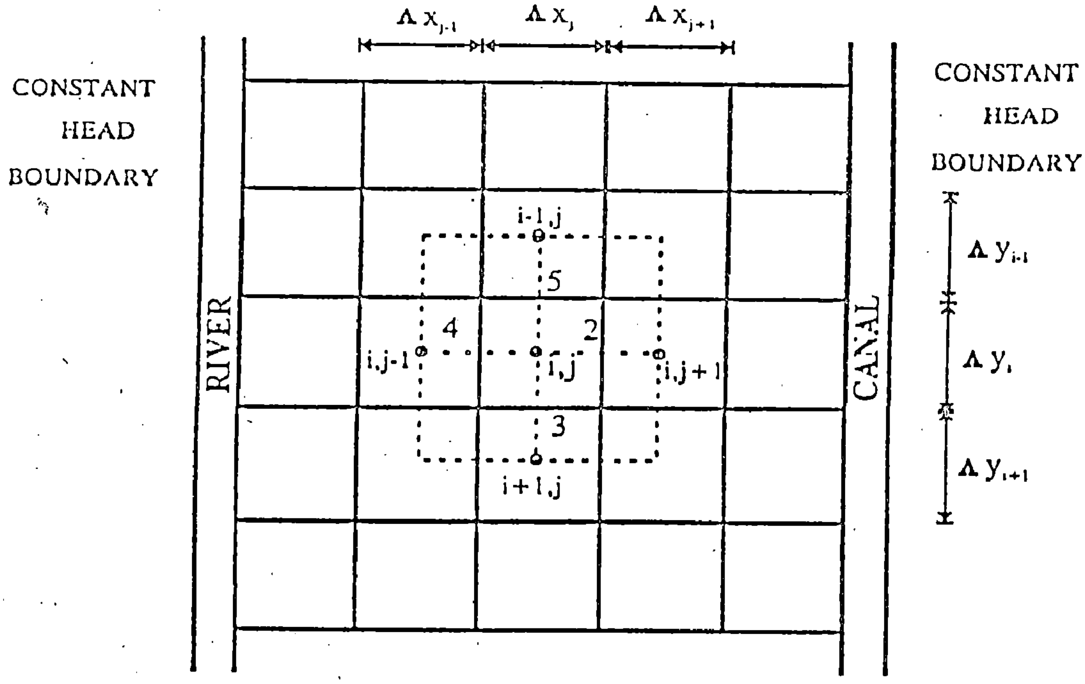


Fig 6.1 Dis cretisation of the flow donmain

6.1.1 Mass Balance Equation

Applying mass balance equation for the control volume containing node i,j for a time period of Δt during k^{th} time step i.e. inflow –outflow = change in storage we get

$$w\left[\begin{array}{l} T_{hm2}(i,j)\left\{\dfrac{h^k(i,j+1)-h^k(i,j)}{\dfrac{\Delta x_{j+1}+\Delta x_j}{2}}\right\}\Delta y_i + T_{hm3}(i,j)\left\{\dfrac{h^k(i+1,j)-h^k(i,j)}{\dfrac{\Delta y_i+\Delta y_{i+1}}{2}}\right\}\Delta x_j \\ + T_{hm4}(i,j)\left\{\dfrac{h^k(i,j-1)-h^k(i,j)}{\dfrac{\Delta x_j+\Delta x_{j-1}}{2}}\right\}\Delta y_i + T_{hm5}(i,j)\left\{\dfrac{h^k(i-1,j)-h^k(i,j)}{\dfrac{\Delta y_{i-1}+\Delta y_i}{2}}\right\}\Delta x_j \end{array}\right]\Delta t$$

$$+(1-w)\left[\begin{array}{l} T_{hm2}(i,j)\left\{\dfrac{h^{k-1}(i,j+1)-h^{k-1}(i,j)}{\dfrac{\Delta x_{j+1}+\Delta x_j}{2}}\right\}\Delta y_i + T_{hm3}(i,j)\left\{\dfrac{h^{k-1}(i+1,j)-h^{k-1}(i,j)}{\dfrac{\Delta y_i+\Delta y_{i+1}}{2}}\right\}\Delta x_j \\ + T_{hm4}(i,j)\left\{\dfrac{h^{k-1}(i,j-1)-h^{k-1}(i,j)}{\dfrac{\Delta x_j+\Delta x_{j-1}}{2}}\right\}\Delta y_i + T_{hm5}(i,j)\left\{\dfrac{h^{k-1}(i-1,j)-h^{k-1}(i,j)}{\dfrac{\Delta y_{i-1}+\Delta y_i}{2}}\right\}\Delta x_j \end{array}\right]\Delta t$$

$$-Q_p^k(i,j)\,\Delta t.\,\Delta x(j)\,\Delta y(i) + Q_R^k(i,j)\,\Delta t.\,\Delta x(j)\,\Delta y(i)$$
$$= S(i,j)\,\Delta x_j\,\Delta y_i\,\{h^k(i,j) - h^{k-1}(i,j)\} \qquad (6.2)$$

Dividing term on either sides by $\Delta x_j\,\Delta y_i\,\Delta t$ and simplifying above Eq. (6.2), it reduces to

$$F_1(i,j)h^k(i,j)+F_2(i,j)h^k(i,j+1)+F_3(i,j)h^k(i+1,j)+F_4(i,j)h^k(i,j-1)+F_5(i,j)h^k(i-1,j)=F_6^k(i,j) \qquad (6.3)$$

In which $F_2(i,j)$, $F_3(i,j)$ etc. are given by:

$$F_2(i,j)=\frac{wT_{hm2}(i,j)}{\left(\frac{\Delta x_j+\Delta x_{j+1}}{2}\right)\Delta xj};\ F_3(i,j)=\frac{wT_{hm3}(i,j)}{\left(\frac{\Delta y_i+\Delta y_{i+1}}{2}\right)\Delta y_i}$$

$$F_4(i,j)=\frac{wT_{hm4}(i,j)}{\left(\frac{\Delta x_{j-1}+\Delta x_j}{2}\right)\Delta x_j};\ F_5(i,j)=\frac{wT_{hm5}(i,j)}{\left(\frac{\Delta y_{i-1}+\Delta y_i}{2}\right)\Delta y_i}$$

$$F_1(i,j)=\frac{-S(i,j)}{\Delta t}-\{F_2(i,j)+F_3(i,j)+F_4(i,j)+F_5(i,j)\}$$

$$F_6^K(i,j) = -S(i,j)h^{K-1}(i,j)/\Delta t + Q_p^K(i,j)/\Delta x_j.\Delta y_i - Q_R^K(i,j)/\Delta x_j.\Delta y_i$$
$$-\left[\frac{(1-w)}{w}\left[F_2(i,j)h^{k-1}(i,j+1)+F_3(i,j)h^{k-1}(i+1,j)+F_4(i,j)h^{k-1}(i,j-1)+F_5(i,j)h^{k-1}(i-1,j)\right]+\right.$$
$$\left.\frac{(1-w)}{w}\{F_2(i,j)+F_3(i,j)+F_4(i,j)+F_5(i,j)\}h^{k-1}(i,j)\right]$$

An equation can be written for each interior node. For nodes adjacent to river boundary, mass balance equation can be written considering the influent or effluent seepage which is governed by the boundary head, unknown head at the node under consideration, distance of the node from the boundary, hydraulic conductivity and river cross section. The influent seepage is given by

$$Q_R^k(i)=\Gamma_r(i)\left[h_{r(i)}^k - h^k(i,j)\right] \qquad (6.4)$$

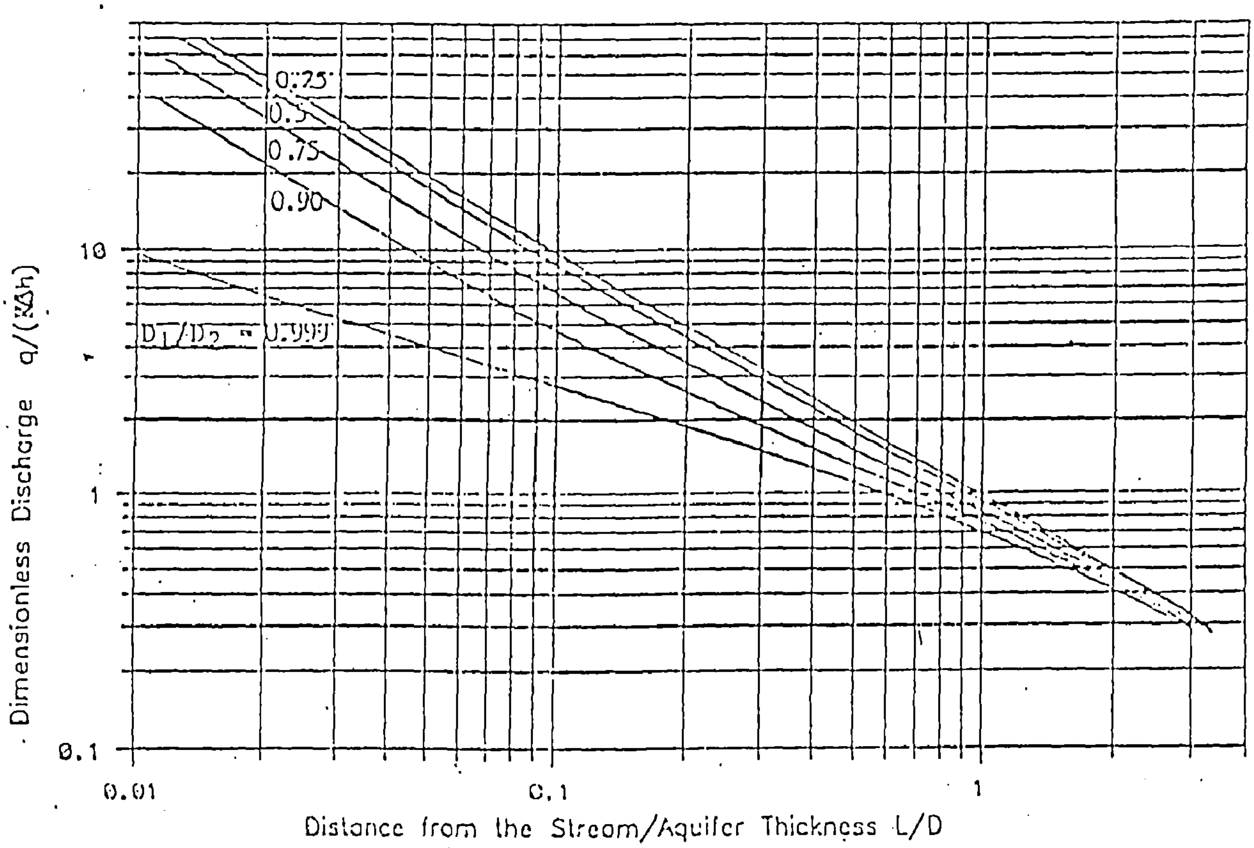


Fig. 6.2 **Variation of $Q_r/K\Delta h)$ with distance from the river bank for different penetration of the river.**

in which $h^k_r(i)$ = head at the river during time k^{th} time step. $\Gamma_r(i)$= reach transmissivity or the constant of proportionality between seepage and potential difference $[h_r^k(i)-h^k(i, j]$.

For a node adjacent to a river which forms the boundary on the left side, Eq. (6.3). reduces to

$$F_1(i, j)\, h^k(i, j) + F_2(i, j)h^k(i, j+1) + F_3(i, j)\, h^k(i+1, j) + F_5(i, j)\, h^k(i-1, j) = F_6^k(i, j)$$

Coefficient $F_1(i, j)$ and $F_6(i, j)$ are given by:

$$F_1(i,j) = \frac{-S(i,j)}{\Delta t} - \left\{F_2(i,j) + F_3(i,j) + w\frac{\Gamma_r(i)}{\Delta x_j} + F_5(i,j)\right\}$$

$$F_6^k(i,j) = -\frac{S(i,j)h^{k-1}(i,j)}{\Delta t} + \frac{Q_P^k(i,j)}{\Delta x_j \Delta y_i} - \frac{Q_R^k(i,j)}{\Delta x_j \Delta y_i}$$

$$+\frac{(1-w)}{w}[F_2(i,j) + F_3(i,j) + F_5(i,j)]h^{k-1}(i,j)$$

$$-\frac{(1-w)}{w}[F_2(i,j)h^{k-1}(i,j+1) + F_3(i,j)h^{k-1}(i+1,j) + F_5(i,j)h^{k-1}(i-1,j)]$$

$$\frac{-w\Gamma_r(i)k}{\Delta x_j}h_r^k(i) - (1-w)\frac{\Gamma_r(i)k}{\Delta x_j}\left[h_r^{k-1}(i) - h^{k-1}(i,j)\right]$$

Applying the observed initial and the prevailing boundary conditions, for known withdrawal and experimentally computed distributed percolation losses and rainfall recharge, the unknown heads at the grid points can be solved.

The seepage losses from canal, the effluent seepage, the subsurface inflow and subsurface outflow and the change in the storage can be computed from a calibrated distributed `groundwater flow model.

The river stage of Kali river and UGC arets taken as 245.0 m, and 262.0 m respectively. The initial head of ground water has been taken as 254.205 m (average). The aquifer thickness (upper) has been taken as 98 m. Reach transmissivity of UGC has been taken as half only because the study area interacts with one side flow only. The Kali river is considered as partially panetrating river, so factor for partially penetrating river has been taken as 0.5 as per fig. 6.2. $D_1/D_2 = 93/98 = 0.94$ and $L/D = (3200/2)/98 \approx 16.0$ At $L/D = 16$ and $D_1/D_2 = 0.94$, factor comes about 0.5.

6.2 HYDROGEOLOGICAL INVESTIGATION FOR GROUND WATER MODELLING

Groundwater modelling is a multi-disciplinary science, involving geology, climateology, surface water hydrology, ground water hydraulics and computer language.

The first phase of a ground water model study consists of collecting all existing geological and hydrological data on the ground water basin in question. This will include information on surface and sub-surface geology, water tables, precipitation, evapotranspiration, pumped abstractions, stream flows, soils, land use, vegetation, irrigation, aquifer characteristics, boundaries and ground water quality.

Development and testing the numerical model requires a set of quantitative hydrogeological data that fall into two categories:

A. Data that define the physical frame work of the ground water basin and

B. Data that describe its hydrological stress.

These two sets of data are then used to assess a ground water balance of the basin. The separate items of each set are listed in Table 6.1.

Table 6.1: Data Required to Develop a Groundwater Model

A. Physical Framework	B. Hydrological Stress
1. Topography	1. Water-table elevation
2. Geology	2. Type and extent of recharge areas
3. Types of aquifer	3. Rate of recharge
4. Aquifer boundaries	4. Type and extent of discharge areas
5. Lithological variations within the aquifer	5. Rate of discharge
6. Aquifer characteristics	

It is common practice to present the results of hydrogeological investigations in the form of maps, geological sections, and table - a procedure that is also followed when developing the numerical model.

An attempt has been made to collect sufficient data. Some of the hydrogeological data have been collected from GROUNDWATER INVESTIGATIN DIVISION, ROORKEE, GROUNDWATER DEPRATMENT, GOVERNMENT OF U.P.(INDIA)

6.2.1 A-Physical Framework

1. Topography

The topography of the chosen basin has slope of 1 in 3000 from NW to SE direction. One side of the basin is Upper Ganga Canal and other side is Kali river. The RMD along with other distriutaries and minors pass through the basin. Since water table is shallow, so mostly private tubewells are existing in the area. Observation wells for measuring watertable are also in existence.

2. Geology

According to Coulson (1940), Indo-Gangetic province and Ganges Basin has abundant sands, high water table and groundwater mostly fresh. Most of the low land of Ganga – Yamuna basin is filled with alluvium from late Tertiary to Quartenary age. It is a soft rock province and ground water occurs under unconfined conditions. Generally sands and gravels constitute good aquifers. The yield of tubewell range between 50 and 150 cum/hour for drawdown of 4 to 5m. The groundwater is of good quality. The alluvial deposits consists of recent unconsolidated fluviatile formations comprising mainly clay, silt, sand and Kankar.

3. Types of Aquifers

In the study area, the shallow aquifers are mostly unconfined and homogeneous in nature.

4. Aquifer Boundary

The UGC and Kali river defines the flow boundary of the study area.

5. Lithological Variations

A generalized Lithological section of U.P. consisting of Litholog section of Western U.P. has been observed. The litholog consists of fine sand, medium sand, clay (2 to 5 m thick) at 15 to 20 m depth and very coarse sand to gravel and boulder.

6. Aquifer Characteristics

Aquifer characteristics required may be:

a. Transmissivity (T)

b. Storage coefficient (S)

c. Specific yield (Sy)

a. **Transmissivity (T)** - Its value lie between 613.81 m^2/day to 1072.50 m^2/day. Average value is 843.15 say 843.0 m^2/day.

b. **Storage Coefficient (S)** - Its value ranges 2.42 x 10^{-3} to 6.74 x 10^{4}. Its mean value is 1.50 x 10^{-3}.

c. **Specific Yield (S_y)**

Its value comes between 15.26 to 16.96. Its average value is 16.11% say 16%. The above aquifer characteristics has also been shown in Table 6.2 and the details is shown in Appendix 5 in table 22.

B. HYDROLOGICAL STRESS

1. Watertable Elevation

Hydrographic station is shown in Fig.4, Appendix 5. Water table elevation is shown in Fig. 6.3 to 6.5. Depth to water table is 1.4 to 2.3m. It has been shown in Fig 6.6.

2. Type and Extent of Recharge Area

Sources of recharge are rainfall, seepage from canal water, irrigation return flow and influent.

3. Rate of Recharge

Rainfall recharge has been taken as 18%, recharge from canal supply has been taken as 20% and irrigation return flow has been taken as 20% of CWR (total supply) (Ref. Table 24 for canal water supply and 25, Appendix 5 for CWR).

4. Type and Extent of Discharge Area

Sources of discharge are springs, trees and plants and rivers. In study area, there is no springs so only trees, crop plants and outflow are sources.

5. Rate of Discharge

The evapotranspiration rate is 1790 mm/year. Abstraction by tubewells are shown in Table 25, Appendix 5.

Table 6.2: Aquifer Characteristics

Place	Value of Trans- missivity (T) m^2/day	Value of Storage Coefficient (S)	Value of Specific yield (Sy) %
Gurukul Narsan (Saharanpur District)	1072.50	2.42×10^{-3}	16.96
Purkazi (M.Nagar District)	613.81	6.74×10^{-4}	15.26
AV	843.155 = 843.00	$1.547 \times 10^{-3} = 1.5 \times 10^{-3}$	16.11 = 16.00

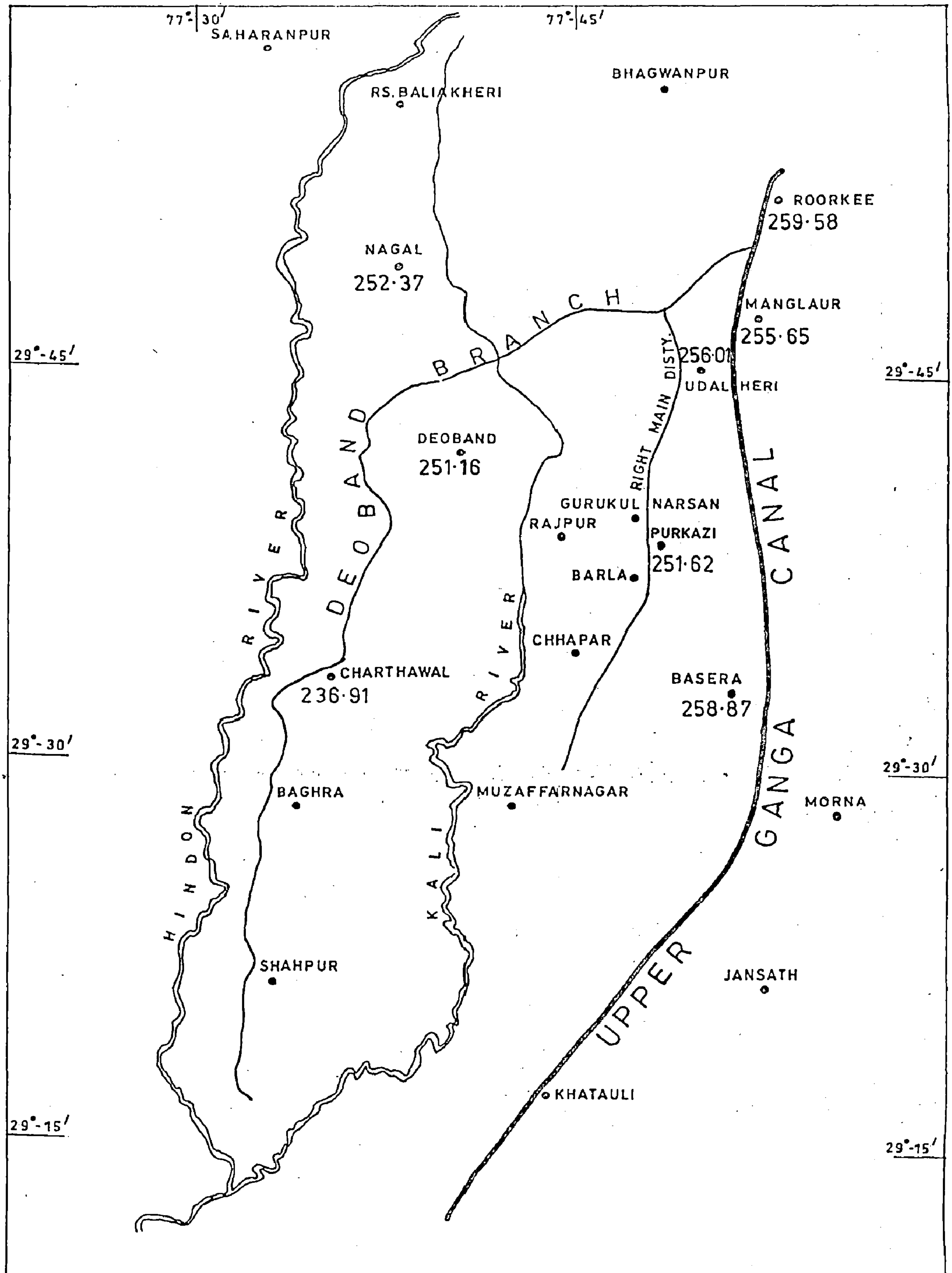


Fig.6·3 -WATER TABLE LEVEL IN FEBRUARY 1998

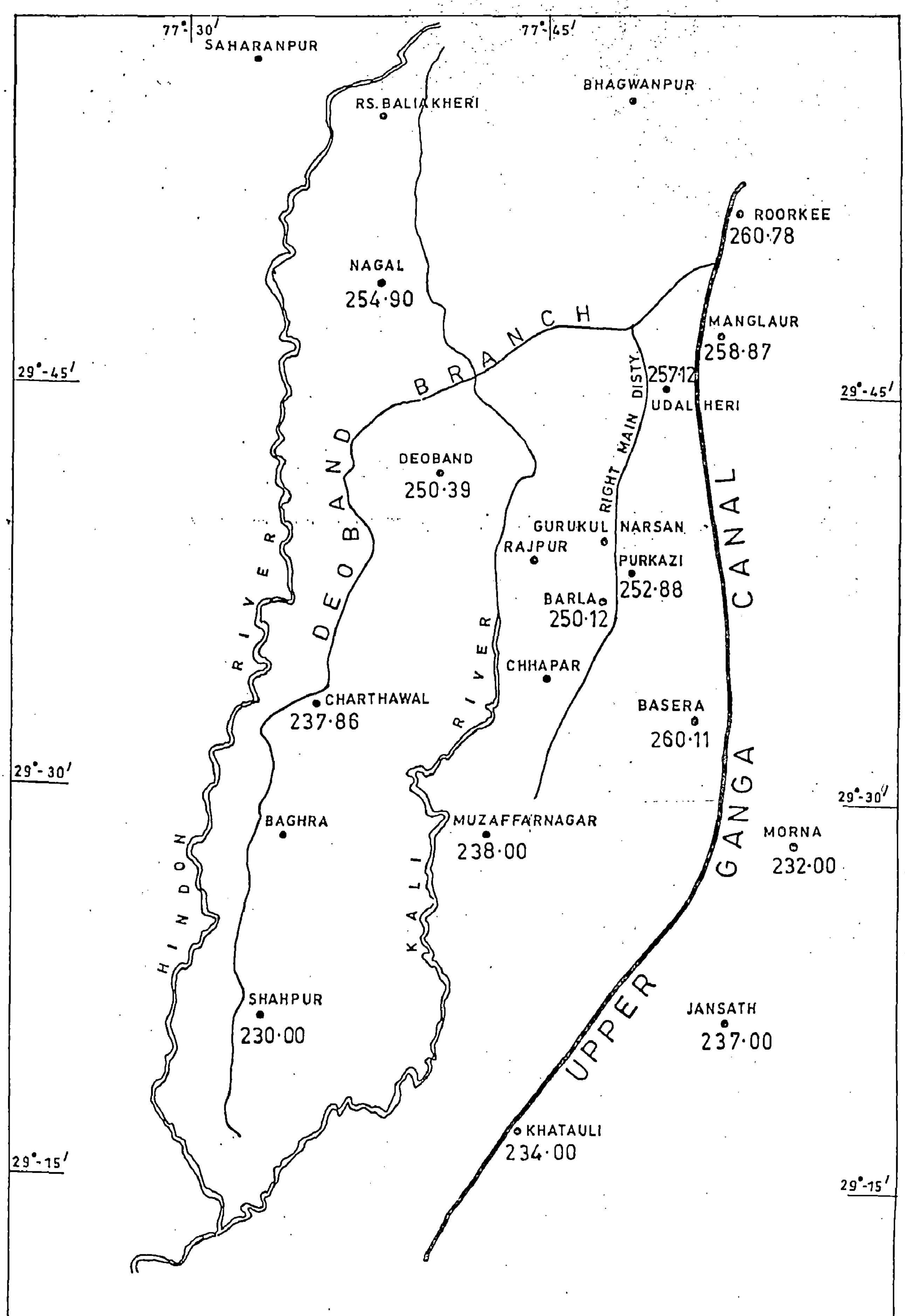


Fig.6·4-WATER TABLE LEVEL IN NOVEMBER 1998

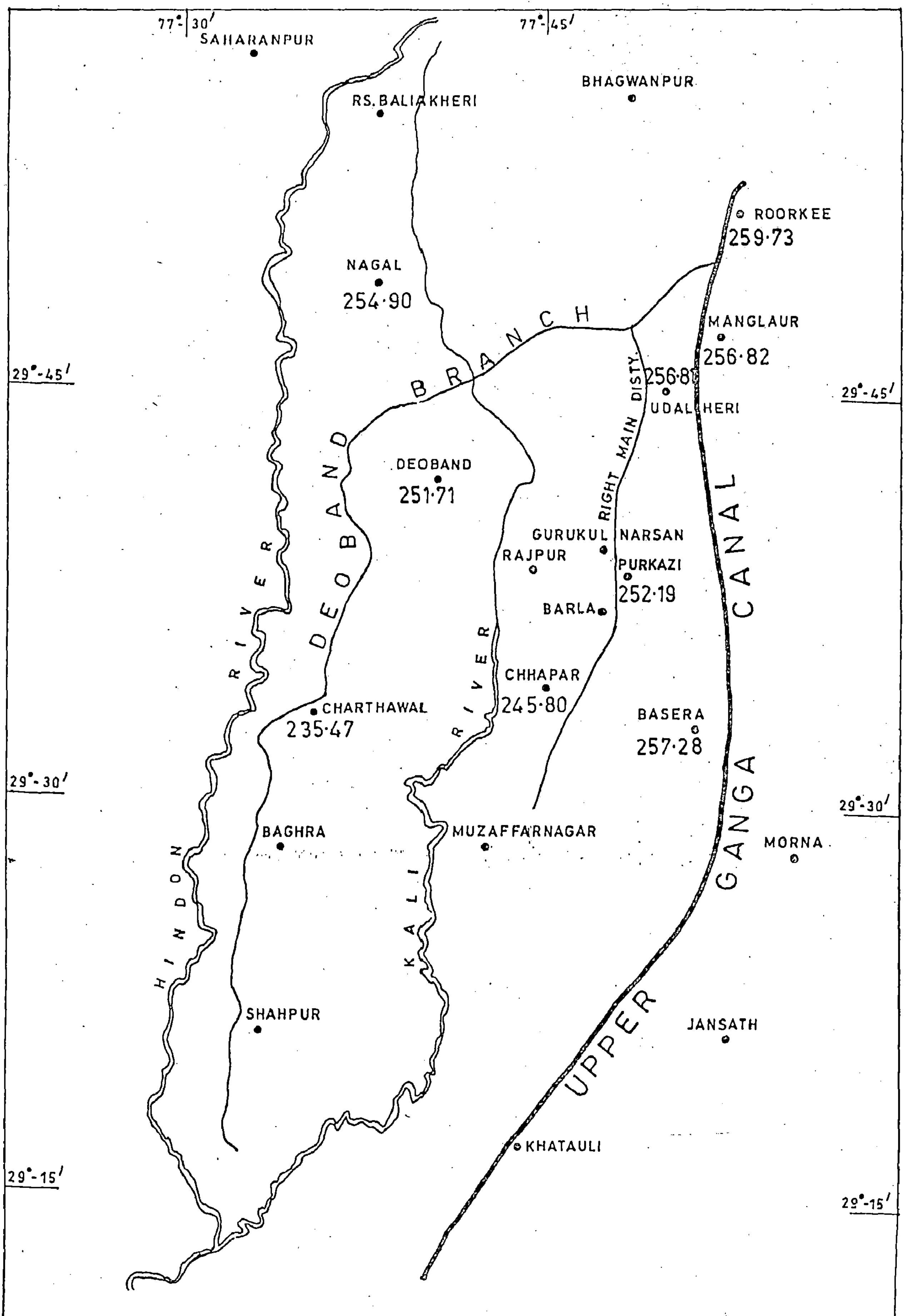


Fig. 6·5 - WATER TABLE LEVEL IN NOVEMBER 1994

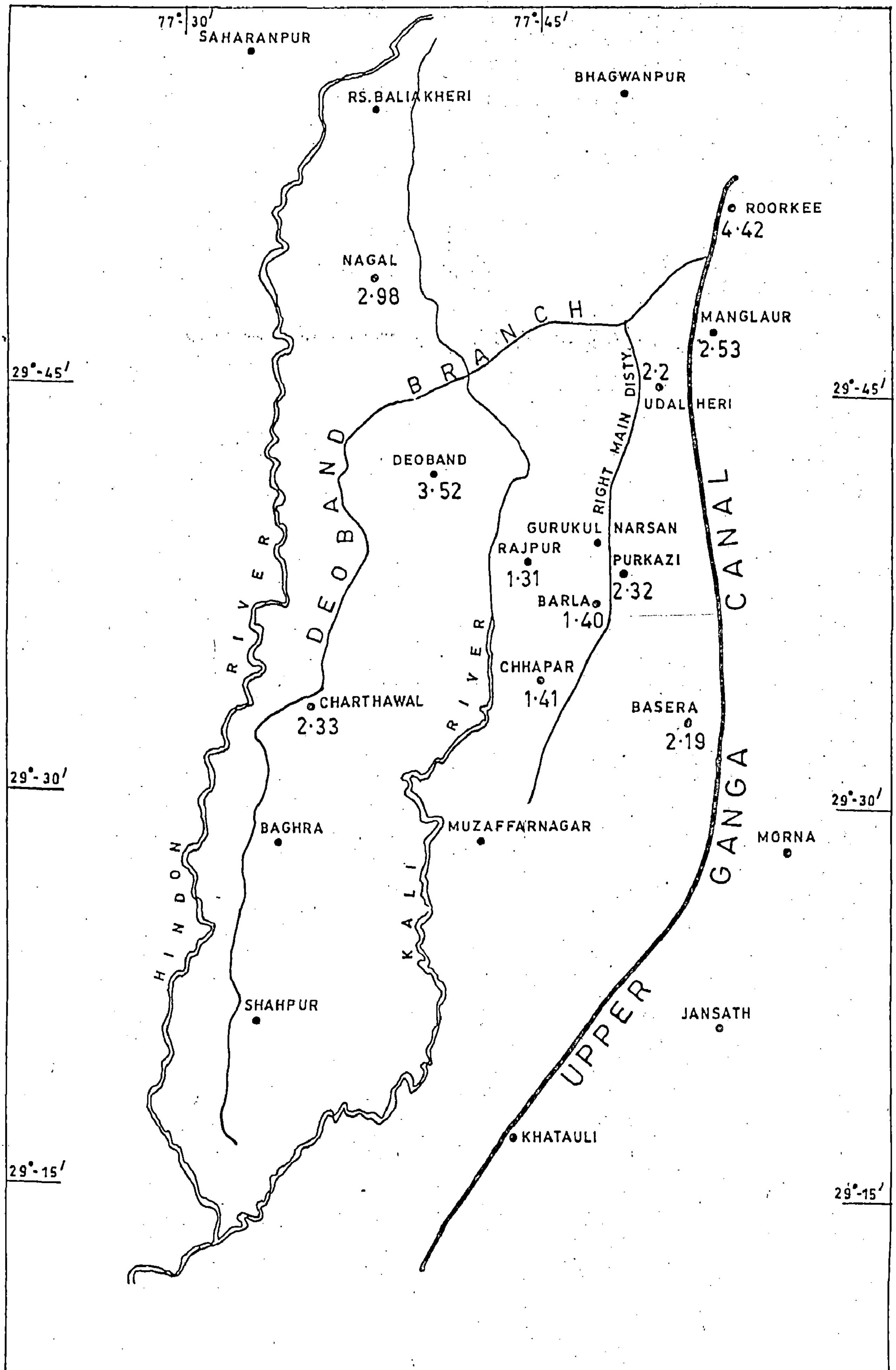
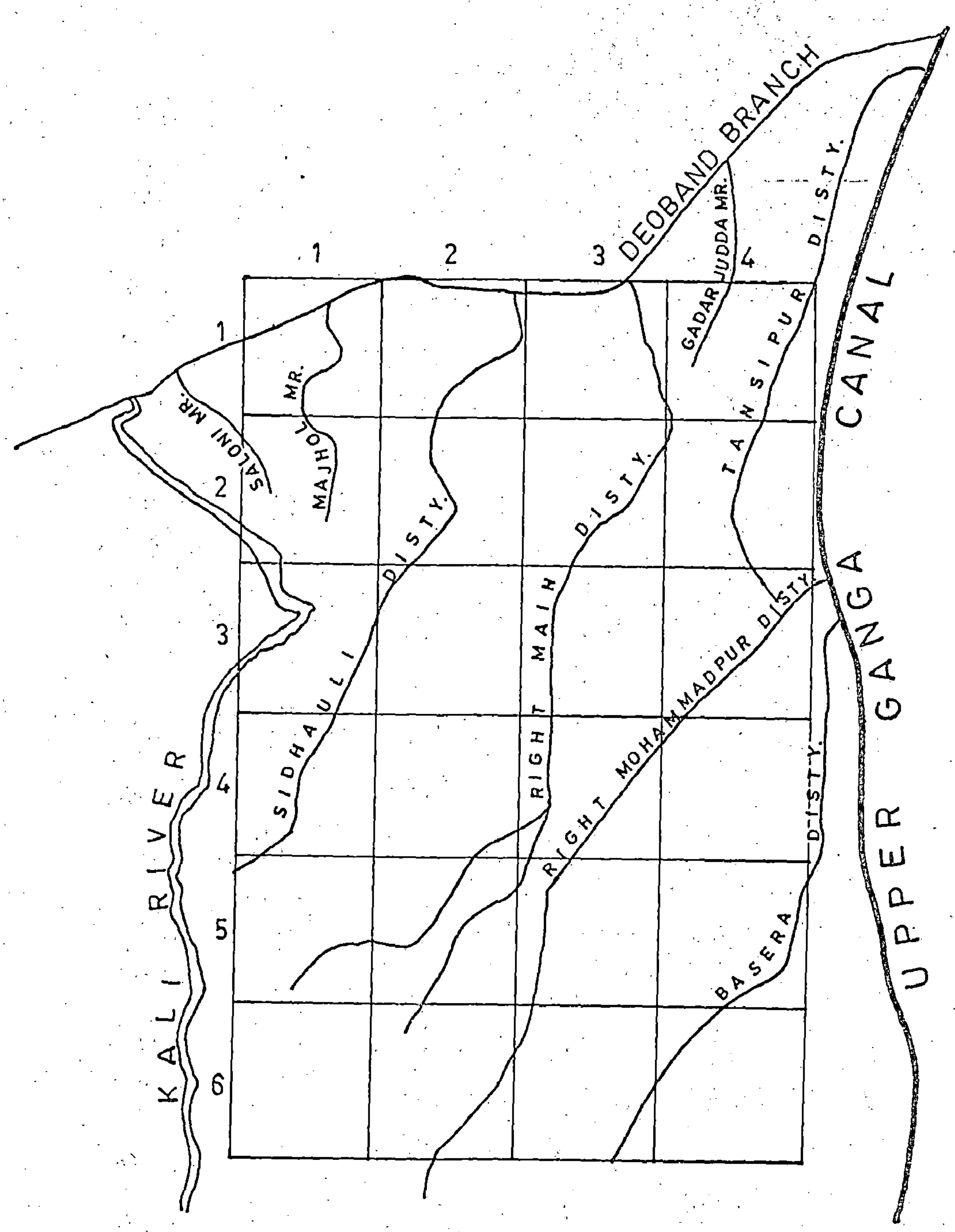


Fig. 6·6 -DEPTH OF WATER TABLE IN METER IN NOV. 1998



GRID SIZE = 3200M. X 4208 M.

SCALE:- VER.- 1cm = 1870·20 M.
HOR.- 1cm = 1361·70 M.

Fig.6·7 - DOMAIN OF THE GROUND WATER MODELING

6.4 DOMAIN OF GROUNDWATER MODELLING

The area between UGC and Kali river ha been discritized into grid size of 3200 m x 4208 m for study purposes which has been shown in Fig. 6.7 above.

6.5 COMPUTER PROGRAMMING AND RESULT OF GROUND WATER MODELLING

A computer programme for ground water modelling has been developed. The programme, input value and output are annexed in Appendix 6.

OPTIMIZATION OF NET RETURN

7.1 GENERAL

For optimization of net return a Linear Programming Model has been applied.

7.2 L.P.MODEL

The objective function is :

$$\text{Max} \quad z = \sum_{i=1}^{n} \sum_{j=1}^{k} [A_{ij}(Y_j * P_j - C_j)] - [C_{sw} + C_{gw}] \qquad (7.1)$$

$$\text{where} \quad C_{sw} = \sum_{i=1}^{n} [C1 \sum_{t=1}^{12} SW_{it}] \qquad (7.2)$$

$$C_{gw} = \sum_{i=1}^{n} [C2 \sum_{t=1}^{12} GW_{it}] \qquad (7.3)$$

And z = Net benefits from irrigated crops (in Rupees).

Y_j = Yield of j^{th} crop irrigated at 100% water level in quintals/ha.

P_j = Selling price of j^{th} crop (in Rs. per quintal).

C_j = Cost of cultivation of j^{th} crop excluding cost of irrigation (in Rs. per ha).

A_{ij} = Area under j^{th} crop in the Zone (in hectares).

C_{sw} = Cost of providing S.W in the study area (in Rs.).

C_{gw} = Cost of providing G.W. in the study area (in Rs.)

$C1$ = Cost of canal water charged (in Rs. per ha-m)

SW_{it} = Surface water allocated to i^{th} zone during t^{th} month (in ha-m)

$C2$ = Cost of G.W. charged (in Rs./ ha-m)

GW_{it} = G.W. pumping in the i^{th} zone during t^{th} month (in ha-m)

i Stands for i^{th} zone of study area = 1,2,3…n

here i = 1 zone only

n = Total no. of zones = 1 here

t stands for t^{th} month, t = 1,2,3…..12

$j = j^{th}$ crop, j = 1,2,3….k

k = Total no. of crops

Constraints

(1) Crop Area Constraint

Keeping in view the crop management consideration and socio-economic needs, the minimum and maximum area under a crop may be restricted.

$$A_{ij} \leq P_j^+ Ai \tag{7.4}$$

$$A_{ij} \geq P_j^- Ai \tag{7.5}$$

Where, P_j^+ = maximum percentage of total irrigated area of zone allotted to the j^{th} crop

and P_j^- = minimum percentage of total irrigated area of zone allotted to the j^{th} crop

(2) CWR(Crop Water Requirement) Constraint

The water requirement of various crops are met in each month and that cannot exceed the monthly availability of surface and g.w.

$$\sum_{j=1}^{k} A_{ij} * W_{jt} \leq [SW_{it} + GW_{it}] \tag{7.6}$$

For all values of i ant t.

W_{jt} = water requirement in the t^{th} month for one hectare of area under j^{th} crop (in metre).

(3) Land Constraint

The total area under crops at any time should be less than equal to total available land.

$$\sum_{j=1}^{k} A_{ij} \leq A_i \tag{7.7}$$

For all values of i & t.

A_i = total cultivable area in the zone (in hectares)

(4) Total surface water availability constraint

Total utilization of S.W. during a month in various zones should not exceed the canal water available during the month.

$$\sum_{i=1}^{n} SW_{it} \leq \text{surface water available during month 't'} \tag{7.8}$$

(5) Ground Water Constraint

Total G.W. pumpage during a year in whole of the area should not exceed the perennial yield.

$$\sum_{i=1}^{n} \sum_{t=1}^{12} GW_{it} \leq \text{Perennial yield} \quad (7.9)$$

(6) Non- Negativity Constraints

Area under a crop, canal water and G.W. withdrawals cannot be negative quantities.

$$A_{ij}, SW_{it}, GW_{it} \geq 0 \quad (7.10)$$

7.3 RESULT OF L.P MODEL

Result of L.P. Model has been annexed in Appendix 7 and result has been analyzed in chapter 8.

RESULT AND DISCUSSION

8.1 GENERAL

The performance evaluation of the study area is based on the recent study of the command area.

8.2 PERFORMANCE EVALUATION OF THE STUDY AREA

The study area is evaluated under the following systems:

1. Main system
2. On farm system
3. Cropping system and
4. Socio-economic system

1 Main System

Here main system means Right Main Distributory (RMD). Design bed width of the channel is 5.4m while its existing bed width is 7.80m.The design discharge is 2.69 cumecs (95 cusecs) while existing discharge is 3.4 cumecs (120 cusecs) and rugosity coefficient is.022.

The above result shows that the existing section and discharge of the channel has increased. The reason may be the over-stressing of the channel due to heavy demand of water for High Yielding Variety (HYV) crops and intensive cropping practice. The rugosity coefficient is normal to high which throws light that the health of the channel is generally normal in head reach. Thus, it can be said that the channel is capable of meeting the water demands of HYV crops and high intensified cropping system.

2. **On Farm System**

The physical system below outlet comes under the on farm system. Outlets are ungated, non-modular, sub-merged pipe outlet of size 4″, 6″ etc. Outlets are susceptible to tempering by the farmers. The longitudinal slope of the area is 1 in 3000 (i.e. 0.033%). Border, furrow and check basin methods of irrigation are practiced. Infiltration rate is 14 mm/hr to 41.7 mm/hr, so flooding (medium to high infilterability class) in short strips is suitable method of irrigation. Field Application Efficiency (FAE) varies from 34% to 97%, storage efficiency is 100%, Deep Percolation Efficiency is same as FAE, and Uniformity of Distribution is 84% to 99%. Water Table in CA is at shallow depth of 1.3 to 2.4 m.Soil of the CA is of class A i.e. soil has no limitations for sustained use. Soil drainability is of class C i.e. subsurface drainage of the area is poor due to shallow depth of WT. Although surface drainage has no any limitations. OSRABANDI is functioning satisfactorily in the CA.

Delivery of Water

a. **Adequacy:** Value of RWS (Relative Water Supply) is less than one because canal water supply is less than water demand. so canal water supply is inadequate.

b. **Equity:** Due to seepage losses in watercourse and filed channels and other losses, IQR (Inter-Quartile Ratio) is more than one in tail end.

c. **Dependability:** Uniform amount of water is not supplied in Kharif and Rabi season. In Rabi season only available amount of water is distributed among many users in larger areas. Thus, uniform supply is not maintained but predictability of supply is followed.

d. **Water quality:** The canal water as well as groundwater is of good quality.

e. **Sustainability:** There is no major salinity or water-logging problem. So irrigated agriculture is sustainable.

Conjunctive use of surface and Groundwater

Due to shortage of canal water supply in peak demand period surface water is supplemented through groundwater by the farmers.

3. Cropping System

Kharif, Rabi and Zaid crops are practiced in the area. The cropping intensity is 144%. Sugarcane is the predominant crop. The soil is deficient in Nitrogen and Phosphorous.

4. Socio-economic system

Market oriented intensive cropping system has put the physical system under stress which gives rise to irregular practices. Majority of farmers are literate. The farmers are well satisfied with OSRABANDI system. There is no canal telegraph or telephone line within the command of RMD.

8.3 CROP WATER REQUIREMENT AND DEFICIT OF WATER

Annual value of ETo comes 179 cm. Crop Water Requirement (CWR) comes 7460.0 ha-m, at 144% CI. Annual Surface Water Availability is 4670 ha-m. Annual deficit of water is 3370 ha-m in normal year of rainfall (Fig. 8.1).

8.4 Ground Water Potential

A ground water model has been developed. The ground water potential and water level rise is shown in Table 8.1.

Table 8.1: Ground Water Potential and Rise in Water Level

Month	Ground Water Potential (m^3)	Water Level Rise (m)
January	-0.1622442E+07	-0.031
February	.0.4878339E+07	0.094
March	-0.3547490E+07	-0.069
April	-0.1553327E+08	-0.300
May	-0.4248282E+08	-0.822
June	-0.6900764E+08	-1.335
July	-0.3801599E+08	-0.735
August	-0.6216212E+07	-0.120
September	0.1275757E+08	0.247
October	0.2720252E+08	0.526
November	0.245905E+08	0.476
December	0.2788941E+08	0.539

Grid wise final water table has been shown month wise in result. There is flow of seepage from UGC to river Kali which is shown below in Table 8.2.

Table 8.2 : Seepage from UGC and Kali River

Month	Seepage from Kali River (m^3)	Seepage from Ganga Canal (m^3)
January	-0.180E+07	0.212E+07
February	-0.180E+07	0.205E+07
March	-0.174 E+07	0.205 E+07
April	-0.16 7E+07	0.208 E+07
May	-0.154 E+07	0.218 E+07
June	-0.141 E+07	0.228 E+07
July	-0.15 E+07	0.208 E+07
August	-0.161 E+07	0.187 E+07
September	-0.166 E+07	0.174 E+07
October	-0.169 E+07	0.163 E+07
November	-0.166 E+07	0.162 E+07
December	-0.165 E+07	0.157 E+07

Recharge due to rainfall, applied irrigation, canal seepage and total recharge is shown below in Table 8.3:

Table 8.3: **Recharge from Rainfall, Applied Irrigation, Canal Seepage and Total Recharge**

Month	Rainfall Rech. (m^3)	Applied Irrigation Rech. (m^3)	Canal Seepage Rech. (m^3)	Total Rech. (m^3)
January	0.143E+07	0.4331 E+07	0.2669 E+07	0.843 E+07
February	0.2181 E+07	0.2391 E+07	0.2327 E+07	0.6900 E+07
March	0.1734 E+07	0.5946 E+07	0.2327 E+07	0.110 E+08
April	0.1658 E+07	0.9695 E+07	0.3723 E+07	0.1508 E+08
May	0.1140 E+07	0.1538 E+08	0.6948 E+07	0.2347 E+08
June	0.3897 E+07	0.1558 E+08	0.8396 E+07	0.2787 E+08
July	0.1681 E+08	0.7368 E+07	0.9120 E+07	0.3330 E+08
August	0.0265 E+08	0.1874 E+07	0.901 E+07	0.3154 E+08
September	0.7330 E+07	0.7433 E+07	0.9042 E+07	0.2381 E+08
October	0.4072 E+07	0.4007 E+07	0.6425 E+07	0.1450 E+08
November	0.3839 E+06	0.4317 E+07	0.2476 E+07	0.6996 E+07
December	0.1129 E+07	0.3684 E+07	0.2443 E+07	0.7256 E+07

Note: The above result is for entire domain of the study area.

8.5 WATER DEFICIT

Water deficit in case of normal rainfall is 3370 ha-m, in 75% of normal rainfall and 80% canal supply, is 4760 ha-m and in case of 50% rainfall and 75% canal supply, it is 5280 ha-m. These values have been presented in Fig. 8.4 below.

8.6 OPTIMAL CROPPING INTENSITY

Existing and proposed cropping intensity are given below:

Season	Crop	Existing C.I. (%)	Proposed C.I.(%)
Kharif	Rice	26	30
	Sorghum and others	20	30
	Sugercane	50	40
		96	100
Rabi	Wheat	32	40
	Berseem	6	5
	Mustard	6	5
	Sugercane	50	40
	Leguminous crops	-	10
		94	100
Zaid	Mung	4	20
	Sesba nia and the others	-	20
Total		194%	240%

Increase in cropping intensity = (240 –194) / 194x 100 = 24%

Existing and proposed cropping intensity has been shown in Fig. 8.2 and crop-wise in Fig. 8.5.

8.7 CROP YIELD

Crop yield in existing condition and under crop management practice has been shown in Table 28 and 30 respectively. Present production rate of paddy is 45 quintal per ha. After scheduling of irrigation it may go upto 69 quintal/ha but only 55 quintal per ha has been considered.. Present level of wheat production is 40 quintal/ha which may go upto 50 quintal/ha. Similarly production level of sugarcane is 700 quintal/ha which may go upto 750 quintal/ha and even more. Change in yield in other crops is not taken into account here. Yield rate (in quintal/ha.) of Sorghum, Mustard, Berseem and Mung is 25, 10, 300 and 10 respectively in all condition.

8.7 NET RETURN

Optimization of net return by applying L.P. model is as below:

(i). At C.I. of 144% in existing crop yield level condition

Net return for study area = 0.6957006E+08

Net return per ha = Rs. 0.6957006x 10^8/5890 = Rs. 11,812.00

(ii). At C.I. of 210% and in existing crop yield level:

Net return = 0.8424781E + 08

Net return per ha = 0.8424781 x 10^8 / 5890 = Rs. 14304.00

(iii). At C.I. of 240% and under proper crop water management practice, yield level will be increased and net return will also be increased correspondingly.

Net return = 0.1121664 E + 09

Net return per ha = 0.1121664 x 10^9/5890 = Rs. 19044.00

Note: Range of C.I. has been taken as existing i.e. minimum and proposed i.e. maximum under the crop area constraint.

Increase in net return = (19044 – 11812) / 11812 = 61%

Fig. 8.3 presents the value of net return.

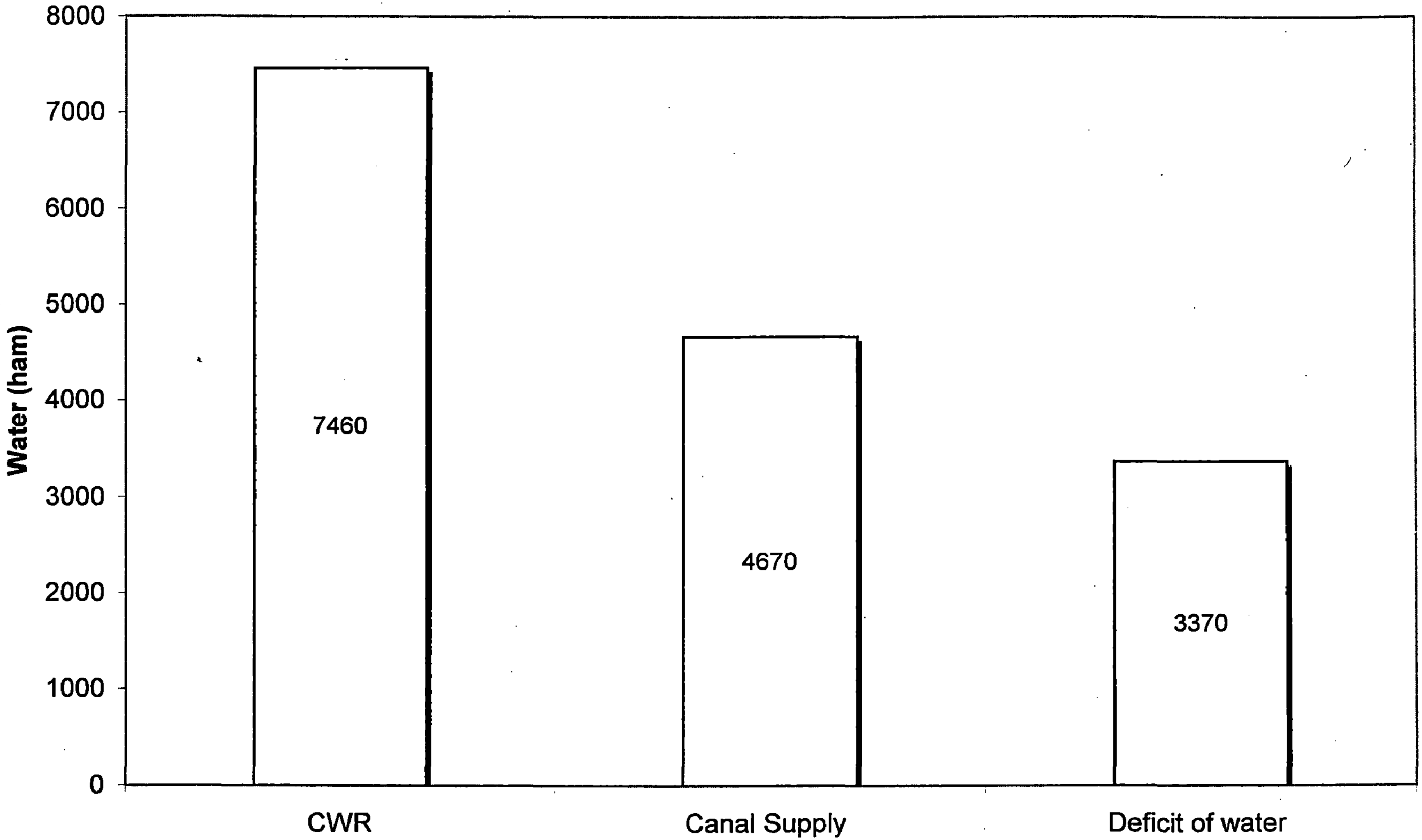


Fig. 8.1 CWR, Canal Supply & Deficit of water

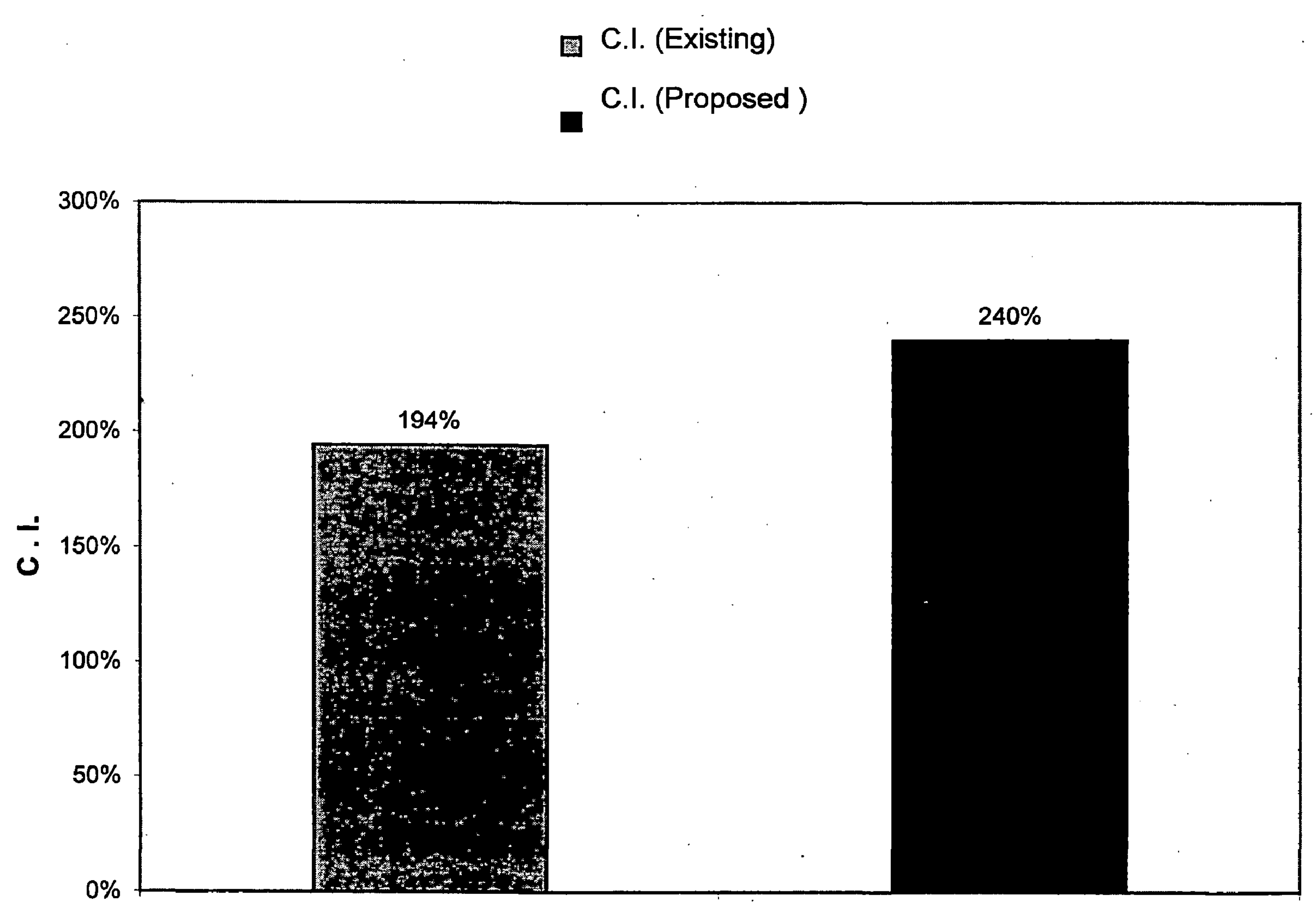


Fig. 8.2 Existing and proposd Cropping Intensity (C. I.)

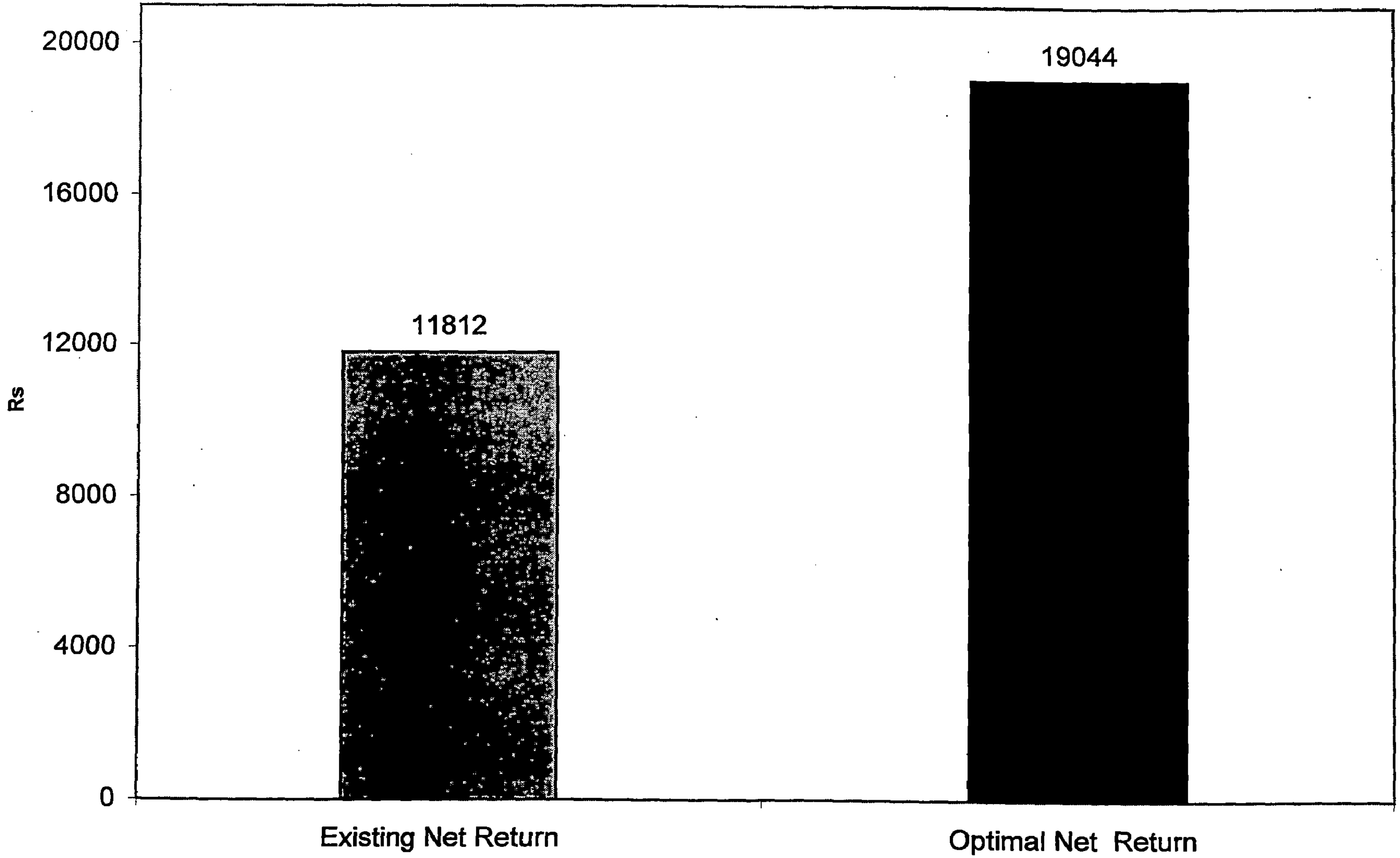


Fig. 8.3 Existing and Optimal Net Return

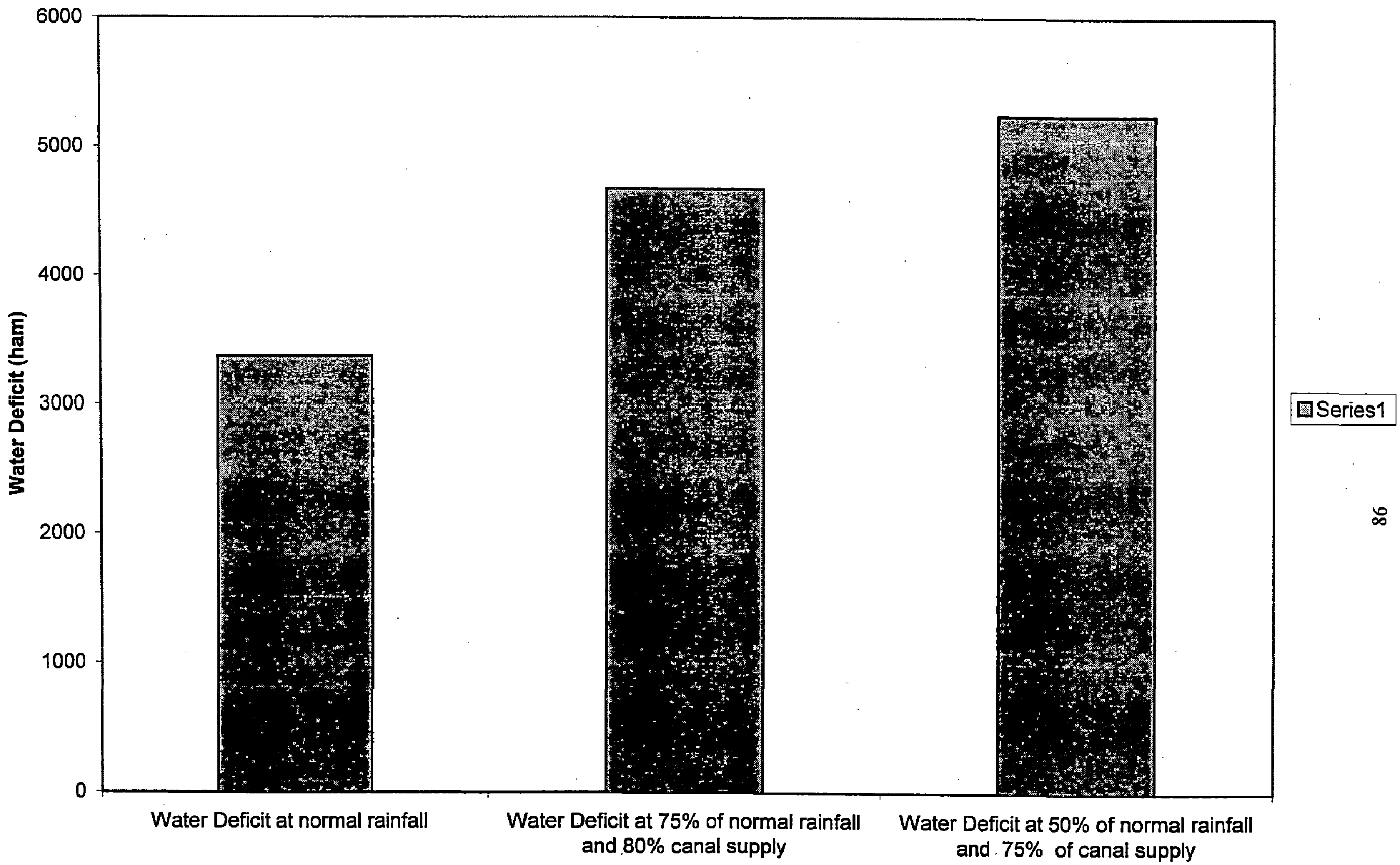


Fig.8.4 Water Deficit in differant rainfall conditionsl

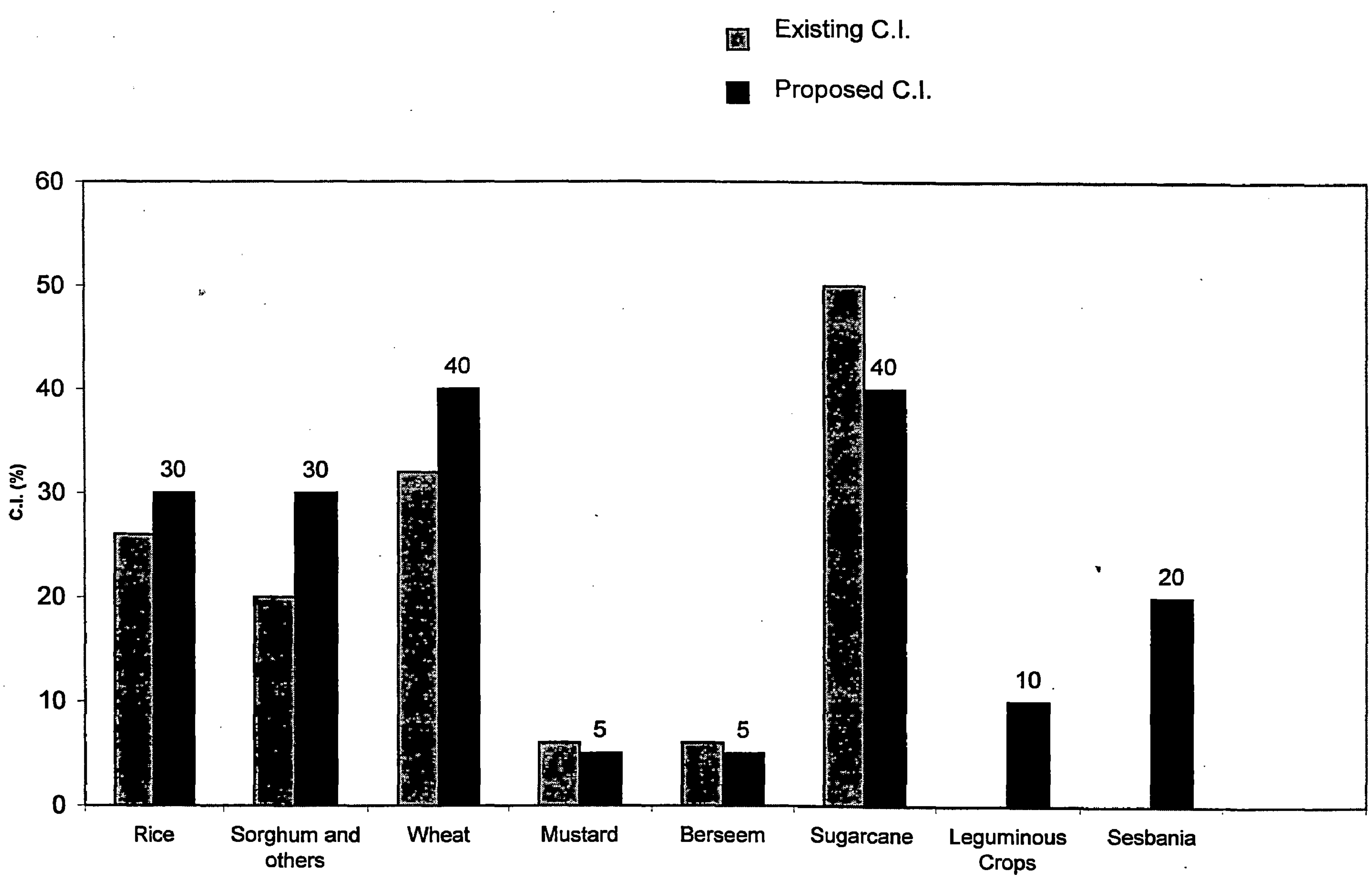


Fig.8.5 Existing and proposed Cropping Intensity of differant crops

CONCLUSIONS AND SUGGESTIONS

9.1 GENERAL

The objective of the study is to determine crop water requirement, deficit of water, availability of groundwater and to optimize net return.

9.2 CONCLUSIONS

Following are the conclusions :

(i). Rainfall analysis and evaportanspiration demand of crops indicate that the annual rainfall (107.5 cm) is not sufficient to meet the evapotranspiration demand (179.0 cm) of the crops. The study area comes in slightly dry zone and is prone to repeated drought cycle.

(ii) The analysis of soil irrigability classification makes it clear that the soil is well irrigable (class A) without any severe limitations.

(iii) The analysis of land drainabliy classification makes it clear that the surface drainage has no any limitation but the subsurface drainage has limitation (C class drainability) due to shallow depth of water table. Depth of watertable is 1.3 to 2.4 m while it should be below 5m depth.

(iv) Irrigation methods practices are suitable.

(v) Adequacy parameter RWS (Relative Water Supply) also indicates that the canal water is not sufficient to meet the crop water requirement. Canal supply only meets the 65% requirement of CWR.

(vi) The annual evapotranspiration is 179.0 cm.

(vii) The annual CWR (Crop Water Requirement) is 7460 ha-m.

(viii) The availability of surface water is 4670 ha-m only which meets the 65% CWR demand only.

(ix) Deficit of water is found to be 3370 ha-m which is 35% of the CWR.

(x) Groundwater is available in sufficient quantity to meet the deficit of water in normal as well as in drought year.

(xi) Groundwater potential is sufficient for drought mitigation.

(xii) With adequate and favourable availability of groundwater and its conjunctive use with surface water, may show good response to equitable distribution of water which is a pressing and basic need in Irrigation Water Management.

(xiii) Existing C.I. is 144%. The proposed C.I. is 240%.

(xiv) Net return in case of existing C.I. of 144% is found to be Rs. 11,812 =00 per ha. Net return for C.I. of 210% is found to be Rs. 14,304=00 per ha while net return for proposed C.I. of 240% and under proper crop-water management is found to be Rs. 19,044=00 per ha. In present condition, sugarcane is the predominant crop and the most beneficial crop while under proper crop water management, rice may become the most beneficial crop.

(xv) Groundwater is reported to be of good quality.

(xvi) There is no indication of salinity or alkalinity problem at present.

(xvii) Irrigated agriculture in study area is found to be sustainable.

9.3 SUGGESTIONS

(i) At present there is no facility of modern communication system in the command area. A modern communication facility like installation of telephones / telegraph. at head works is required.

(ii) Outlets should have measuring devices. Farm structures are also required for controlled supply of water.

(iii) Watercourse and Field channels should be well compacted and bank should be strengthened.

(iv) Extension workers may be emphasized the need for smaller water depths in early stage of the crop to improve the application efficiency. For rice cultivation, application of 7cm deep irrigation 3-5 days after subsidence of previously applied irrigation is good enough to obtain optimum yield.

(v) Soil is reported to be deficient of Nitrogen and Phosphorous. The practice of leguminous crops in rotation and incorporation of green manure crops as Dhaincha (Sesbania) and Mung will be beneficial. Also greater use of animal manure, compost and judicial dose of chemical fertilizer will be beneficial.

(vi) Better field preparation before transplanting of crops result in better utilization of water. Effective puddling before rice transplanting may minimize the unproductive loss.

(vii) It is reported that shortage of water in critical stage reduces the crop yield substantially. It is recommended that water should not fall short in critical stage of crops.

(viii) Crop management practice can yield the sugarcane 750 to 800 quintal/ha and wheat 450 to 500 quintal/ha. The sugarcane have the potentiality to yield even more than that.

(ix) Generation of full spirit of co-operation and self-discipline among farmers by creating congenial environments would be helpful in smooth operation and maintenance of canal. Water User Association may be helpful for this.

(x) Massive training to farmers and officers will be helpful in adopting modern agriculture technology for sustained use.

(xi) Leaf Area Index should be more than 1 for proper exploitation of solar energy.

(xii) The study area has full potentiality of ground water and it should be used at large level, specially in the head reaches, for equitable distribution of water.

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APPENDIX - 1

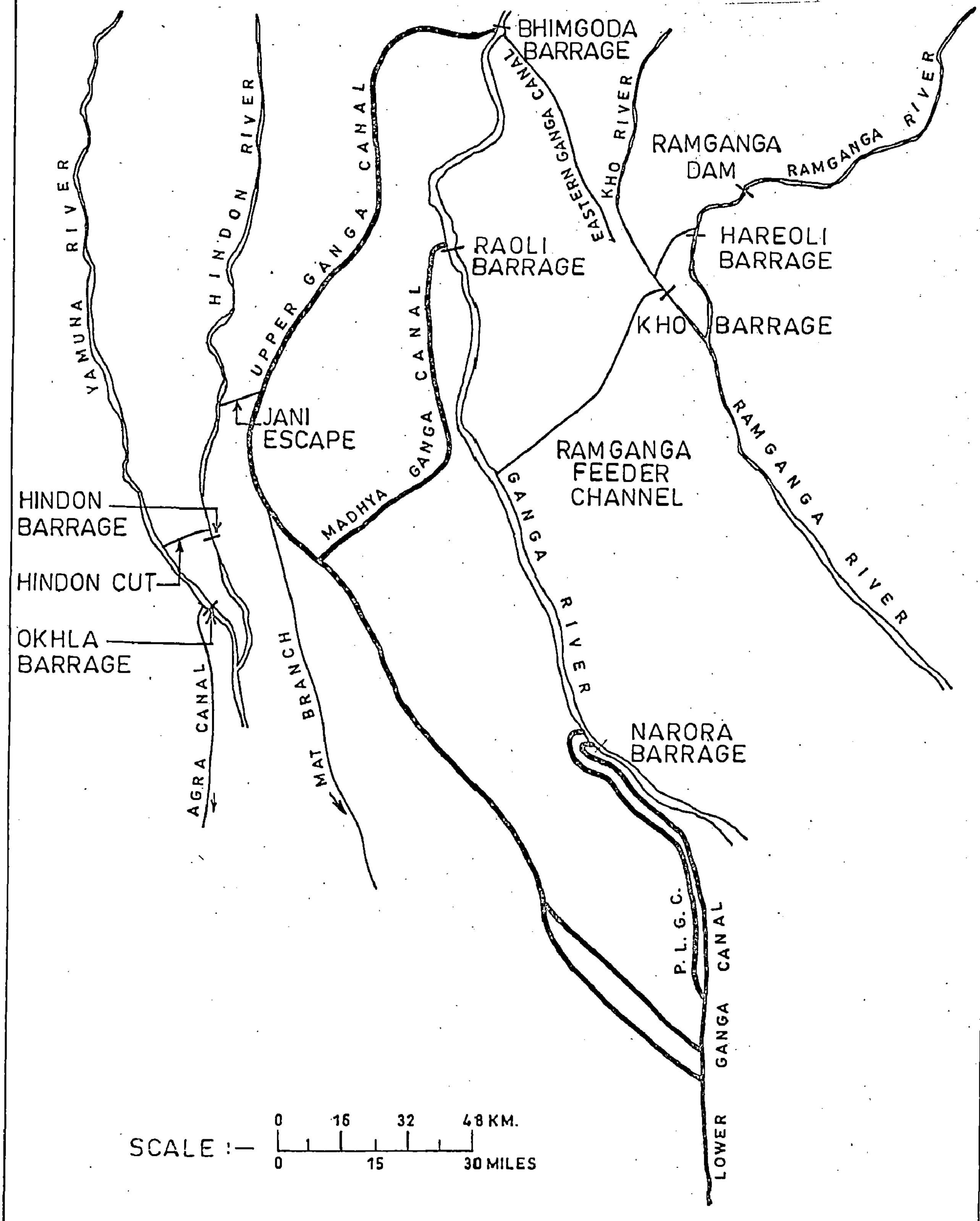

Fig. 1 - LOCATION OF VARIOUS CANAL HEADWORKS ON GANGA RIVER

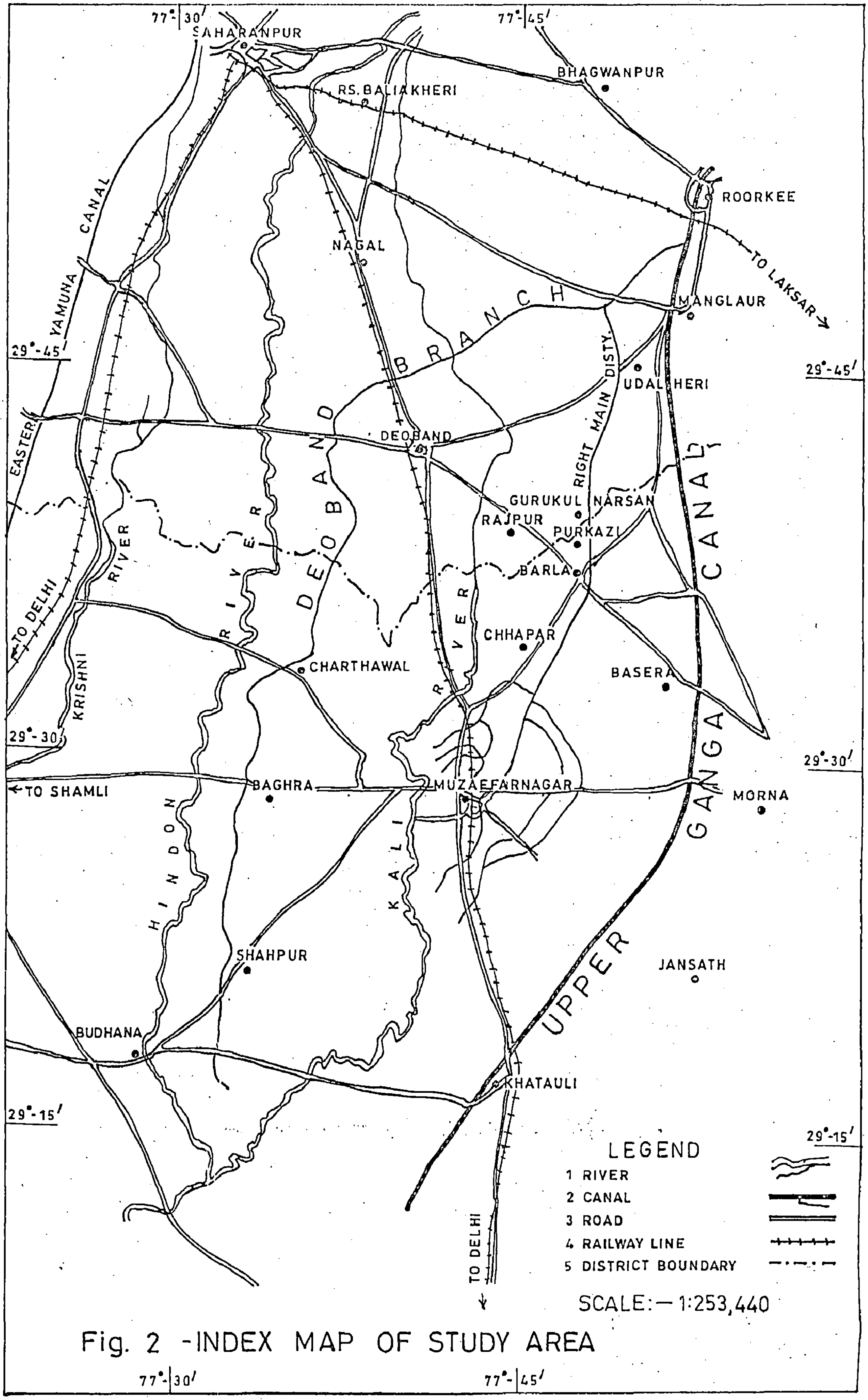

Fig. 2 -INDEX MAP OF STUDY AREA

APPENDIX - 2

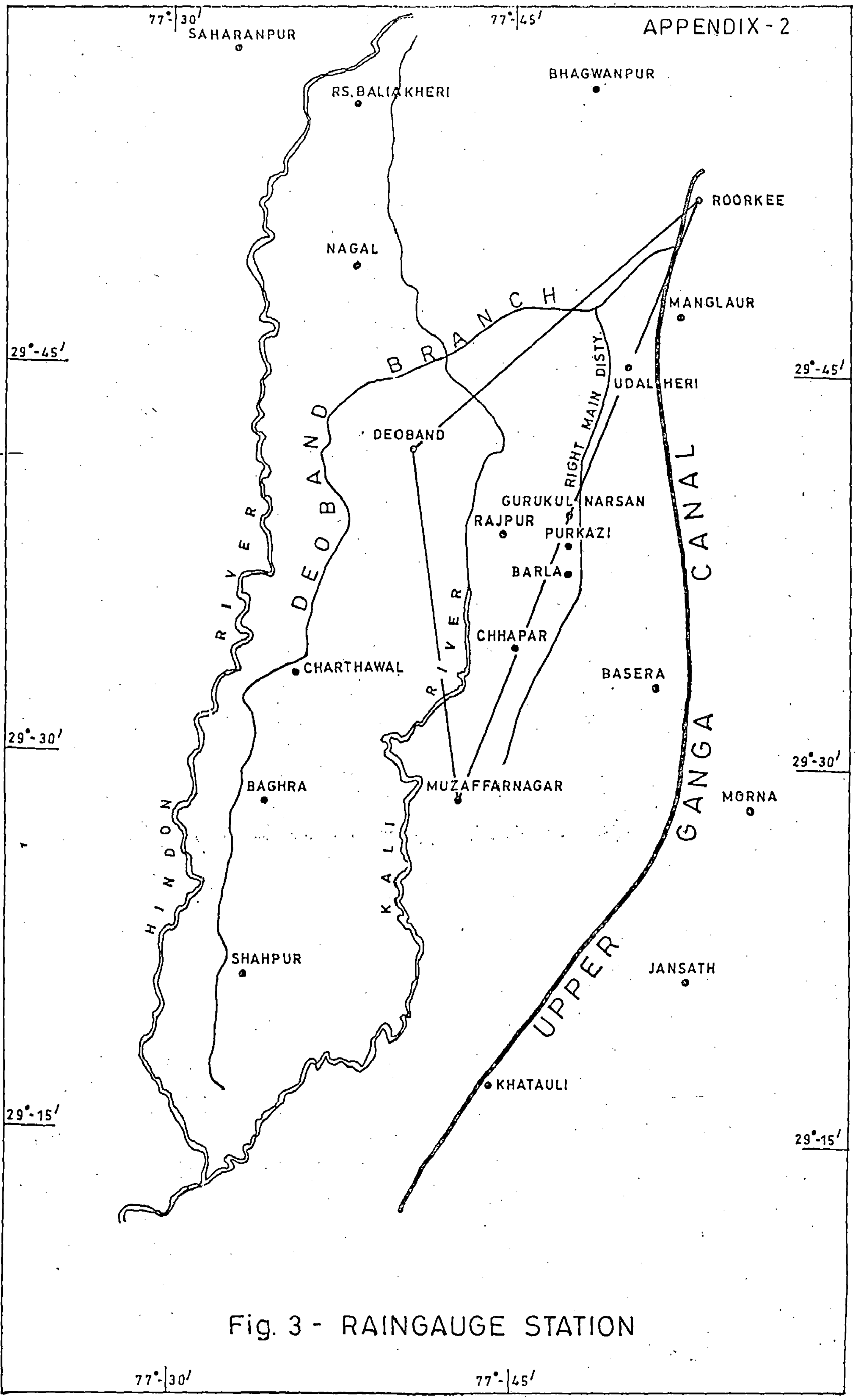

Fig. 3 - RAINGAUGE STATION

Table 1: Rainfall data for 20 years

Observatory: Mohammadpur (Narson Block, Khanpur)

District: Saharanpur

Rain gauge station (Tehsil)	Year of observation	Rainfall in mm												Total annual rainfall (mm)	Seasonal rainfall	
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.		Monsoon season (mm)	Non-monsoon season (mm)
Gurukul Narson	1979	56	56	19	4.0	13	64	210	117	73		-	21	633	464	169
	1980	12	8	19	-	-	162	327	205	54	36	10	35	868	748	120
	1981	39	6	59	-	26	126	343	65	93	-	45	-	802	627	175
	1982	-	-	-	-	15	51	172	341	-	4	-	27	610	564	175
	1983	48	10	11	116	37	35	236	311	87	-	-	7	890	669	46
	1984	14	64	-	-	5	252	271	487	183	-	-	-	1276	1193	83
	1985	-	-	-	-	-	40	197	337	63	84	-	10	731	637	94
	1986	-	19	8	2	140	57	71	318	222.01	5	-	5	847	668	179.0
	1987	9	25	22	2	59	135	5	120	67	50	-	5	499	327	172
	1988	-	9	119	5	5	65	875	1111	727	-	-	3	2919	2778	141
	1990	-	11	1.5	-	15	20	231	395	172	-	12	57	1027	818	209
	1991	-	20	5	7	-	4	5	101	120	-	7	30	335	266	69
	1992	15	20	-	-	-	12	110	217	110	-	-	-	484	449	35
	1993	-	10	-	-	8	15	80	40	147	-	-	-	300	282	18
	1994	20	25	-	-	10	-	200	140	-	-	-	-	395	340	55
	1995	45	-	-	-	-	30	110	271	89	-	-	-	545	500	45
	1996	-	-	-	-	-	39	25	363	-	-	-	-	427	427	-
	1997	17	-	-	47	14	21	162	256	5	17	25	49	444	275	169
	1998	-	17	71	56	51.80	57	205	403	173	178	-	-	-	-	-
	Av.	22	21.3	16.7	12	20	62.75	202.5	292.25	129.25	18.70	5.0	16.0	812.15		

Source of Data : Ground water Investigation Division, Roorkee

1. Monsoon Season – June to Oct.
2. Non-Monsoon Season - Nov. to May

Table 2: Deoband Observatory: Deoband & Nangal

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1994	25.5	62.7	-	36	21.50	135.5	560.3	484.4	26.0	-	-	-	
1995	62	12.7	-	4	-	51	209.2	447.96	129.2	-	-	-	
1996	1	81.03	-	6.03	-	-	57	135.6	245.7	452.4	-	-	
1997	8	-	3.8	59.9	29.5	84.7	352.4	201	14	19.40	31.50	113.5	
1998	2	65.50	167.8	115	56	78.5	349.5	441.5	190.9	221.5	-	-	
Average	19.7	44.4	34.32	44.2	21.40	70	305.70	342.0	121.16	138.7	6.3	22.7	1147.88

Table 3: Roorkee Observatory

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1994	38	105	-	30	46	18	463	407	6	-	-	-	
1995	70	55	3	8	-	135	418	626	165	-	-	-	
1996	33	124	10	-	5	61	184	499	355	63	-	-	
1997	23	-	4	70	15	39	350	279	82	67	37	101	
1998	-	2	112	89	36	82	257	472	214	157	-	-	
Average	32.8	60.8	25.8	39.4	20.4	67	334.4	456.60	164.4	57.4	7.4	20.20	1286.6

Table 4: Muzaffarnagar Observatory : Baghra, Charthawal, Purkazi

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1994	2	46	-	22.4	7	35	487.3	295.8	1.4	-	-	-	
1995	73	12	29	-	-	76.1	152.3	164.2	-	-	-	-	
1996	33	72	10	-	-	112	128	527	293	60	-	-	
1997	7	-	110	62	56	75	354	345	28	69	39	94	
1998	4	19	64	8	21	44	464	312	125	193	-	-	
Average	23.80	29.80	42.6	18.48	16.8	68.42	317.12	328.8	89.50	64.4	7.8	18.80	1026.32

Table 5: Average Rainfall (mm)

Particulars of observatory	MONTHS												Total
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Gurukul Narson	22	15	16.70	12	20	62.75	202.5	292.25	129.25	18.70	5	16	812.15
Deoband	19.70	44.4	34.32	44.2	21.4	70	305.70	342	121.16	138.70	6.3	22.70	1147.88
Muzaffarnagar	23.80	29.80	42.60	18.48	16.80	68.42	317.12	328.8	89.5	64.4	7.8	18.8	1026.32
Roorkee	32.80	60.80	25.80	39.40	20.40	67	334.40	456.60	164.40	57.40	7.4	20.20	1286.60
Average	24.60	37.5	29.85	28.5	19.65	67	289.9	354.9	126	69.8	6.6	19.4	1073.70

Say 1075.0

AGRO-CLIMATIC STUDY

1. Rainfall in a year = 1075 mm

2. Average PET (potential evapotranspiration) = 1790.3 mm

MAI = Moisture Availability Index

$$= \left(\frac{P}{PET} - 1\right) \times 100$$

$$= \left(\frac{1075}{1790.3} - 1\right) \times 100$$

= -39.95

According to ICAR classification, the C.A. is in **slightly dry zone.**

Table 6 : ICAR Classification

S.N.	Value of MAI	Zone description	Classification
1	<(-80)	Extremely dry	A
2	(-60) to (-80)	Semi-arid	B
3	(-40) to (-60)	Dry	C
4	**(-20) to (-40)**	**Slightly dry**	**D**
5	0 to (-20)	Slightly moisture	E
6	20 to 50	Moist	F
7	50 to 100	Wet	G
8	> 100	Extremely wet	H

From Thornthwiate classification, the areas comes under **semiarid climate.**

Table 7 : Thornthwait classification

Climatic type	Moisture index
A-prehumid	>100
B_4-Humid	80-100
B_3-Humid	60-80
B_2-Humid	40-60
B_1 –Humid	20-40
C_2-Moist subhumid	0-20
C_1-Dry subhumid	(-33.3) to 0.
D-Semiarid	**(-66.7)-(-33.3)**
E-Arid	<(-66.7)

Hargreaves classification

MAI = Moisture Adequacy Index

$$= \frac{P}{PET} = \frac{P}{ET_0} = \frac{1075}{1790} = 0.60$$, i.e. **somewhat deficient.**

Table 8: Hargreaves classification

S. No.	MAI	Description
1	0-0.33	Very deficient
2	0.34-0.57	Moderate deficient
3	**0.58-1.0**	**Somewhat deficient**
4	1.10 –1.33	Adequate moisture
5	>1.34	Excessive moisture

APPENDIX – 3

Table 9 : Criteria for Classifying Soils into Irrigability Classes-Semi-Arid Regions

(Table 2.1)

Soil Properties	Irrigable Soil Classes				Non-irrigable soil class E
	A	B	C	D	
Effective Soil Depth (Useful to crops).	More than 90 cm	45-90 cm	22.5-45 cm	7.5-22.5 cm	Less than 7.5. cm
Texture of surface 30 cm	Sandy loam to clay loam inclusive	Loamy sand clay.	Sand; clay	Sand; clay	Any texure
Soil Permeability (of least permeable layer)	5-50 mm/hr	1.3-5 mm/hr	0.3-1.3 mm/hr	Less than 0.3 mm/hr	Not applicable
Available water holding capacity to depth of 90 cm	12 cm or more	9-12 cm	6-9 cm	2-6 cm	Less than 2 cm
Coarse fragments (%) Cobbles and Stones (> 75 mm)	Less than 5	5-15	15-35	35-65	More than 65
Gravel and Kankar (25 to 75mm)	Less than 15	15-35	35-55	55-70	More than 70
Rock-out-crops (distance apart in metres)	40	20	15	5	Less than 5
Salinity Ece $X10^3$ (in Saturation extract)	Less than 4 mmhos	4-8 mmhos	8012 mmhos	12-16 mmhos	More than 16 mmhos
Salt affected (visual) (% of area affected)	Less than 20%			20-50%	More than 50
Severity of alkali problem	ESP less than 15%			More than 15%	
Sub-soil or substrata drainage characteristics	Lower sub-soil is atleast moderately permeable or a permeable layer of atleast 6' thickness occurs immediately below the soil but within 10 feet (sand, gravel).		No moderately permeable sub-soil or other permeable layer of at least 6' thickness occurs within depth of 10 feet.		
Soil erosion status	Effects of sheets and rill erosion are reflected in effective soil depth, available moisture bolding capacity and are some other factors shown above. Moderately of severely gullied soils may be classified based on local experience.				

Table 10 : Specifications for Land Irrigability Classes

(Table 2.2)

Land Characteristics	IRRIGABLE LAND CLASS				Class 5 Temporarily Non-irrigable (unclassified)	Class 6 Not suitable for irrigation
	Class 1	Class 2	Class 3	Class 4		
SOILS					Further investigations needed.	Includes lands, which do not meet the minimum requirements for the other lad classes and are not suitable for irrigation. or small isolated tracts (specifying size or distance from canal) not susceptible to delivery of irrigation water.
Soil Irrigability Class	A	A to B	A to C	A to D		
TOPOGRAPHY						
1. Slope	Less than 1%	1-3%	3-5%	5-10%		
2.Surface grading	No restriction or less than metres excavation per feet. Less than me tre average cut and fill.	Moderate restrictions (specifications to be developed locally)	Moderately severe restrictions (develop specifications locally).	Severe restrictions (develop specification s locally)		
DRAINAGE						
1. Outlets	Suitable outlets available.	Suitable outlets available.	Suitable outlets available.	No drainage outlets available.	Further investigations needed.	
2. Surface	Less than .... metres of shallow surface drains required per acre.	Less than .... metres of shallow surface drains required per acre.	Develop specifications.			
3. Subsurface	No subsurface drainage needed; or land is within ..... metres of adequate drainage way (Nalla or river).	No subsurface drainage needed; or land is within ..... metres of adequate drainage way (Nalla or river).	Subsurface drainage needed. Specifications to be developed.	No natural drainage outlets available, cost of pump off off drainage exceed ...... Rs. / feet.		
4. Depth of water table.	More than 5 metres.	3.0-5 metres.	1.5-3 metres.	1.5 metres and below.		

With regard to items under Topography (2) and Drainage (2) and (3), the criteria will have to be worked out for each project on the basis of local conditions.

APPENDIX – 4

Table 11: Climatolgoical Data

Country : India, Meteo Station: Roorkee, Latitude: $29^0 45'$, Longitude: $77^0 30'$

U day/ U night =2

Altitude: 260.0 m,

SN	Month	Temperature ^{0}C			Humidity (%) RH (mean)	Wind vel. Km/day	Sunshine (hr)	U day m/s	U night m/s	Rainfall (mm) Av.	Remarks
		Maxi.	Minim.	Mean							
1.	Jan.	20.10	6.6	13.35	73	69	6.90	1.90	1.2	24.60	30 years average value of climatological data and 5 years average value of rainfall
2.	Feb.	22.90	8.7	15.8	65	78	7.70	2.60	1.2	37.50	
3.	Mar.	28.70	13.1	20.9	51	86	8.40	3.20	1.3	29.85	
4.	Apr.	35.2	18.2	26.7	39	104	9.70	3.50	1.3	28.50	
5.	May	39.40	23.6	31.5	35	121	10.80	3.0	1.3	19.65	
6.	June	38.50	25.9	32.2	49	121	9.60	3.2	1	67.0	
7.	July	33.30	25.5	29.4	77	95	6.20	2.8	1	289.9	
8.	Aug.	32.30	25	28.65	79	78	6.10	2.40	1.3	354.90	
9.	Sept.	32.40	23.40	27.90	76	69	7.80	2.20	1.3	126.0	
10.	Oct.	30.90	17.20	24.05	70	60	9.0	1.40	1.3	69.80	
11.	Nov.	26.50	10.10	18.3	68	52	8.40	1.80	1.7	6.60	
12.	Dec.	22.0	6.80	14.40	73	60	7.70	1.70	1.3	19.40	

India Meteorological Department
Indian Daily Weather Report
Station: Roorkee,
Year 1959 to 1989
Source : Library, IRI, Roorkee, Yadav(2000), Ground Water Investigation Div., Roorkee.

Table 12: Reference Crop Evapotranspiration by Modified Penman Method

$ETo = c[W.Rn + (1-W).f(U).(ea-ed)]$

SN	Items	Reference table of FAO:24	M			O		N		T		H	S	
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1.	Part A: Aerodynamic Term = (1-W.) f (U). (ea – ed)													
2.	e_a	9	15.385	17.96	24.75	35.07	46.25	48.14	41.02	39.295	37.59	29.80	21.02	16.46
3.	ed= (ea x RH) /100		11.231	11.674	12.623	13.677	16.187	23.589	31.585	31.043	28.568	20.86	14.294	12.016
4.	ea-ed		4.154	6.286	12.127	21.393	30.063	24.551	9.435	8.252	9.022	8.94	6.726	4.444
5.	f(U) = 0.27 (1+U/100)		0.456	0.481	0.502	0.551	0.597	0.597	0.527	0.481	0.456	0.432	0.410	0.432
6.	1-W	15	0.394	0.363	0.295	0.238	0.200	0.198	0.223	0.204	0.231	0.265	0.335	0.386
7.	Part A (Row 4 x 5x 6)		0.746	1.097	1.796	2.805	3.679	2.902	1.108	0.809	0.950	1.023	0.924	0.741
8.	Part B: WRn													
9.	Ra	10	8.925	10.80	13.20	15.20	16.50	16.97	16.75	15.70	14.0	11.70	9.60	8.40
10.	N		6.90	7.70	8.40	9.70	10.80	9.60	6.20	6.10	7.80	9.0	8.40	7.70
11.	N	11	10.415	11.110	12.0	12.89	13.585	13.89	13.88	13.190	12.40	11.50	10.585	10.215
12.	n/N		0.663	0.694	0.7	0.752	0.794	0.686	0.646	0.462	0.629	0.783	0.792	0.755
13.	0.25+0.5 n/N		0.582	0.597	0.60	0.626	0.647	0.593	0.573	0.481	0.565	0.642	0.646	0.628
14.	Rs = Row (9 x 13)		5.194	6.448	7.92	9.515	10.676	10.051	9.598	7.552	7.91	7.511	6.202	5.275
15.	0.75 Rs		3.896	4.836	5.94	7.136	8.007	7.538	7.198	5.664	5.932	5.633	4.651	3.956
16.	f(T)	12	13.37	13.77	14.78	16.04	17.075	17.25	16.58	16.03	16.28	15.413	14.26	13.56
17.	f (ed)	13	0.192	0.189	0.184	0.177	0.163	0.126	0.093	0.095	0.104	0.139	0.174	0.187
18.	f(n/N)	14	0.697	0.725	0.73	0.777	0.815	0.717	0.681	0.516	0.666	0.805	0.813	0.780
19.	Rnl = Row(16x17x 18)		1.789	1.887	1.985	2.206	2.268	1.558	1.050	0.786	1.128	1.725	2.017	1.980
20.	Rn =Row 15 –Row 19		2.107	2.949	3.955	4.93	5.739	5.98	6.148	4.878	4.804	3.908	2.634	1.976
21.	W	15	0.605	0.637	0.705	0.762	0.80	0.802	0.777	0.778	0.775	0.735	0.665	0.614
22.	Part B: WRn = Row (21 x 20)		1.276	1.893	2.962	3.757	4.555	4.82	4.813	3.795	3.718	2.872	1.765	1.227
23.	Part A + Part B, Row (7+22)		2.022	2.975	4.49	6.562	8.18	7.663	5.892	4.676	4.648	3.895	2.675	1.955
24.	Part c	16	0.99	0.990	0.96	1.10	1.11	1.10	1.10	1.04	1.02	1.04	1.05	0.995
25.	ET_O mm/day = c x Row 23		2.00	2.940	4.310	7.218	9.08	8.43	6.48	4.863	4.74	4.05	2.808	1.94

Total ET_O of 1 year = 179.03 cm, say 179.0 cm.

Table 13 : Existing Cropping Pattern in Study Area

Sl. No.	Season	Name of Crop	Cropping Intensity %	Growing period	Growing periods	Remarks.
1.	Kharif	1. Paddy 2. Fodder(K) (sorghum)	26 20	15th June to 15th Oct. 15th July to Sept.	123 days 78 days	Sorghum (Jowar)
2.	Rabi	1. Wheat 2. Oilseed (Mustard) 3. Fodder (Berseem) 4. Pulse (green gram)	32 6 6 4	15th Nov.to 25th Mar. 1 Nov. to 16th Feb. 1 Oct. to 31st May 1 March to 31st May	131 days 108 days 242 days 92 days	Mung (green gram)
3.	Annual	1. Sugarcane	50	Ist Jan. to 31st Dec.	365 days	
		Total	144%			

Table 14 : G.I.R. Estimation of Rice

(i) Date of sowing : 15th June

(ii) Date of harvesting : 15th Oct.

(iii) Growing period : 123 days.

Sl. No.	Particulars	MONTHS					REMARKS
		June	July	Aug.	Sept.	Oct.	
1	ET_O (mm / day)	8.43	6.48	4.863	4.740	4.05	$P_e = 0.8\,P - 25$ if $P > 75$ mm/ month; $P_e = 0.6\,P - 10$ if $P < 75$ mm /month
2	K_C	1.125	1.28	1.20	1.01	1.00	
3	$ET_C = K_C \times ET_O$ (mm/day)	9.484	8.294	5.836	4.787	4.05	
4	ET_C (period) mm.	151.74	257.126	180.90	143.622	60.75	
5	**Special needs**						
	Land preparation,	30	50	-	-	-	
	Nursery	30					
	Standing water	-	100	-	-	-	
	Deep percolation	-	50	150	150	40	
	Total	60	200	150	150	40	
6	Cu (mm)	211.74	457.126	330.9	293.622	100.75	
7	Av. rainfall (mm)	67	289.9	354.90	126.0	69.80	
8	Effective rainfall (mm)	50.00	206.92	258.92	75.80	40	
9	NIR (mm)	161	250.21	71.98	217.82	60	
10	FIR (mm)	201.25	312.76	89.97	272.28	75	
11	GIR (mm)	252.27	390.75	112.47	340.35	94.92	

Table 15 : GIR Estimation of Fodder (Kharif i.e. Sorghum)

(i) Sowing Date : 15th July

(ii) Harvesting Date : 31st September

(iii) Growing period : 78 days

SN	PARTICULARS	MONTHS			REMARKS
		July	Aug.	Sept.	
1	ET_O (mm / day)	6.48	4.863	4.74	SORGHUM (BAJRA) has been taken as a fodder crop in khraif season.
2	K_C	0.5	0.96	0.77	
3	$ET_C = K_C \times ET_O$ (mm/day)	3.24	4.668	3.65	
4	ET_C (period) mm.	55.08	144.708	109.50	
6	Cu (mm)	55.08	144.708	109.50	
7	Av. rainfall (mm)	289.90	354.90	126.00	
8	Effective rainfall (mm)	55.08	144.708	85.84	
9	NIR (mm)	-	-	23.66	
10	FIR (mm)	-	-	29.58	
11	GIR (mm)	-	-	36.70	

Table 16 : G.I.R. Estimation of Wheat

(i) Sowing date : 15th Nov.

(ii) Harvesting date : 25th March.

(iii) Growth period : 131 days.

SN	PARTICULARS	MONTHS				
		Nov.	Dec.	Jan.	Feb.	Mar.
1	ETo (mm/day)	2.808	1.94	2.00	2.94	4.31
2	Kc	0.35	0.70	0.98	0.70	0.32
3	ETc=Kc x ETo (mm/day)	0.983	1.358	1.96	2.058	1.379
4	ETc (Period) mm.	15.724	42.098	60.76	57.624	42.75
5	Cu (mm)	15.724	42.098	60.76	57.624	42.75
6	Av. rainfall (mm)	6.60	19.40	24.60	37.50	29.85
7	Effective rainfall (mm)	-	-	-	28.08	20.6
8	NIR(mm)	15.724	42.098	60.76	29.62	22.15
9	FIR (mm)	19.66	52.62	75.95	37.03	27.65
10	GIR (mm)	24.47	65.78	105.59	50.02	34.6

Table 17 : G.I.R. Estimation of oilseed (Mustard)

(i) Sowing date : 1Nov.

(ii) Harvesting date : 16 Feb.

(iii) Growing period :108 days.

SN	PARTICULARS	MONTHS				REMARKS
		NOV	Dec.	Jan.	Feb.	
1	ETo (mm/day)	2.808	1.940	2.00	2.940	(i) Mustard is a oilseed crop. (ii) Sunflower has been taken as a oilseed crop for Mustard here.
2	Kc	0.54	0.97	0.86	0.54	
3	ETc= Kc x ETo (mm/day)	1.516	1.882	1.72	1.587	
4	ETc (Period) (mm/day)	45.48	58.342	53.32	44.45	
5	Cu (mm)	45.48	58.342	53.32	44.45	
6	Av. rainfall (mm)	6.60	19.40	24.60	37.50	
7	Effective rainfall (P_e) (mm)	-	-	-	28.08	
8	NIR(mm) = Cu $-P_e$	45.48	58.342	53.32	16.37	
9	FIR (mm) = NIR /0.80	56.85	72.93	66.65	20.46	
10	GIR (mm) = FIR / 0.8	71.06	91.16	83.31	24.4	

Table 18 : G.I.R. Estimation of Fodder (Rabi – Berseem)

(i) Sowing date : 1st Oct.

(ii) Harvesting date : 31st May

(iii) Growing period : 242 days.

SN	Particulars	MONTHS								Remarks
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	
1	ETo (mm/day)	4.05	2.808	1.94	2.00	2.94	4.31	7.218	9.08	Alfalfa is taken as a crop for berseem. Alfalfa is a grass. For crop development stage, mid season stage and late season stage value of K_c has been taken same as wheat.
2	Kc	0.35	0.70	0.75	1.08	1.125	0.75	0.70	1.07	
3	ETc= Kc x ETo (mm/day)	1.417	1.966	1.455	2.16	3.308	3.233	5.053	9.716	
4	ETc (Period) (mm/day)	43.943	58.968	45.105	66.96	92.61	100.208	151.578	301.184	
5	Cu (mm)	43.943	58.968	45.105	66.96	92.61	100.208	151.578	301.184	
6	Av. rainfall (mm)	69.80	6.50	19.3	24.60	37.50	29.85	28.50	19.65	
7	Effective rainfall (mm)	43.943	-	-	-	28.08	21.60	21.0	-	
8	NIR(mm)	-	58.968	45.105	66.96	64.53	78.61	130.58	301.184	
9	FIR (mm)	-	73.71	56.38	83.70	80.66	98.26	163.23	376.48	
10	GIR (mm)	-	92.13	70.48	104.63	100.83	122.83	204.03	470.60	

Table 19 : GIR Estimation of MUNG (Pulse)

(i) Sowing Date : 1st March

(ii) Harvesting Date : 31st May

(iii) Growing period : 92 days

SN	Particulars	MONTHS		
		Mar.	Apr.	May
1	ET_O (mm / day)	4.31	7.218	9.08
2	K_C	0.46	1.015	0.69
3	$ET_C = K_C \times ET_O$ (mm/day)	1.983	7.326	6.265
4	ET_C (period) mm.	61.473	219.78	194.215
5	Cu (mm)	61.43	219.78	194.215
6	Av. rainfall (mm)	29.85	28.5	19.65
7	Effective rainfall (mm)	20.60	20.58	-
8	NIR (mm)	40.87	192.18	194.215
9	FIR (mm)	51.08	240.23	242.77
10	GIR (mm)	63.86	300.30	303.460

Table 20: GIR Estimation of Sugarcane

(i) Sowing Date : 1st Jan.

(ii) Harvesting Date : 31st Dec.

(iii) Growing period : 365 days

SN	PARTICULARS	M		O		N		T		H		S	
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1.	ET_O (mm / day)	2.0	2.94	4.31	7.218	9.08	8.43	6.48	4.863	4.74	4.05	2.808	1.94
2.	K_C	0.45	0.51	0.85	0.85	0.90	1.15	1.15	1.05	0.78	0.78	0.71	0.55
3.	$ET_C = K_C \times ET_O$ (mm/day)	0.9	1.50	3.66	6.14	8.17	9.70	7.45	5.10	3.69	3.16	2.0	1.07
4.	ET_C (period) mm.	27.90	42	113.46	184.2	253.27	291.0	230.95	158.10	110.70	97.96	60.0	33.17
5.	Cu (mm)	27.90	42	113.46	184.2	253.27	291.0	230.95	158.10	110.70	97.96	60.0	33.17
6.	Av. rainfall (mm)	24.60	37. 5	29.85	28.50	19.65	67.0	289.90	354.90	126.0	69.80	6.50	19.3
7.	Effective rainfall (mm)	-	25	23	22	-	67.0	215.60	158.1	86.10	50.26	-	-
8.	NIR (mm)	27.90	17.0	91.46	161.20	253.27	224.00	15.35	-	24.60	47.70	60.0	33.17
9.	FIR (mm)	34.87	21.25	114.32	201.50	316.59	280.0	19.19	-	30.75	59.63	75	41.46
10.	GIR (mm)	43.59	26.56	142.90	251.88	395.73	350.0	24.0	-	38.44	74.53	93.75	51.83

Table 21: Gross Irrigation Requirement of Right Main Distributary Command (ha-m)

Total CCA = 5890 ha

SN	Crop	C.I (%)	Area (ha)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1.	Kharif	46														
	Paddy	26	1531.40	-	-	-	-	-	386. 22	598.7	172.24	520. 68	145. 50	-	-	1823.34
	Fodder (sorghum)	20	1178.00	-	-	-	-	-	-	-	-	43.23	-	-	-	43.23
2.	Rabi															
	Wheat	32	1884.80	199.04	94.24	65.21	-	-	-	-	-	-	-	46.31	123.98	528.78
	Oilseeds	6	353.40	30.04	9.05	-	-	-	-	-	-	-	-	25.11	32.22	96.42
	Pulse (Mung)	4	235.60	-	-	15.05	70.75	71.50	-	-	-	-	-	-	-	157.30
	Fodder (Berseem)	6	353.40	36.98	35.63	43.40	72.10	166.31	-	-	-	-	-	32.58	24.90	411.91
3.	Annual															
	Sugarcane	50	2945.00	128.37	78.22	420.84	741.78	1165.42	1030.75	70.68	-	113.20	219.50	276.09	152.64	4397.49
	Total	144	8481.60	394.43	217.14	544. 5	884.63	1403.23	1416.97	669.38	172.24	677.11	365.00	380.09	333.78	7458.50 ≅ 7460

DETERMINATION OF VALUE OF K_C FOR CROPS

1. PADDY

1. Initial stage @ 15% of growth stage = 123 x 15/100 = 18.45 ≅ 20 days.
   i.e. from 15th June to 4th July.
2. Crop development stage @ 25% = 123 x 25/100 = 30.75 days ≅ 30 days
   5th July to 3rd August
3. Mid season stae @ 25% = 30 days.
   4th August to 2nd September
4. Late season stage @ 25% = 30 days
   3rd September to 2nd October
5. Harvesting stage @ 10% = 123 x 10/100 = 12.3 days = 13 days.
   3rd October to 15th October

Value of K_C (FAO Table 18)

1. Value of K_C is taken as mean of minimum and maximum. The reason is that RH_{min} is neither high nor low. It is medium, so average value is considered.
2. Value of K_C is averaged (weighted) stage-wise

June

15th June to 30th June = 16 days = ½ (1.1+1.5) x 16 = 18

July 4 day = Initial stage = 4 x K_{cav} = 4 x ½(1.1 +1.5) = 4.5

July 5 to 31st = 27 days = 27 x 1.3 =35.1

Total in July = 4.5 + 35.1 = 39.6

Average per day = 39.6/31 = 1.28

August

3 days = crop development stage = 3 x 1.3 = 3.9

4th August to 31st August = 28 days (mid season stage)

= 28 x 1.2 = 33.6

$$\text{Average in August} = \frac{3.9+33.6}{31} = 1.20$$

September

2 days = mid season stage = 2 x 1.2 = 2.4

28 days = late season stage = ½ (0.95 + 1.05) x 28 = 1 x 28 = 28

Total in Sept. = 2.4 + 28 = 30.4

Average in 30 days = 30.4/30 = 1.01

October

2 days = Late season stage = 2 x 1.01 = 2.02

13 days = Harvesting stage = 13 x 1.0 = 13

$$\text{Average} = \frac{(2.02 + 13)}{15} = 1.00$$

2. WHEAT

Cropping period 15th Nov. to 25th March = 131 days

1. Initial stage @ 15% of growth stage = 131 x 15/100 = 19.65 = 20 days

   i.e. from 15th Nov. To 4th December

2. Crop development stage @ 25% = 131 x 25/100 = 32.75 ≅ 30 days

   i.e. from 5th Dec. to 3rd Jan.

3. Mid season stage @ 25% = 30 days

   i.e. from 4th Jan. to 2nd Feb.

4. Late season stage @ 25% = 30 days

   = 3rd Feb. to 4th March.

5. Harvesting stage @ 10% = 131 x 10/100 = 13.1 days = 21 days

   i.e. from 5th March to 25th March.

Value of K_C

1. November

15th Nov. to 30th Nov. = 16 days = 16 x ½(0.3 + 0.4)

= 16 x 0.35 = 5.6

AV K_C = 5.6/16 = 0.35

2. **December**

4 days in initial stage = 4 x 0.35 = 1.4

27 days in crop development stage

= 27 x ½ (0.7+0.8) = 27 x 0.75

= 20.25

Average value = $\frac{1.4 + 20.25}{31}$ = 0.70

3. **January**

3 days = crop development stage = 3 x 0.75 = 2.25

28 days = Mid season stage = 28 x ½ (1.05 + 1.2)

=31.5

Average value = $\frac{2.25 + 31.5}{31}$ = 1.09

4. **February**

2 days in mid season stage = 2 x 1.125 = 2.25

3rd Feb. to 28th Feb. i.e. 26 days in late season

= 26 x 0.70 = 18.2

Average value = $\frac{2.25 + 18.2}{28}$ = 0.73

5. **March**

5 days in late season stage = 5 x 0.7 = 3.5

20 days in harvesting stage = 20 x ½ (0.2 + 0.25) = 4.5

Average value of K_C = $\frac{3.5 + 4.5}{25}$ = 0.32

3. OILSEED : MUSTARD

Growing period 1 Nov. to 16th Feb. = 108 days.

Initial stage @ 15% of growth stage = 15/100 x 108 = 16.2 days ≅ 16 days.

i.e. from 1st Nov. to 16th Nov.

Crop development stage @ 25% of growth stage = 108 x 25/100 = 27 days

i.e. from 17th Nov. to 13th December

Mid season stage @ 25% of growth stage = 27 days

i.e. from 14th Dec. to 9th January.

Late season stage @ 25% = 27 days

i.e. from 10th January to 6th February

Harvesting stage @ 10% = 108 x 10/100 = 10.8 days

i.e. from 7th Feb. to 16th February.

Value of K_C : Assuming sunflower as oilseed.

i) November (a) 16 days in initial stage

= 16 x 0.35 = 5.6

(b) 14 days in crop development stage

= 14 x 0.75 = 10.5

(c) Total = 5.6 + 10.5

(d) Av. K_C = 16.1 /30 = 0.54

ii) December (a) 13 days in crop development stage

= 13 x 0.75 = 9.75

(b) 18 days in mid season stage

= 18 x 1.125 = 20.25

(c) Total = 9.75 + 20.25 = 30

(d) $\text{Av. } K_C = \frac{\text{Total } K_C}{\text{No. of days in a month}}$

= 30/31 = 0.97

iii) January (a) 9 days in mid season stage

= 9 x 1.125 = 10.125

(b) 22 days in late season stage

= 22 x 0.775 = 17.05

(c) Total = 10.125 + 17.05 = 27.3

(d) Av. $K_C = \frac{\text{Total } K_C}{\text{No. of days in a month}}$

= 27.3 /31 = 0.88.

iv) February (a) 6th days in late stage

= 6 x 0.775 = 4.65

(b) 10 days in harvest stage

= 10 x 0.4 = 4.0

(c) Total = 4.65 + 4.0 = 8.65

(d) Av. K_C = 8.65/16 = 0.54

4. FODDER : BERSEEM (Taking Alfalfa as crop)

Growing season = 1 Oct. to 31st May = 242 days

i) Initial stage @ 15% = 242 x 15/100 = 36.3 days ≅ 35 days

i.e. from 1st Oct. to 4th Nov.

ii) Crop development stage @ 25% = 242/25/100 = 60.5 days ≅ 60 days

i.e. from 5th Nov. to 3rd January..

iii) Mid season stage @ 25% = 60 days

i.e. from 4th January to 4th March.

iv) Late season stage @ 25% = 60 days

i.e. from 5th Mach to 4th May.

v) Harvesting stage @ 10% = 242 x 10/100 = 24.2 days ≅ 27 days

i.e. from 5th May to 31st May

Value of K_C

October

31 days in initial stage = 31 x 0.35 = 10.85

Av. K_C = 10.85/31 = 0.35

November

a) 4 days in initial stage = 4 x 0.35 = 1.4

b) 26 days in crop development stage

= 26 x 0.75 = 19.5

Note : K_c value of wheat is considered for mid and late season stages.

c) Total K_C = 1.4 + 19.5 = 20.9

d) Av. K_C = 20.9/30 = 0.70

December

31 days in crop development stage = 0.75

January

a) 3 days in crop development stage = 3 x 0.75 = 2.25

b) 28 days in mid season stage

= 28 x 1.125 = 31.5

c) Total = 2.25 + 31.5 = 33.75

d) Av. K_C = 33.75/31 = 1.08

February

28 days in mid season stage = 1.125

March

a) 4 days in mid season stage

= 4 x 1.125 = 4.5

b) 27 days in late season stage

= 27 x 0.70 (value from wheat crop)= 18.9

c) Total = 4.5 + 18.9 = 23.4

d) Av. K_C = 0.75

April

Av. K_C = 0.7

May

a) 4 days in late season stage

= 4 x 0.7 = 2.8

b) 27 days in harvesting stage

$= 27 \times 1.125 = 30.375$

c) Total $K_C = 2.8 + 30.375 = 33.175$

d) Av. $K_C = \dfrac{\text{Total } K_C}{\text{No. of days in a month}}$

$= 33.175 / 31 = 1.07$

5. <u>MUNG</u> : Pea is taken for mung.

6. <u>FODDER (KHARIF) :</u> SORGHUM

Growing period = 15th July to Sept. = 78 days

i) Initial stage @ 15% = 78 x 75/100 = 11.7 days ≅ 10 days
i.e. from 15st July to 24th July.

ii) Crop development stage @ 25% = 78 x 25/100 = 19.5 days ≅ 20 days
i.e. from 25th July to 13rd August.

iii) Mid season stage @ 25% = 20 days
i.e. from 14th Aug. to 14th Sept.

iv) Late season stage @ 25% = 20 days
i.e. from 4th Sept. to 23rd Sept.

v) Harvesting stage @ 10% = 78 x 10/100 = 7.8 days
i.e. from 24th Sept. to 31st Sept.

Value of K_C

July

a) 10 days in initial stage = 10 x 0.35 = 3.5

b) 7 days in crop development stage = 7 x 0.725 = 5.075

c) Total = 3.5 + 5.075 = 8.575

d) Av. K_C = 8.575 / 17 (days) = 0.5

August

a) 13 days in crop development stage = 13 x 0.725 = 9.425

b) 18 days in mid season stage = 18 x 1.125 = 20.25

c) 9.425 + 20.25 = 29.675

d) Av. K_C = 29.675 / 31 = 0.96

September

a) 3 days in mid season stage = 3 x 1.125 = 3.375

b) 20 days in late season stage = 20 x 0.775 = 15.5

c) 8 days in harvesting stage = 8 x 0.525 = 4.2

d) Total = 3.375 +15.5 + 4.2 = 23.075

a) Av. K_C = 23.075 / 30 = 0.77

7. SUGARCANE

Growing period = 1st January to 31st December = 365 days

i) Initial stage @ 15% = 365 x 15/100 = 54.75 days ≅ 55 days
i.e. from 1st January to 24th February.

ii) Crop development stage @ 25% = 365 x 25/100 = 91.25 ≅ 90 days
i.e. from 25th Feb. to May 25

iii) Mid season stage @ 25% = 90 days
i.e. from 26 May to 23rd August.

iv) Late season stage @ 25% = 90 days
i.e. from 24th August to 21 Nov.

v) Harvesting stage @ 10% = 365 x 10/100 = 36.5 days ≅40 day
i.e. from 22 Nov. to 31 Dec.

Value of K_C

January

31 days in initial stage = 0.45

February

a) 24 days in initial stage = 24 x 0.45 = 10.8

b) 4 days in mid season stage = 4 x 0.85 = 3.4

c) Total = 10.8 +3.4 = 14.2

d) Av. K_C = 14.2 / 28 = 0.51

March

31 days in crop development stage = 0.85

April

K_C = 0.85

May

a) 25 days in c.d. stage = 25 x 0.85 = 21.25

b) 6 days in mid season stage = 6 x 1.15 = 6.9

c) Total = 21.25 +6.9 = 28.15

d) Av. K_C = 28.15 / 31 = 0.90

June and July = 1.15

August

a) 23 days in mid season stage = 23 x 1.15 = 26.45

b) 8 days in late season stage = 8 x 0.775 = 6.2

c) Total = 26.45+ 6.2 = 32.65

d) Av. K_C = 32.65 / 31 = 1.05

September & October = 0.775

November

a) 21 days in late season stage = 21 x 0.775 = 16.275

b) 9 days in harvesting stage = 9 x 0.55 = 4.95

c) Total = 16.275 + 4.95

d) Av. K_C = 21.225 / 30 = 0.71

December 0.55

APPENDIX -- 5

Table 22: AQUIFER CHARACTERISTICS (based on Pump Test)

D= Dist., B = Block., V = Village.

S.N	1st block/place	Duration of Test (Minutes)	Av.Disch. (m^3/day)	St.Coeff. (S)	Specific yield (Sy)	Transmissivity (T) (m^2/day)	Radius of Influence (m)	Total depth (m)
1	2	3	4	5	6	7	8	9
1.	D-Saharanpur B-Deoband V-PWD IH	NA	NA	$5.4x10^{-3}$	-	429.81	-	NA
2.	D-Spur B-Deoband V-STW 41	NA	NA	$2.73x10^{-2}$	-	5565.71	-	NA
3.	D-Hardwar B-Roorkee V.STW Iqbal	NA	NA	$2.92x10^{-2}$	-	1189.95	-	NA
4.	D-Hardwar B-Roorkee V-PTW Saliyar	-	-	$2.00x10^{-2}$	-	335.00	-	-
5.	D-Hardwar B-Laksar V-PTW B. TANDA	-	-	$7.65x10^{-3}$	20.27	1028.56	106	-
6.	D-Hardwar B-Rampur V-R.P. MAN HARAN	-	-	$1.38x10^{-3}$	13.06	951	128	-
7.	D-Hardwar B-Roorkee V-Lather Deva	1000	738.0	$1.89x10^{-3}$	14.68	807.11	111	59
8.	D-Saharanpur B-G.Narsan V-Nagla Amad	NA	NA	$2.42x10^{-3}$	16.96	1072.50	119	NA
9.	D-M.Nagar B-Khatauli V-IH Khatauli	-	-	$5.36x10^{-3}$	-	1195.56	-	-
10.	D-M.Nagar B-Morna V-Gadala	1200	1073.45	$2.39x10^{-3}$	15.62	633.81	96	56
11.	D-M.Nagar B-Purkazi V-Purkazi	850	984.0	$6.74x10^{-4}$	15.26	613.81	94	60
12.	D-M.Nagar B-Morna V-Bhadaheri	1100	2051.04	$1.31x10^{-3}$	16.77	1372.25	132	60
13.	D-M.Nagar B-Jansath V-Kaval	1100	902.35	$1.85x10^{-3}$	17.58	1657.24	145	60
14.	D-M.Nagar B-M.Nagar V-Nirana	1210	1280	$8.71x10^{-3}$	14.38	1485.35	153	60
15.	D-M.Nagar B-Charthawal V-Baheri	1150	1280	$3.67x10^{-4}$	16.85	543.99	85	585

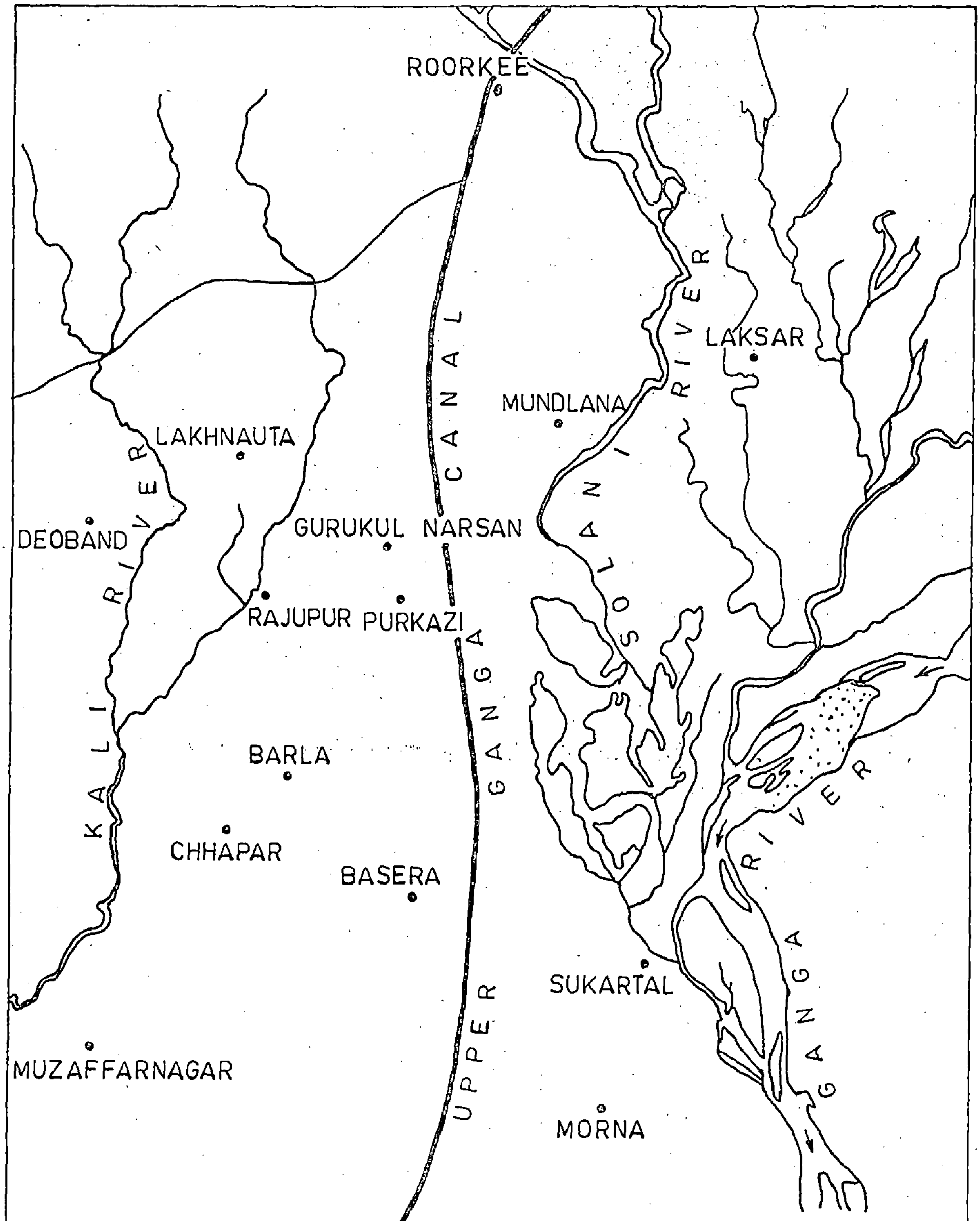

Fig. 4 - HYDROGRAPHIC STATION

Table 23: Total Canal Water Supply in Study Area (ham)

Month	CH – 01		CH – 02		CH – 03		CH – 04		CH – 05		CH – 06		CH – 07		CH – 08		Total
	RD	CHDEL	RD	CHDEL	RD	CHDEL	RD	CHDEL	RD	CHDEL	RD	CHDEL	RD	CHDEL	RD	CHDEL	
Jan	7	16.9	7	116.7	7	25.7	7	12.0	7	127	14	750	2	81.2	7	205.6	1335.1
Feb	7	16.9	7	116.7	7	25.7	7	12.0	7	127	7	375	7	284.2	7	205.6	1163.1
Mar	7	16.9	7	116.7	7	25.7	7	12.0	7	127	7	375	7	284.2	7	205.6	1163.1
Apr	7	16.9	13	216.8	13	47.7	13	22.5	13	235	13	696.4	6	243.6	13	381.8	1860.7
May	16	38.7	16	266.8	15	55	15	55.9	24	435	22	1178.5	24	974.6	16	470.01	3474.5
June	16	38.7	18	300.2	14	51.4	14	24	30	544	30	1607	30	1218.2	14	411.3	4194.8
July	14	33.8	21	350.2	14	51.4	14	24	31	562	31	1660.6	31	1258.8	21	616.8	4557.6
Aug	14	33.8	17	283.5	16	58.7	16	27.6	31	562	31	1660.6	31	1258.8	21	616.8	4501.8
Sep	14	33.8	25	416.9	21	77.1	21	36.0	30	544	30	1607	30	1218.2	20	587.5	4520.5
Oct	14	33.8	14	233.5	16	58.7	16	27.6	21	381	21	1125	21	852.6	17	499.4	3211.6
Nov	10	24.19	10	166.7	10	36.7	10	17.2	7	127	7	375	7	284.2	7	205.6	1236.6
Dec	7	16.9	7	116.7	7	25.7	7	12	7	127	7	375	7	284.2	9	264.4	1221.9

RD = Running days of canal in a month

CH 01 = Gadarjuda minor, CH02 = Sidhauli dy, CH03 = Majhol dy, CH04 = Saloni minor, CH05 = Tansipur dy, CH06 = Right mohd. dy, CH07 = Basera dy, CH08 = RMD.

Table 24: Canal Water Supply Per Unit Area

Month	Quantity of water (m^3)	Depth of canal water applied per unit area (m)
Jan	1335.1×10^4	0.0413
Feb	1163.1×10^4	0.0360
Mar	1163.1×10^4	0.0360
Apr	1860.7×10^4	0.0576
May	3474.5×10^4	0.1075
June	4194.8×10^4	0.1299
July	4557.6×10^4	0.1411
Aug	4501.8×10^4	0.1394
Sept	4520.5×10^4	0.1399
Oct	3211.6×10^4	0.0994
Nov	1236.60×10^4	0.03828
Dec	1221.9×10^4	0.0378

Table 25: Abstraction by Tubewell

Month	CWR (ham)	Canal supply (ham)	Deficit of water (ham)	Deficit of water per unit area (m)	CWR Per unit area (m)
Jan	394.43	205.632	188.798	0.0321	0.067
Feb	217.14	205.632	12.00	0.0020	0.037
Mar	544.50	205.632	338.868	0.0580	0.092
Apr	884.63	381.888	502.742	0.0850	0.150
May	1403.23	470.016	933.214	0.158	0.238
June	1416.97	411.264	1005.706	0.1710	0.241
July	669.38	616.896	52.404	0.0089	0.114
Aug	172.24	616.896	-	-	0.029
Sept	677.11	587.52	89.59	0.0152	0.115
Oct	365.00	499.392	-	-	0.062
Nov	380.09	205.632	174.418	0.0296	0.064
Dec	333.78	264.384	69.396	0.0120	0.057
Total	7460	4670	3370	-	-

```
$DebuG
C       IN THIS PROGRAMME THE HEADS AT VARIOUS NODES HAVE B
EEN FOUND
C       DIRECTLY USING MATRIX INVERSION METHOD.

        DIMENSION  DELX(4),DELY(6),JINI(6),JFIN(6),T(6,4),S
(6,4)
        DIMENSION  CSEEP(12),RAIN(12),APPI(12),GWITHD(12),G
POT(12)
        DIMENSION  RTK4(6),RTG2(6),RSK4(6,0:12),ARISE(12)
        DIMENSION  RSG2(6,0:12)
        DIMENSION  UGRAD(4,12),BGRAD(4,12), H(6,4,0:12)
        DIMENSION  QP(6,4,12),QR(6,4,12)
      DIMENSION  FC1(6,4),FC2(6,4),FC3(6,4),FC4(6,4),
     1           FC5(6,4),FC6(6,4,12),HSOL(24),
     2           A(24,24),RIGHT(24),AA(24,24),AAAA(24,24)
,
     3  SEEPG(12),SEEPK(12),SEEPBI(12),SEEPBO(12),RECH(12),
PUMP(12),
     4  DSTOR(12),QR1(6,4,12),QR2(6,4,12),QR3(6,4,12),RECH1
(12),
     5  RECH2(12),RECH3(12),RESIDUE(12)
        OPEN(1,FILE='YADAVY.DAT',STATUS='OLD')
        OPEN(2,FILE='YADAVY.OUT',STATUS='UNKNOWN')
C
        READ(1,*)W1,W2
        READ(1,*)IMAX,JMAX
        READ(1,*) (JINI(I),JFIN(I),I=1,IMAX)

        WRITE(2,101)
101     FORMAT(9X,'I',6X,'JINI(I)',5X,'JFIN(I) ')
        WRITE(2,50)(I,JINI(I),JFIN(I),I=1,IMAX)
50      FORMAT(5X,I5,5X,I5,5X,I5)
        WRITE(2,102)
102     FORMAT(9X,'J',5X,'DELX(J)')

        READ(1,*) (DELX(J),J=1,JMAX)
        WRITE(2,51)(J,DELX(J),J=1,JMAX)
51      FORMAT(5X,I5,5X,F8.2)
        WRITE(2,103)
103     FORMAT(9X,'I', 5X,'DELY(I)')

        READ(1,*) (DELY(I),I=1,IMAX)
        WRITE(2,51)(I,DELY(I),I=1,IMAX)
        WRITE(2,104)
104     FORMAT(6X,'DELT',7X, 'NTIME')

        READ(1,*) DELT,NTIME
```

```
      WRITE(2,52)DELT,NTIME
52    FORMAT(F10.2,5X,I5)
C     RTK4(I)=REACH TRANSMISSIVITY CONSTANT FOR KALI
C     IN X DIRECTION
C     RTG2(I)=REACH TRANSMISSIVITY CONSTANT FOR GANGA CAN
AL
C             IN X DIRECTION
C

53    FORMAT(I5,5X,F8.2)

      READ(1,*)(RAIN(K),K=1,NTIME)
      READ(1,*)(APPI(K),K=1,NTIME)
      READ(1,*)(GWITHD(K),K=1,NTIME)
      READ(1,*)(CSEEP(K),K=1,NTIME)
      READ(1,*)SYIELD,CRRECH,CAIR,CSEEPF,FACT1


C
C     TRANSMISSIVITY VALUES ARE BEING READ
C
C     WRITE(2,*)'TRANSMISSIVITY VALUES'

      DO I=1,IMAX
      DO J=1,JMAX
C     READ(1,*)  (T(I,J),J=JINI(I),JFIN(I))
C     WRITE(2,54)(T(I,J),J=JINI(I),JFIN(I))
      T(I,J)=843.*30.
      END DO
      END DO


C
C     STORAGE COEFFICIENT VALUES ARE BEING READ
C
C     WRITE(2,*)'STORATIVITY VALUES'
      DO I=1,IMAX
      DO J=1,JMAX
C     READ(1,*)  (S(I,J),J=JINI(I),JFIN(I))
C     WRITE(2,54)(S(I,J),J=JINI(I),JFIN(I))
      S(I,J)=SYIELD
      END DO
      END DO
C
```

```
      WP=79.4
      THICK=93.
      TRANS=843.*30.
      REACHTG=0.5*TRANS/THICK*((0.5*WP+THICK)/(0.5*(DELX(
1)+THICK)))

      DO I=1,IMAX
      RTK4(I)=T(I,1)*2./DELX(1)*FACT1
      RTG2(I)=REACHTG
      END DO
C
      WRITE(2,105)
105   FORMAT('ROW NO',5X,'REACH TRANSMISSIVITY OF RIVER K
ALI')
      WRITE(2,53)(I,RTK4(I),I=1,IMAX)
      WRITE(2,106)
106   FORMAT('ROW NO',5X,'REACH TRANSMISSIVITY OF GANGA C
ANAL')
      WRITE(2,53)(I,RTG2(I),I=1,IMAX)
C
C
      DO K=1,NTIME
      DO J=JINI(1),JFIN(1)
      UGRAD(J,K)=0.002
      END DO
      END DO
C
C
C
      DO K=1,NTIME
      DO J=JINI(IMAX),JFIN(IMAX)
      BGRAD(J,K)=0.002
      END DO
      END DO
C
C
C     PUMPING RATES ARE BEING DEFINED

C
      DO K=1,NTIME
      DO I=1,IMAX
      DO J=1,JMAX
      QP(I,J,K)=GWITHD(K)*DELX(J)*DELY(I)
      QR(I,J,K)=(RAIN(K)*CRRECH+APPI(K)*CAIR+CSEEP(K)*CSE
EPF)
     1 *DELX(J)*DELY(I)
      QR1(I,J,K)=RAIN(K)*CRRECH*DELX(J)*DELY(I)
      QR2(I,J,K)=APPI(K)*CAIR*DELX(J)*DELY(I)
```

```
      QR3(I,J,K)=CSEEP(K)*CSEEPF*DELX(J)*DELY(I)
      END DO
      END DO
      END DO
C
C
C     INTIAL HEAD VALUES ARE BEING READ
C
C    WRITE(*,*)'INITIAL HEAD '
      DO I=1,IMAX
      DO J=1,JMAX
      H(I,J,0)=254.205
      END DO
      END DO
54    FORMAT(5F10.5)
C
C     KALI RIVER STAGES ARE BEING DEFINED
C
      DO K=1,NTIME
      DO I=1,IMAX
      RSK4(I,K)=245.
      END DO
      END DO
C
C
C
      DO  I=1,IMAX
      RSK4(I,0)=RSK4(I,1)
      END DO
C
C     GANGA CANAL  STAGES ARE BEING DEFINED
C
      DO K=1,NTIME
      DO I=1,IMAX
      RSG2(I,K)=262.
      END DO
      END DO
C
C
C
      DO I=1,IMAX
      RSG2(I,0)=RSG2(I,1)
      END DO
C
C
C
C     COEFFICIENTS OF HEADS AT INTERIOR NODES
```

```
C       IN FINITE DIFFERENCE EQUATION
C
        DO 40 I=2,IMAX-1
        DO J=JINI(I)+1,JFIN(I)-1

        HMT2=(DELX(J)+DELX(J+1))/(DELX(J)/T(I,J)+DELX(J+1)/
T(I,J+1))
        HMT3=(DELY(I)+DELY(I+1))/(DELY(I)/T(I,J)+DELY(I+1)/
T(I+1,J))
        HMT4=(DELX(J)+DELX(J-1))/(DELX(J)/T(I,J)+DELX(J-1)/
T(I,J-1))
        HMT5=(DELY(I)+DELY(I-1))/(DELY(I)/T(I,J)+DELY(I-1)/
T(I-1,J))

        TERML2=2./((DELX(J)+DELX(J+1))*DELX(J))
        TERML3=2./((DELY(I)+DELY(I+1))*DELY(I))
        TERML4=2./((DELX(J)+DELX(J-1))*DELX(J))
        TERML5=2./((DELY(I)+DELY(I-1))*DELY(I))

        FC2(I,J)=HMT2*TERML2
        FC3(I,J)=HMT3*TERML3
        FC4(I,J)=HMT4*TERML4
        FC5(I,J)=HMT5*TERML5
        FC1(I,J)=-S(I,J)/DELT-W2*(FC2(I,J)+FC3(I,J)+FC4(I,J
)+FC5(I,J))
        END DO
40      CONTINUE

C
C       GENERATION OF COEFICIENTS FOR  NODES FOR TOP BOUNDA
RY
C       EXCEPT CORNER NODES
C
        I=1
        DO J=JINI(I)+1, JFIN(I)-1

        HMT2=(DELX(J)+DELX(J+1))/(DELX(J)/T(I,J)+DELX(J+1)/
T(I,J+1))
        HMT3=(DELY(I)+DELY(I+1))/(DELY(I)/T(I,J)+DELY(I+1)/
T(I+1,J))
        HMT4=(DELX(J)+DELX(J-1))/(DELX(J)/T(I,J)+DELX(J-1)/
T(I,J-1))

        TERML2=2./((DELX(J)+DELX(J+1))*DELX(J))
        TERML3=2./((DELY(I)+DELY(I+1))*DELY(I))
        TERML4=2./((DELX(J)+DELX(J-1))*DELX(J))

        FC2(I,J)=HMT2*TERML2
```

```
      FC3(I,J)=HMT3*TERML3
      FC4(I,J)=HMT4*TERML4
      FC5(I,J)=0.
      FC1(I,J)=-S(I,J)/DELT-W2*(FC2(I,J)+FC3(I,J)+FC4(I,J
))
      END DO
C
C     GENERATION OF COEFFICIENTS AT THE TOP LEFT NODE
C
      I=1
      J=JINI(I)

      HMT2=(DELX(J)+DELX(J+1))/(DELX(J)/T(I,J)+DELX(J+1)/
T(I,J+1))
      HMT3=(DELY(I)+DELY(I+1))/(DELY(I)/T(I,J)+DELY(I+1)/
T(I+1,J))

      TERML2=2./((DELX(J)+DELX(J+1))*DELX(J))
      TERML3=2./((DELY(I)+DELY(I+1))*DELY(I))
      FC2(I,J)=HMT2*TERML2
      FC3(I,J)=HMT3*TERML3
      TERM4=RTK4(I)/DELX(J)
      FC4(I,J)=0.
      FC5(I,J)=0.
      FC1(I, J)=-S(I,J)/DELT-W2*(FC2(I,J)+FC3(I,J)+TERM4)

C
C     GENERATION OF COEFFICIENTS AT THE TOP RIGHT NODE
C

      J=JFIN(1)

      HMT3=(DELY(I)+DELY(I+1))/(DELY(I)/T(I,J)+DELY(I+1)/
T(I+1,J))
      HMT4=(DELX(J)+DELX(J-1))/(DELX(J)/T(I,J)+DELX(J-1)/
T(I,J-1))

      TERML3=2./((DELY(I)+DELY(I+1))*DELY(I))
      TERML4=2./((DELX(J)+DELX(J-1))*DELX(J))

      TERM2=RTG2(I)/DELX(J)
      FC2(I,J)=0.
      FC3(I,J)=HMT3*TERML3
      FC4(I,J)=HMT4*TERML4
      FC5(I,J)=0.
      FC1(I,J)=-S(I,J)/DELT-W2*(TERM2+FC3(I,J)+FC4(I,J))

C
```

```
C       GENERATION OF COEFICIENTS FOR  NODES FOR BOTTOM BOU
NDARY
C       EXCEPT CORNER NODES
C
        I=IMAX
        DO J=JINI(I)+1,JFIN(I)-1

        HMT2=(DELX(J)+DELX(J+1))/(DELX(J)/T(I,J)+DELX(J+1)/
T(I,J+1))
        HMT4=(DELX(J)+DELX(J-1))/(DELX(J)/T(I,J)+DELX(J-1)/
T(I,J-1))
        HMT5=(DELY(I)+DELY(I-1))/(DELY(I)/T(I,J)+DELY(I-1)/
T(I-1,J))

        TERML2=2./((DELX(J)+DELX(J+1))*DELX(J))
        TERML4=2./((DELX(J)+DELX(J-1))*DELX(J))
        TERML5=2./((DELY(I)+DELY(I-1))*DELY(I))

        FC2(I,J)=HMT2*TERML2
        FC3(I,J)=0.
        FC4(I,J)=HMT4*TERML4
        FC5(I,J)=HMT5*TERML5
        FC1(I,J)=-S(I,J)/DELT -W2*(FC2(I,J)+FC4(I,J)+FC5(I,
J))
        END DO
C
C       GENERATION OF COEFFICIENTS AT THE BOTTOM LEFT NODE
C
        I=IMAX
        J=JINI(IMAX)

        HMT2=(DELX(J)+DELX(J+1))/(DELX(J)/T(I,J)+DELX(J+1)/
T(I,J+1))
        HMT5=(DELY(I)+DELY(I-1))/(DELY(I)/T(I,J)+DELY(I-1)/
T(I-1,J))

        TERML2=2./( (DELX(J)+DELX(J+1)) *DELX(J))
      TERML5=2./( (DELY(I)+DELY(I-1)) *DELY(I))

        FC2(I,J)=HMT2*TERML2
        FC3(I,J)=0.
        TERM4=RTK4(I)/DELX(J)
        FC4(I,J)=0.
        FC5(I,J)=HMT5*TERML5

        FC1(I,J)=-S(I,J)/DELT-W2*(FC2(I,J)+TERM4+FC5(I,J))

C
```

```
C       GENERATION OF COEFFICIENTS AT THE BOTTOM RIGHT NODE
C
        I=IMAX
        J=JFIN(IMAX)

        HMT4=(DELX(J)+DELX(J-1))/(DELX(J)/T(I,J)+DELX(J-1)/
T(I,J-1))
        HMT5=(DELY(I)+DELY(I-1))/(DELY(I)/T(I,J)+DELY(I-1)/
T(I-1,J))

        TERML4=2./((DELX(J)+DELX(J-1))* DELX(J))
        TERML5=2./((DELY(I)+DELY(I-1))*DELY(I))

        TERM2=RTG2(I)/DELX(J)
        FC2(I,J)=0.
        FC3(I,J)=0.
        FC4(I,J)=HMT4*TERML4
        FC5(I,J)=HMT5*TERML5

        FC1(I,J)=-S(I,J)/DELT -W2*(TERM2+FC4(I,J)+FC5(I,J))

C
C       COEFFICIENTS OF  HEADS AT NODES NEAR THE RIVER KALI

C
C
        DO I=2,IMAX-1
        J=JINI(I)

        HMT2=(DELX(J)+DELX(J+1))/(DELX(J)/T(I,J)+DELX(J+1)/
T(I,J+1))
        HMT3=(DELY(I)+DELY(I+1))/(DELY(I)/T(I,J)+DELY(I+1)/
T(I+1,J))
        HMT5=(DELY(I)+DELY(I-1))/(DELY(I)/T(I,J)+DELY(I-1)/
T(I-1,J))

        TERML2=2./((DELX(J)+DELX(J+1))*DELX(J))
        TERML3=2./((DELY(I)+DELY(I+1))*DELY(I))
        TERML5=2./((DELY(I)+DELY(I-1))*DELY(I))

        FC2(I,J)=HMT2*TERML2
        FC3(I,J)=HMT3*TERML3
        TERM4=RTK4(I)/DELX(J)
        FC4(I,J)=0.
        FC5(I,J)=HMT5*TERML5

        FC1(I,J)=-S(I,J)/DELT-W2*(FC2(I,J)+FC3(I,J)+TERM4+F
C5(I,J))
```

```
      END DO
C
C     COEFFICIENTS OF  HEADS AT NODES NEAR THE GANGA CANA
L
C

      DO  I=2,IMAX-1

      J=JFIN(I)

      HMT3=(DELY(I)+DELY(I+1))/(DELY(I)/T(I,J)+DELY(I+1)/
T(I+1,J))
      HMT4=(DELX(J)+DELX(J-1))/(DELX(J)/T(I,J)+DELX(J-1)/
T(I,J-1))
      HMT5=(DELY(I)+DELY(I-1))/(DELY(I)/T(I,J)+DELY(I-1)/
T(I-1,J))

      TERML3=2./((DELY(I)+DELY(I+1))*DELY(I))
      TERML4=2./((DELX(J)+DELX(J-1))*DELX(J))
      TERML5=2./((DELY(I)+DELY(I-1))*DELY(I))

      TERM2=RTG2(I)/DELX(J)
      FC2(I,J)=0.
      FC3(I,J)=HMT3*TERML3
      FC4(I,J)=HMT4*TERML4
      FC5(I,J)=HMT5*TERML5

      FC1(I,J)=-S(I,J)/DELT-W2*(TERM2+FC3(I,J)+FC4(I,J)+F
C5(I,J))

      END DO
C
C     GENERATION OF MATRIX COEFFICIENTS
C
      M=0

      DO I=1,IMAX
      M=M+JFIN(I)-JINI(I)+1
      END DO

      DO I=1,M
      DO J=1,M
      A(I,J)=0.
      END DO
      END DO
C
C     ELEMENT OF THE SPARCE BANDED MATRIX
C
```

```
      DO I=1,M
      INDEX=0
      DO I1=1,IMAX
      DO J1=JINI(I1),JFIN(I1)
      INDEX=INDEX+1
      IF(I.EQ.INDEX) GO TO  1
      GO TO 6
1     CONTINUE
      A(I,INDEX)=FC1(I1,J1)
      IF(J1.EQ.JFIN(I1)) GO TO 2
      A(I,INDEX+1)=FC2(I1,J1)*W2
2     CONTINUE
      IF(J1.EQ.JINI(I1)) GO TO 3
      A(I,INDEX-1)=FC4(I1,J1)*W2
3     CONTINUE
C
      IF(I1.EQ.IMAX) GO TO 4

      A(I,INDEX+JFIN(I1)-JINI(I1+1)+1)=FC3(I1,J1)*W2
4     CONTINUE
C
      IF(I1.EQ.1) GO TO 5
C     ICHECK=INDEX-JFIN(I1-1)+JINI(I1)-1
C     CHECK =FC5(I1,J1)
C     WRITE(*,*)ICHECK,CHECK
      A(I,INDEX-JFIN(I1-1)+JINI(I1)-1)=FC5(I1,J1)*W2
5     CONTINUE
6     CONTINUE
      END DO
      END DO
      END DO
C
C     WRITE(2,*)'ELEMENT OF THE MATRIX'
C     DO I=1,M
C     WRITE(2,197)(A(I,J),J=1,M)
C     END DO
C
C     STORING OF THE MATRIX ELEMENT
C
      DO I=1,M
      DO J=1,M
      AA(I,J)=A(I,J)
      END DO
      END DO
C
C
C     CALL MATRIX INVERSE
C
```

```
C       WRITE(2,*)'WRITING THE MATRIX ELEMENT BEFORE INVERS
ION'
C       DO I=1,M
C       WRITE(2,197)(A(I,J),J=1,M)
C       END DO
197     FORMAT(8F10.4)
198     FORMAT(8E10.2)
C
C
C
        CALL MATIN (A,M)
C       WRITE(2,*)'MATRIX ELEMENT AFTER INVERSION'
C       DO I=1,M
C       WRITE(2,198)(A(I,J),J=1,M)
C       END DO

C       WRITE(2,*)'CHECKING THE MATRIX INVERSION'
        K=0
        DO I=1,M
        SUM=0
        K=K+1
        DO J=1,M
        SUM=SUM+AA(I,J)*A(J,I)
        END DO
        AAAA(I,K)=SUM
        END DO
199     FORMAT(16F6.3)
        DO I=1,M
C       WRITE(2,199)(AAAA(I,J),J=1,M)
        END DO
C
C       SOLUTION FOR THE FIRST TIME STEP
C
C
        K=1

500     CONTINUE

C
C
C       FC6(I,J,K)  AT  INTERIOR NODES
C
        DO 33 I=2,IMAX-1


        DO J=JINI(I)+1,JFIN(I)-1

        FC6(I,J,K)=S(I,J)*H(I,J,K-1)/DELT-QP(I,J,K)/(DELX(J
```

```
)*DELY(I))
     1  +QR(I,J,K)/(DELX(J)*DELY(I))
     2  -H(I,J,K-1)   *W1*( FC2(I,J)+FC3(I,J)+FC4(I,J)+FC5(I
,J))
     3  +H(I,J+1,K-1)*W1*FC2(I,J)
     4  +H(I+1,J,K-1)*W1*FC3(I,J)
     5  +H(I,J-1,K-1)*W1*FC4(I,J)
     6  +H(I-1,J,K-1)*W1*FC5(I,J)

        END DO

33      CONTINUE
C
C       FC6(I,JINI(I),K) FOR  NODES NEAR RIVER KALI
C
        DO I=2,IMAX-1
        J=JINI(I)

        FC6(I,J,K)=S(I,J)/DELT*H(I,J,K-1)-QP(I,J,K)/(DELX(J
)*DELY(I))
     1  +QR(I,J,K)/(DELX(J)*DELY(I))
     2  +W2*RTK4(I)/DELX(J)*RSK4(I,K)
     3  +W1*RTK4(I)/DELX(J)*(RSK4(I,K-1)-H(I,J,K-1))
     4  +W1*FC2(I,J)*(H(I,J+1,K-1)-H(I,J,K-1))
     5  +W1*FC3(I,J)*(H(I+1,J,K-1)-H(I,J,K-1))
     6  +W1*FC5(I,J)*(H(I-1,J,K-1)-H(I,J,K-1))

        END DO
C
C       FC6(I,JFIN(I),K) FOR NODES NEAR GANGA CANAL
C

        DO I=2,IMAX-1
        J=JFIN(I)

        FC6(I,J,K)=S(I,J)/DELT*H(I,J,K-1)-QP(I,J,K)/(DELX(J
)*DELY(I))
     1  +QR(I,J,K)/(DELX(J)*DELY(I))
     2  +W2*RTG2(I)/DELX(J)*RSG2(I,K)
     3  +W1*RTG2(I)/DELX(J)*(RSG2(I,K-1)-H(I,J,K-1))
     4  +W1*FC3(I,J)*(H(I+1,J,K-1)-H(I,J,K-1))
     5  +W1*FC4(I,J)*(H(I,J-1,K-1)-H(I,J,K-1))
     6  +W1*FC5(I,J)*(H(I-1,J,K-1)-H(I,J,K-1))

        END DO

C
C       FC6(1,JINI(1),K) FOR  TOP LEFT NODE
```

```
C
          FC6(1,JINI(1),K)=S(1,JINI(1))/DELT*H(1,JINI(1),K-1)
     1    -QP(1,JINI(1),K)/(DELX(JINI(1))*DELY(1))
     2    +QR(1,JINI(1),K)/(DELX(JINI(1))*DELY(1))
     3    +W2*RTK4(1)/DELX(JINI(1))*RSK4(1,K)
     4    +W1*RTK4(1)/DELX(JINI(1))*(RSK4(1,K-1)-H(1,JINI(1),
K-1))
     5    +T(1,JINI(1))*UGRAD(JINI(1),K)/DELY(1)
     6    +W1*FC2(1,JINI(1))*(H(1,JINI(1)+1,K-1)-H(1,JINI(1),
K-1))
     7    +W1*FC3(1,JINI(1))*(H(2,JINI(1),K-1)-H(1,JINI(1),K-
1))

C
C         FC6(IMAX,JINI(IMAX),K) FOR  BOTTOM LEFT NODE
C

        FC6(IMAX,JINI(IMAX),K)=W2*RTK4(IMAX)/DELX(JINI(IMAX))
*RSK4(IMAX,K)
     1+W1*RTK4(IMAX)/DELX(JINI(IMAX))*(RSK4(IMAX,K-1)
     2-H(IMAX,JINI(IMAX),K-1))-T(IMAX,JINI(IMAX))*BGRAD(JIN
I(IMAX),K)
     3/DELY(IMAX)-QP(IMAX,JINI(IMAX),K)/(DELX(JINI(IMAX))*D
ELY(IMAX))
     4+QR(IMAX,JINI(IMAX),K)/(DELX(JINI(IMAX))*DELY(IMAX))
     5+W1*FC2(IMAX,JINI(IMAX))*(H(IMAX,JINI(IMAX)+1,K-1)
     6-H(IMAX,JINI(IMAX),K-1))+W1*FC5(IMAX,JINI(IMAX))
     7*(H(IMAX-1,JINI(IMAX),K-1)-H(IMAX,JINI(IMAX),K-1))
     8+S(IMAX,JINI(IMAX))/DELT*H(IMAX,JINI(IMAX),K-1)

C
C         FC6(1,JFIN(1),K) FOR  TOP RIGHT NODE
C

          FC6(1,JFIN(1),K)=S(1,JFIN(1))/DELT*H(1,JFIN(1),K-1)
     1    +T(1,JFIN(1))*UGRAD(JFIN(1),K)/DELY(1)
     2    -QP(1,JFIN(1),K)/(DELX(JFIN(1))*DELY(1))
     3    +QR(1,JFIN(1),K)/(DELX(JFIN(1))*DELY(1))
     4    +W2*RTG2(1)/DELX(JFIN(1))* RSG2(1,K)
     5    +W1*RTG2(1)/DELX(JFIN(1))*(RSG2(1,K-1)-H(1,JFIN(1),
K-1))
     6    +W1*FC3(1,JFIN(1))*(H(2,JFIN(1),  K-1)-H(1,JFIN(1),
K-1))
     7    +W1*FC4(1,JFIN(1))*(H(1,JFIN(1)-1,K-1)-H(1,JFIN(1),
K-1))

C
```

```
C        FC6(IMAX,JFIN(IMAX),K) FOR  BOTTOM RIGHT NODE
C

         IM=IMAX
         JM=JMAX
         FC6(IM,JFIN(IM),K)=S(IM,JFIN(IM))/DELT*H(IM,JFIN(IM
),K-1)
      1  -T(IM,JFIN(IM))*BGRAD(JFIN(IM),K)/DELY(IM)
      2  -QP(IM,JFIN(IM),K)/(DELX(JFIN(IM))*DELY(IM))
      3  +QR(IM,JFIN(IM),K)/(DELX(JFIN(IM))*DELY(IM))
      4  +W2*RTG2(IM)/DELX(JFIN(IM))* RSG2(IM,K)
      5  +W1*RTG2(IM)/DELX(JFIN(IM))*(RSG2(IM,K-1)-H(IM,JFIN
(IM),K-1))
      6  +W1*FC4(IM,JFIN(IM))*(H(IM,JFIN(IM)-1,K-1)-H(IM,JFI
N(IM),K-1))
      7  +W1*FC5(IM,JFIN(IM))*(H(IM-1,JFIN(IM),K-1)-H(IM,JFI
N(IM),K-1))

C        GENERATION OF FC6(1,J,K) FOR  NODES FOR TOP BOUNDAR
Y
C        EXCEPT CORNER NODES
C
         DO J=JINI(1)+1, JFIN(1)-1
         FC6(1,J,K)=UGRAD(J,K)*T(1,J)/DELY(1)
      1  -QP(1,J,K)/(DELX(J)*DELY(1))+QR(1,J,K)/(DELX(J)*DEL
Y(1))
      2  +S(1,J)/DELT*H(1,J,K-1)
      3  +W1*FC2(1,J)*(H(1,J+1,K-1)-H(1,J,K-1))
      4  +W1*FC3(1,J)*(H(2,J,K-1)-H(1,J,K-1))
      5  +W1*FC4(1,J)*(H(1,J-1,K-1)-H(1,J,K-1))
         END DO

C
C        GENERATION OF FC6(IMAX,J,K) FOR  NODES FOR BOTTOM B
OUNDARY
C        EXCEPT CORNER NODES
C
         DO J=JINI(IMAX)+1,JFIN(IMAX)-1
         FC6(IMAX,J,K)=-BGRAD(J,K)*T(IMAX,J)/DELY(IMAX)
      1  -QP(IMAX,J,K)/(DELX(J)*DELY(IMAX))
      2  +QR(IMAX,J,K)/(DELX(J)*DELY(IMAX))
      3  +S(IMAX,J)/DELT*H(IMAX,J,K-1)
      4  +W1*FC2(IMAX,J)*(H(IMAX,J+1,K-1)-H(IMAX,J,K-1))
      5  +W1*FC5(IMAX,J)*(H(IMAX-1,J,K-1)-H(IMAX,J,K-1))
      6  +W1*FC4(IMAX,J)*(H(IMAX,J-1,K-1)-H(IMAX,J,K-1))
         END DO
C
C
```

```
C
          INDEX=0
          DO I=1,IMAX
          DO J=JINI(I),JFIN(I)
          INDEX=INDEX+1
          RIGHT(INDEX)=-FC6(I,J,K)
C         WRITE(2,*)INDEX,RIGHT(INDEX)
          END DO
          END DO

          DO I=1,M
          HSOL(I)=0.
          DO J=1,M
          HSOL(I)=HSOL(I)+A(I,J)*RIGHT(J)
          END DO
          END DO
C
          INDEX=0
          DO I=1,IMAX
          DO J=JINI(I),JFIN(I)
          INDEX=INDEX+1
          H(I,J,K)=HSOL(INDEX)
          END DO
          END DO

          K=K+1
          IF(K.LE.NTIME) GO TO 500

          DO K=1,NTIME
          WRITE(2,*)'MONTH=',K

          WRITE(2,*) 'HEAD IN EACH GRID AT THE END OF THE MON
TH'

          DO I=1,IMAX
          WRITE(2,222)(H(I,J,K), J=JINI(I),JFIN(I))
222       FORMAT(5F8.2)
          END DO
          END DO
C         COMPUTATION OF WATER BALANCE
C         INFLOW



          WRITE(2,107)
107       FORMAT(2X,'MONTHLY WATER BALANCE')
          WRITE(2,108)
108       FORMAT(3X,'SUM1',5X,'SUM2',5X,'SUM3',5X,'SUM4',5X,'
```

```
SUM5',5X,
     1  'SUM6',5X,'SUM7',3X,'SUM8')

        SUM8=0.

        DO K=1,NTIME
        SUM1=0.
        SUM2=0.
        SUM3=0.
        SUM4=0.
        SUM41=0.
        SUM42=0.
        SUM43=0.
        SUM5=0.
        SUM6=0.
        SUM7=0.

        DO I=1,IMAX
        SUM1=SUM1+RTK4(I)*(RSK4(I,K)-H(I,1,K))    *DELY(I)
        SUM2=SUM2+RTG2(I)*(RSG2(I,K)-H(I,JMAX,K))*DELY(I)
        END DO

        SEEPK(K)=SUM1
        SEEPG(K)=SUM2

        DO I=1,IMAX
        DO J=1,JMAX
        SUM3=SUM3+QP(I,J,K)
        SUM4=SUM4+QR(I,J,K)
        SUM41=SUM41+QR1(I,J,K)
        SUM42=SUM42+QR2(I,J,K)
        SUM43=SUM43+QR3(I,J,K)
        END DO
        END DO

        PUMP(K)=SUM3
        RECH(K)=SUM4
        RECH1(K)=SUM41
        RECH2(K)=SUM42
        RECH3(K)=SUM43

        DO J=1,JMAX
        SUM5=SUM5+UGRAD(J,K)*DELX(J)
        SUM6=SUM6+BGRAD(J,K)*DELX(J)
        END DO

        SEEPBI(K)=SUM5
        SEEPBO(K)=SUM6
```

```
        DO I=1,IMAX
        DO J=1,JMAX
        DSTOR(K)=(H(I,J,K)-H(I,J,K-1))*SYIELD*DELX(J)*DELY(
I)
        SUM7=SUM7+(H(I,J,K)-H(I,J,K-1))*SYIELD*DELX(J)*DELY
(I)
        END DO
        END DO

        SUM8=SUM8+SUM1+SUM2-SUM3+SUM4+SUM5-SUM6
        RESIDUE(K)=SUM1+SUM2-SUM3+SUM4+SUM5-SUM6-SUM7
        GPOT(K)=SUM8
        ARISE(K)=GPOT(K)/(JMAX*IMAX*DELX(1)*DELY(1)*SYIELD)
        WRITE(2,109)SUM1,SUM2,SUM3,SUM4,SUM5,SUM6,SUM7,SUM8
109     FORMAT(8E9.3)
        END DO

        WRITE(2,110)
110     FORMAT(3X,'MONTH',7X,'RESIDUE(K)',8X,'GROUND WATER
POTENTIAL',
     1  2X,'WATER LEVEL RISE')

        DO K=1,NTIME
        WRITE(2,22)K,RESIDUE(K),GPOT(K),ARISE(K)
22      FORMAT(I5,5X,E16.5,5X,E16.7,9X,F10.3)
        END DO

        WRITE(2,111)
111   FORMAT(2X,'MONTH',2X,'SEEPAGE FROM KALI',2X,'SEEPAGE
FROM GANGA
     1  CANAL')

        DO K=1,NTIME
        WRITE(2,23)K,SEEPK(K),SEEPG(K)
        END DO

        WRITE(2,112)
112     FORMAT(2X,'MONTH',7X,'INFLOW FROM TOP',5X,'OUTFLOW
AT BOTTOM')

        DO K=1,NTIME
        WRITE(2,23)K,SEEPBI(K),SEEPBO(K)
23      FORMAT(I5,10X,E10.3,10X,E10.3)
        END DO

        WRITE(2,113)
113     FORMAT('RECH. FROM:',2X,'RAIN FALL',2X,'APPLIED IRR
```

```
I',
     1  2X,'CANAL SEEPAGE',2X,'TOTAL RECHARGE')

        DO K=1,NTIME
        WRITE(2,24)RECH1(K),RECH2(K),RECH3(K),RECH(K)
24      FORMAT(10X,4E12.4)
        END DO

        WRITE(2,114)
114     FORMAT(2X,'MONTH'2X,'RAIN FALL',2X,'GROUND WATER WI
THDRAWAL',2X,
     1  'CHANGE IN STORAGE')

        DO K=1,NTIME
        WRITE(2,115)K,RAIN(K),PUMP(K),ARISE(K)
115     FORMAT(I5,5X,F10.5,2X,E16.5,4X,F10.3)
        END DO

        STOP
        END


        SUBROUTINE MATIN (AAA,MMM)

        DIMENSION AAA(24,24),B(24),C(24)

        NN=MMM-1

        AAA(1,1)=1./AAA(1,1)

        DO 8 M=1,NN

        K=M+1

        DO 3 I=1,M

        B(I)=0.0

        DO 3 J=1,M

3       B(I)=B(I)+AAA(I,J)*AAA(J,K)

        D=0.0

        DO 4 I=1,M

4       D=D+AAA(K,I)*B(I)
```

```
      D=-D+AAA(K,K)
      AAA(K,K)=1./D
      DO 5 I=1,M
5     AAA(I,K)=-B(I)*AAA(K,K)
      DO 6 J=1,M
      C(J)=0.0
      DO 6 I=1,M
6     C(J)=C(J)+AAA(K,I)*AAA(I,J)
      DO 7 J=1,M
7     AAA(K,J)=-C(J)*AAA(K,K)
      DO 8 I=1,M
      DO 8 J=1,M
8     AAA(I,J)=AAA(I,J)-B(I)*AAA(K,J)
      RETURN
      END
```

0.	1.				
	4				
1	4				
1	4				
1	4				
1	4				
1	4				
1	4				
3200.	3200.	3200.	3200.		
4208.	4208.	4208.	4208.	4208.	4208.
1	12				
.0246	.0375	.0298	.0285	.0196	.067
.289	.355	.126	.070	.0066	.0194
0.067	0.037	0.092	0.15	0.238	0.241
0.114	0.029	0.115	0.062	0.064	0.057
.0321	0.002	0.058	0.085	0.158	0.171
.0089	0.0	0.0152	0.	0.0296	0.012
.0413	.036	0.036	0.0576	0.1075	0.1299
0.1411	0.1394	0.1399	0.0994	0.0383	0.0378
0.16	0.18	0.20	0.2	0.5	

I	JINI(I)	JFIN(I)
1	1	4
2	1	4
3	1	4
4	1	4
5	1	4
6	1	4

J	DELX(J)
1	3200.00
2	3200.00
3	3200.00
4	3200.00

I	DELY(I)
1	4208.00
2	4208.00
3	4208.00
4	4208.00
5	4208.00
6	4208.00

DELT	NTIME
1.00	12

ROW NO	REACH TRANSMISSIVITY OF RIVER KALI
1	7.90
2	7.90
3	7.90
4	7.90
5	7.90
6	7.90

ROW NO	REACH TRANSMISSIVITY OF GANGA CANAL
1	10.96
2	10.96
3	10.96
4	10.96
5	10.96
6	10.96

MONTH= 1

HEAD IN EACH GRID AT THE END OF THE MONTH

254.10	254.24	254.24	254.40
254.03	254.17	254.17	254.33
254.03	254.17	254.17	254.33
254.03	254.17	254.17	254.33
254.03	254.16	254.17	254.33
253.96	254.09	254.10	254.26

MONTH= 2

HEAD IN EACH GRID AT THE END OF THE MONTH

254.16	254.43	254.44	254.75
254.02	254.28	254.30	254.61
254.02	254.28	254.30	254.60

```
 254.02  254.28  254.30  254.60
 254.01  254.28  254.29  254.60
 253.87  254.13  254.15  254.46
MONTH=            3
HEAD IN EACH GRID AT THE END OF THE MONTH
 253.93  254.33  254.35  254.80
 253.72  254.11  254.14  254.59
 253.72  254.11  254.13  254.59
 253.72  254.11  254.13  254.59
 253.71  254.10  254.13  254.58
 253.50  253.89  253.91  254.37
MONTH=            4
HEAD IN EACH GRID AT THE END OF THE MONTH
 253.64  254.15  254.20  254.78
 253.36  253.87  253.91  254.50
 253.36  253.86  253.90  254.50
 253.36  253.86  253.90  254.50
 253.35  253.85  253.90  254.49
 253.07  253.57  253.61  254.22
MONTH=            5
HEAD IN EACH GRID AT THE END OF THE MONTH
 253.06  253.68  253.74  254.47
 252.72  253.33  253.39  254.13
 252.71  253.32  253.38  254.12
 252.71  253.32  253.38  254.12
 252.71  253.31  253.37  254.11
 252.36  252.95  253.01  253.78
MONTH=            6
HEAD IN EACH GRID AT THE END OF THE MONTH
 252.50  253.22  253.30  254.16
 252.10  252.79  252.87  253.77
 252.09  252.78  252.86  253.75
 252.09  252.78  252.86  253.75
 252.07  252.77  252.85  253.74
 251.67  252.34  252.43  253.35
MONTH=            7
HEAD IN EACH GRID AT THE END OF THE MONTH
 253.05  253.86  253.97  254.96
 252.59  253.37  253.48  254.50
 252.57  253.36  253.46  254.49
 252.57  253.36  253.46  254.49
 252.55  253.34  253.45  254.47
 252.09  252.85  252.96  254.02
MONTH=            8
HEAD IN EACH GRID AT THE END OF THE MONTH
 253.61  254.53  254.67  255.75
 253.09  253.98  254.11  255.24
 253.07  253.96  254.09  255.23
```

```
 253.07   253.96  254.09  255.22
 253.05   253.93  254.07  255.21
 252.53   253.38  253.51  254.70
MONTH=          9
HEAD IN EACH GRID AT THE END OF THE MONTH
 253.92   254.95  255.12  256.29
 253.35   254.34  254.50  255.73
 253.32   254.31  254.47  255.71
 253.32   254.31  254.47  255.71
 253.30   254.28  254.44  255.68
 252.72   253.66  253.83  255.12
MONTH=         10
HEAD IN EACH GRID AT THE END OF THE MONTH
 254.15   255.29  255.48  256.74
 253.52   254.61  254.80  256.12
 253.49   254.58  254.77  256.09
 253.49   254.57  254.77  256.09
 253.46   254.54  254.74  256.06
 252.82   253.86  254.06  255.45
MONTH=         11
HEAD IN EACH GRID AT THE END OF THE MONTH
 254.05   255.29  255.52  256.85
 253.36   254.55  254.78  256.18
 253.33   254.51  254.74  256.15
 253.33   254.51  254.74  256.15
 253.29   254.47  254.70  256.11
 252.60   253.73  253.96  255.45
MONTH=         12
HEAD IN EACH GRID AT THE END OF THE MONTH
 254.06   255.41  255.67  257.07
 253.33   254.61  254.87  256.35
 253.29   254.56  254.82  256.31
 253.28   254.56  254.82  256.31
 253.24   254.51  254.78  256.27
 252.50   253.71  253.98  255.56
 MONTHLY WATER BALANCE
  SUM1     SUM2     SUM3     SUM4     SUM5     SUM6     SUM7    SU
M8
-.180E+07 .212E+07 .104E+08 .843E+07 .256E+02 .256E+02-.162E+07-.1
62E+07
-.180E+07 .205E+07 .646E+06 .690E+07 .256E+02 .256E+02 .650E+07 .4
88E+07
-.174E+07 .205E+07 .187E+08 .100E+08 .256E+02 .256E+02-.843E+07-.3
55E+07
-.167E+07 .208E+07 .275E+08 .151E+08 .256E+02 .256E+02-.120E+08-.1
55E+08
-.154E+07 .218E+07 .511E+08 .235E+08 .256E+02 .256E+02-.269E+08-.4
25E+08
```

```
-.141E+07 .228E+07 .553E+08 .279E+08 .256E+02 .256E+02-.265E+08-.6
90E+08
-.151E+07 .208E+07 .288E+07 .333E+08 .256E+02 .256E+02 .310E+08-.3
80E+08
-.161E+07 .187E+07 .000E+00 .315E+08 .256E+02 .256E+02 .318E+08-.6
22E+07
-.166E+07 .174E+07 .491E+07 .238E+08 .256E+02 .256E+02 .190E+08 .1
28E+08
-.169E+07 .163E+07 .000E+00 .145E+08 .256E+02 .256E+02 .144E+08 .2
72E+08
-.166E+07 .162E+07 .957E+07 .700E+07 .256E+02 .256E+02-.261E+07 .2
46E+08
-.165E+07 .157E+07 .388E+07 .726E+07 .256E+02 .256E+02 .330E+07 .2
79E+08
    MONTH        RESIDUE(K)          GROUND WATER POTENTIAL  WATER LEV
EL RISE
      1          -.25825E+03          -.1622442E+07                -.031
      2          -.61150E+03           .4878339E+07                 .094
      3          -.22900E+03          -.3547490E+07                -.069
      4          -.14325E+03          -.1553327E+08                -.300
      5          -.27275E+03          -.4248282E+08                -.822
      6          -.29150E+03          -.6900764E+08               -1.335
      7          -.40325E+03          -.3801599E+08                -.735
      8          -.37000E+03          -.6216212E+07                -.120
      9          -.38338E+03           .1275757E+08                 .247
     10          -.35700E+03           .2720252E+08                 .526
     11          -.38688E+03           .2459054E+08                 .476
     12          -.23963E+03           .2788941E+08                 .539
   MONTH   SEEPAGE FROM KALI   SEEPAGE FROM GANGA      CANAL
      1           -.180E+07            .212E+07
      2           -.180E+07            .205E+07
      3           -.174E+07            .205E+07
      4           -.167E+07            .208E+07
      5           -.154E+07            .218E+07
      6           -.141E+07            .228E+07
      7           -.151E+07            .208E+07
      8           -.161E+07            .187E+07
      9           -.166E+07            .174E+07
     10           -.169E+07            .163E+07
     11           -.166E+07            .162E+07
     12           -.165E+07            .157E+07
   MONTH         INFLOW FROM TOP      OUTFLOW AT BOTTOM
      1            .256E+02            .256E+02
      2            .256E+02            .256E+02
      3            .256E+02            .256E+02
      4            .256E+02            .256E+02
      5            .256E+02            .256E+02
      6            .256E+02            .256E+02
```

7	.256E+02	.256E+02
8	.256E+02	.256E+02
9	.256E+02	.256E+02
10	.256E+02	.256E+02
11	.256E+02	.256E+02
12	.256E+02	.256E+02

RECH. FROM:	RAIN FALL	APPLIED IRRI	CANAL SEEPAGE	TOTAL RECHARG E
	.1431E+07	.4331E+07	.2669E+07	.8431E+07
	.2181E+07	.2391E+07	.2327E+07	.6900E+07
	.1734E+07	.5946E+07	.2327E+07	.1001E+08
	.1658E+07	.9695E+07	.3723E+07	.1508E+08
	.1140E+07	.1538E+08	.6948E+07	.2347E+08
	.3897E+07	.1558E+08	.8396E+07	.2787E+08
	.1681E+08	.7368E+07	.9120E+07	.3330E+08
	.2065E+08	.1874E+07	.9010E+07	.3154E+08
	.7330E+07	.7433E+07	.9042E+07	.2381E+08
	.4072E+07	.4007E+07	.6425E+07	.1450E+08
	.3839E+06	.4137E+07	.2476E+07	.6996E+07
	.1129E+07	.3684E+07	.2443E+07	.7256E+07

MONTH	RAIN FALL	GROUND WATER WITHDRAWAL	CHANGE IN STORAGE
1	.02460	.10374E+08	-.031
2	.03750	.64635E+06	.094
3	.02980	.18744E+08	-.069
4	.02850	.27470E+08	-.300
5	.01960	.51062E+08	-.822
6	.06700	.55263E+08	-1.335
7	.28900	.28763E+07	-.735
8	.35500	.00000E+00	-.120
9	.12600	.49122E+07	.247
10	.07000	.00000E+00	.526
11	.00660	.95660E+07	.476
12	.01940	.38781E+07	.539

Existing Net Return

```
bat
!
 MAX 9940A11 + 3100A12 + 7840A13 + 10640A14 + 6570A15 + 13880A16
       + 11500A17 - 450SW11 -450SW12 -450SW13 - 450SW14 - 450SW15

       450SW16 - 450SW17 - 450SW18 -450SW19 - 450SW110 - 450SW111

       450SW112 - 1580GW11 - 1580GW12 - 1580GW13 - 1580GW14 -
       1580GW15 - 1580GW16 - 1580GW17 - 1580GW18 - 1580GW19 -
       1580GW110 - 1580GW111 - 1580GW112
SUBJECT TO
 A11 =1531.4
 A12 =1178.0
 A13 >=1884.8
 A14 =353.4
 A15 =353.4
 A16 =235.6
 A17 <=2945.0
 .1056A13 + .085A14 + .1046A15 + .04359A17 -SW11 - GW11 <=0
 .050A13 + .029A14 + .10A15 + .026A17 - SW12 - GW12 <=0
 .0346A13 + .1288A15 + .063A16 + .1429A17 - SW13 - GW13 <=0
 .204A15 + .30A16 + .2518A17 -SW14 - GW14 <=0
 .470A15 + .3035A16 + .3957A17 -SW15 - GW15 <=0
 .252A11 + .35A17 - SW16 - GW16 <=0
 .39A11 + .024A17 - SW17 - GW17 <=0
 .1125A11 - SW18 - GW18 <=0
 .34A11 + .0367A12 + .0384A17 - SW19 - GW19 <=0
 .094A11 + .0745A17 - SW110 - GW110 <=0
 .02457A13 + .071A14 + .09213A15 + .09375A17 - SW111 - GW111 <=0
 .06578A13 + .0912A14 + .0705A15 + .05183A17 - SW112 - GW112 <=0
 A11 + A12 + A13 + A14 + A15 + A16 + A17 <=8481.6
 SW11 <=205.64
 SW12 <=205.64
 SW13 <=205.64
 SW14 <=381.88
 SW15 <=470.0
 SW16 <=411.26
 SW17 >=617.0
 SW18 =617.0
 SW19 <=587.52
 SW110 <=499.4
 SW111 <=205.64
 SW112 <=264.4

 GW11 + GW12 + GW13 + GW14 + GW15 + GW16 + GW17 + GW17 + GW18 +
 GW19 + GW110 + GW111 + GW112 <=3370.0
 end
 bat
```

LP OPTIMUM FOUND AT STEP 32

OBJECTIVE FUNCTION VALUE

1) 0.6957006E+08

VARIABLE	VALUE	REDUCED COST
A11	1531.400024	0.000000
A12	1178.000000	0.000000
A13	1884.800049	0.000000
A14	353.399994	0.000000
A15	353.399994	0.000000
A16	235.600006	0.000000
A17	2944.999512	0.000000
SW11	205.639999	0.000000
SW12	205.639999	0.000000
SW13	205.639999	0.000000
SW14	381.880005	0.000000
SW15	470.000000	0.000000
SW16	411.260010	0.000000
SW17	667.925964	0.000000
SW18	617.000000	0.000000
SW19	587.520020	0.000000
SW110	363.354065	0.000000
SW111	205.639999	0.000000
SW112	264.399994	0.000000
GW11	188.772064	0.000000
GW12	10.758594	0.000000
GW13	340.775269	0.000000
GW14	502.444489	0.000000
GW15	932.938965	0.000000
GW16	1005.402649	0.000000
GW17	0.000000	1130.000000
GW18	0.000000	1580.000000
GW19	89.476578	0.000000
GW110	0.000000	1130.000000
GW111	174.413391	0.000000
GW112	69.366264	0.000000

Net Return at 210% CI

```
bat
!
 MAX 9940A11 + 3100A12 + 7840A13 + 10640A14 + 6570A15 + 13880A16
        + 11500A17 - 450SW11 -450SW12 -450SW13 - 450SW14 - 450SW15

        450SW16 - 450SW17 - 450SW18 -450SW19 - 450SW110 - 450SW111

        450SW112 - 1580GW11 - 1580GW12 - 1580GW13 - 1580GW14 -
        1580GW15 - 1580GW16 - 1580GW17 - 1580GW18 - 1580GW19 -
        1580GW110 - 1580GW111 - 1580GW112
SUBJECT TO
 A11 <=1767.0
 A11 >=1531.4
 A12 <=1767.0
 A12 >=1178.0
 A13 < =2356.0
 A13 >=1884.8
 A14 >=294.5
 A14 <=353.4
 A15 >=294.5
 A15 <=353.4
 A16 >=235.6
 A16 <=1178.0
 A17 =2356.0
 .1056A13 + .085A14 + .1046A15 + .04359A17 -SW11 - GW11 <=0
 .050A13 + .029A14 + .10A15 + .026A17 - SW12 - GW12 <=0
 .0346A13 + .1288A15 + .063A16 + .1429A17 - SW13 - GW13 <=0
 .204A15 + .30A16 + .2518A17 -SW14 - GW14 <=0
 .470A15 + .3035A16 + .3957A17 -SW15 - GW15 <=0
 .252A11 + .35A17 - SW16 - GW16 <=0
 .39A11 + .024A17 - SW17 - GW17 <=0
 .1125A11 - SW18 - GW18 <=0
 .34A11 + .0367A12 + .0384A17 - SW19 - GW19 <=0
 .094A11 + .0745A17 - SW110 - GW110 <=0
 .02457A13 + .071A14 + .09213A15 + .09375A17 - SW111 - GW111 <=0
 .06578A13 + .0912A14 + .0705A15 + .05183A17 - SW112 - GW112 <=0
 A11 + A12 + A13 + A14 + A15 + A16 + A17 <=12369
 SW11 + SW12 + SW13 + SW14 + SW15 + SW16 + SW17 + SW18 +
 SW19 + SW110 + SW111 + SW112 <=4670
 GW11 + GW12 + GW13 + GW14 + GW15 + GW16 + GW17 + GW17 + GW18 +
 GW19 + GW110 + GW111 + GW112 <=4000.00
 end
 bat
 leave
```

LP OPTIMUM FOUND AT STEP 29

OBJECTIVE FUNCTION VALUE

1) 0.8424781E+08

VARIABLE	VALUE	REDUCED COST
A11	1767.000000	0.000000
A12	1767.000000	0.000000
A13	2356.000000	0.000000
A14	353.399994	0.000000
A15	353.399994	0.000000
A16	1178.000000	0.000000
A17	2356.000000	0.000000
SW11	0.000000	0.000000
SW12	0.000000	0.000000
SW13	537.921936	0.000000
SW14	1018.734436	0.000000
SW15	933.538330	0.000000
SW16	0.000000	0.000000
SW17	745.673950	0.000000
SW18	0.000000	0.000000
SW19	756.099304	0.000000
SW110	341.619995	0.000000
SW111	336.412048	0.000000
SW112	0.000000	0.000000
GW11	418.496277	0.000000
GW12	224.644608	0.000000
GW13	0.000000	0.000000
GW14	0.000000	0.000000
GW15	522.351929	0.000000
GW16	1269.884033	0.000000
GW17	0.000000	0.000000
GW18	198.787491	0.000000
GW19	0.000000	0.000000
GW110	0.000000	0.000000
GW111	0.000000	0.000000
GW112	334.233948	0.000000

Optimal Net Return

```
bat
!
MAX 14940A11 + 3100A12 + 12940A13 + 10640A14 + 6570A15 + 13880A16
       + 14500A17 - 450SW11 -450SW12 -450SW13 - 450SW14 - 450SW15

       450SW16 - 450SW17 - 450SW18 -450SW19 - 450SW110 - 450SW111

       450SW112 - 1580GW11 - 1580GW12 - 1580GW13 - 1580GW14 -
       1580GW15 - 1580GW16 - 1580GW17 - 1580GW18 - 1580GW19 -
       1580GW110 - 1580GW111 - 1580GW112
SUBJECT TO
 A11 <=1767.0
 A11 >=1531.4
 A12 <=1767.0
 A12 >=1178.0
 A13 < =2356.0
 A13 >=1884.8
 A14 >=294.5
 A14 <=353.4
 A15 >=294.5
 A15 <=353.4
 A16 >=235.6
 A16 <=1178.0
 A17 =2356.0
 .1056A13 + .085A14 + .1046A15 + .04359A17 -SW11 - GW11 <=0
 .050A13 + .029A14 + .10A15 + .026A17 - SW12 - GW12 <=0
 .0346A13 + .1288A15 + .063A16 + .1429A17 - SW13 - GW13 <=0
 .204A15 + .30A16 + .2518A17 -SW14 - GW14 <=0
 .470A15 + .3035A16 + .3957A17 -SW15 - GW15 <=0
 .252A11 + .35A17 - SW16 - GW16 <=0
 .39A11 + .024A17 - SW17 - GW17 <=0
 .1125A11 - SW18 - GW18 <=0
 .34A11 + .0367A12 + .0384A17 - SW19 - GW19 <=0
 .094A11 + .0745A17 - SW110 - GW110 <=0
 .02457A13 + .071A14 + .09213A15 + .09375A17 - SW111 - GW111 <=0
 .06578A13 + .0912A14 + .0705A15 + .05183A17 - SW112 - GW112 <=0
 A11 + A12 + A13 + A14 + A15 + A16 + A17 <=12369
 SW11 + SW12 + SW13 + SW14 + SW15 + SW16 + SW17 + SW18 +
 SW19 + SW110 + SW111 + SW112 <=4670
 GW11 + GW12 + GW13 + GW14 + GW15 + GW16 + GW17 + GW17 + GW18 +
 GW19 + GW110 + GW111 + GW112 <=4000.00
 end
 bat
 leave
```

LP OPTIMUM FOUND AT STEP 29

OBJECTIVE FUNCTION VALUE

1) 0.1121664E+09

VARIABLE	VALUE	REDUCED COST
A11	1767.000000	0.000000
A12	1767.000000	0.000000
A13	2356.000000	0.000000
A14	353.399994	0.000000
A15	353.399994	0.000000
A16	1178.000000	0.000000
A17	2356.000000	0.000000
SW11	0.000000	0.000000
SW12	0.000000	0.000000
SW13	537.921936	0.000000
SW14	1018.734436	0.000000
SW15	933.538330	0.000000
SW16	0.000000	0.000000
SW17	745.673950	0.000000
SW18	0.000000	0.000000
SW19	756.099304	0.000000
SW110	341.619995	0.000000
SW111	336.412048	0.000000
SW112	0.000000	0.000000
GW11	418.496277	0.000000
GW12	224.644608	0.000000
GW13	0.000000	0.000000
GW14	0.000000	0.000000
GW15	522.351929	0.000000
GW16	1269.884033	0.000000
GW17	0.000000	0.000000
GW18	198.787491	0.000000
GW19	0.000000	0.000000
GW110	0.000000	0.000000
GW111	0.000000	0.000000
GW112	334.233948	0.000000

Table 26: Optimization of Net Return

SN.	Name of crop	C.I. %	Cropping Area (A_{ij})	Yield quintal/ ha (Y_j)	Price per quintal (P_j) (Rs.)	Cost of cultivation of crop (C_j) (Rs/ha)	Cost of providing G.W. (Rs) (C2)	Cost of canal water charged (Rs/ham) (C1)
1	Paddy	26	1531.40	45.00	500.0	12560	1580	450
2	Sorghum (kharif fodder)	20	1178.0	25	400	6900		
3	Wheat	32	1884.80	40.00	510.00	13785		
4	Oil seeds (mustard)	6	353.40	10	1700	6360		
5	Berseem (Rabi fodder)	6	353.40	300.00	60.00	11430.00		
6	(Pulse Green gram)	4	235.60	10.00	2000	6120		
7	Sugarcane	50	2945	750.00	60.00	33500		
	Total	144	8481.60					

Source: Socio-economic survey April 2000, W.R.D.T.C., U.O.R., ROORKEE

Table 27: Cost of Cultivation

SN	Crops	Human Labour cost (Rs/ha)	Bullock Labour cost (Rs/ha)	Seed cost (Rs/ha)	Fertiliser cost (Rs/ha)	Pesticides cost (Rs/ha)	Misc cost (Rs/ha)	Total cost
1	Paddy	4000	2500	800	2500	1500	1260	12560
2	Sorghum	-	-	-	-	-	-	6900
3	Wheat	4000	2500	800	2500	1500	1260	12560
4	Oilseeds (mustard)	-	-	-	-	-	-	6360
5	Berseem	-	-	-	-	-	-	11430
6	Mung (Green gram)	-	-	-	-	-	-	6120
7	Sugarcane	6000	4500	6000	12000	-	2000	30500

Source: Socio-economic Survey during Diagnostic Analysis of Gadarjuda minor of UGC system in 2000.

Table 28 cost $Y_j P_j - C_j$ (Existing)

Y= yield of crop (quintal per hec.), P = Price of crop (Rs./quinta),

C = Cost of cultivation of crop (in Rs.).

j = 1 to 7 for 7 crops.

SN.	Name of crop	$Y_j P_j-C_j$	Value	Result
1	Paddy	$Y_1 P_1-C_1$	45 x 500-12560	9940
2	Sorghum	$Y_2P_2-C_2$	25 x 400 - 6900	3100
3	Wheat	$Y_3 P_3-C_3$	40 x 510 – 12560	7840
4	Mustard	$Y_4 P_4-C_4$	10 x 1700 – 6360	10640
5	Berseem	$Y_5 P_5-C_5$	300 x 60 – 11430	6570
6	Mung	$Y_6 P_6-C_6$	10 x 2000 – 6120	13880
7	Sugarcane	$Y_7 P_7-C_7$	700 x 60 – 30500	11500

Source: Socio-economic Survey during Diagnostic Analysis of Gadarjuda minor UGC in April 2000.

Table 29 : CWR Month Wise and Crop-wise (m)

SN	Crop	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total (m)
1	Paddy	-	-	-	-	-	0.252	0.391	0.112	0.340	0.094	-	-	1.2
2	Sorghum	-	-	-	-	-	-	-	-	0.037	-	-	-	0.037
3	Wheat	0.1056	0.05	0.0346	-	-	-	-		-	-	0.025	0.066	0.28
4	Mustard	0.085	0.025	-	-	-	-	-	-	-	-	0.071	0.091	0.273
5	Berseem	0.105	0.10	0.123	0.204	0.471	-	-	-	-	-	0.092	0.071	1.2
6	Moong	-	-	0.064	0.30	0.304	-	-	-	-	-	-	-	0.667
7	Sugarcane	0.044	0.027	0.143	0.252	0.396	0.35	0.024	-	0.038	0.074	0.093	0.052	1.5
	Total	0.3396	0.202	0.3646	0.756	1.171	0.602	0.415	0.112	0.415	0.168	0.281	0.28	-

(a) Ref. Table 14 to 21

Table 30 : Cost YjPj – Cj (after Water Resource Management)

SN.	Name of crop	$Y_i P_i$-C_i	Value	Result
1	Paddy*	$Y_1 P_1$-C_1	55 x 500-12560	14940
2	Sorghum	Y_2P_2-C_2	25 x 400 - 6900	3100
3	Wheat**	$Y_3 P_3$-C_3	50 x 510 – 12560	12940
4	Mustard	$Y_4 P_4$-C_4	10 x 1700 – 6360	10640
5	Berseem	$Y_5 P_5$-C_5	300 x 60 – 11430	6570
6	Mung	$Y_6 P_6$-C_6	10 x 2000 – 6120	13880
7	Sugarcane***	$Y_7 P_7$-C_7	750 x 60 – 30500	14500

* At Pantnagar, in silty clay loam soils, scheduling irrigation to rice 3-days after disappearance of ponded water produced 6.9 t/ha maximum grain yield. Incorporation of 55 days old Sesbania green manure was found to be beneficial for higher rice production. (Ref. Annual Report 1998-99, Directorate of Water Management Research, Patna – 801505, ICAR).

** DA Report (1987) states 4.5 to 5.0 t/ha.

*** CO.SH.787 variety of sugarcane has the potentiality to yield 1150-1280 quintal/ha. (DA Report, 1987).