FIELD RESEARCH PROGRAM ON CONJUNCTIVE USE MANAGEMENT OF SURFACE AND GROUND WATER IN MADHYA GANGA COMMAND AREA - A STATUS REPORT

BY

WATER AND LAND MANAGEMENT INSTITUTE - U..P., OKHLA, NEW DELHI, INDIA. &
WATER RESOURCES DEVELOPMENT TRAINING CENTRE UNIV. OF ROORKEE,U.P.,INDIA

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INTRODUCTION

Context of the Study:

This research proposal is to investigate the feasibility and implementation of conjunctive use management of surface and ground water in a selected area under Madhya Ganga Project. The study is being carried out jointly by the Water Resources Deve- lopment Training Centre (WRDTC), Roorkee, Water and Land Management Institute (WALMI), Okhla and the Irrigation Depart- ment, Government of Uttar Pradesh (IDUP) under INDIA - IIMI Collaborative project.

Background Information:

A historical development of the project and its present status:

The selected area for investigation is under Madhya Ganga Canal Project (MGCP). The location map and a schematic diagram showing developments in and near Uppr Ganga Canal (UG) Command and the linkage of Madhya Ganga Canal (MGC) with UGC and other canal system in the grid is shown in Figure 1,2 and 3. MGCP envisages the utilization of surplus water of river Ganga during monsoon period for providing 178 thousand hectares rice irrigation, out of which 114 thousand hectares is proposed in the command of upper Ganga Canal System by providing additional water to its existing channels and 64 thousand hectares, through new canal systems in new culturable command area of 256 thousand hectares in districts Bulundshahr and Aligarh.

The main components of the MGCP are a barrage across the river Ganga 10 Km. west of Bijnor town, a main canal 115.45 Km. long with a design head discharge of 234 cumecs, the Lakhaoti Branch system 74.13 Km. long taking off from main canal at Km.82.4 with a head discharge of 63 cumecs and distributaries, minors and field channels serving a CCA of 193 thousand hectares and proposed rice irrigation of 49.55 thousand hectares; Mat feeder of 47.7 Km. long having a head capacity of 78 cumecs, supplementing 55.5 cumecs to existing Mat branch under upper Ganga canal and irrigating a new CCA of 63 thousand hectares for rice irrigation. Water utilization and proposed irrigation under MGCP is given below:

Sr. No.	System	Discharge cumecs	Proposed Rice irrigtion 000 ha.
1.	Upper Ganga Canal System		
	i) Anupshahr branch	25.5	20.00
	ii) Mat and Hathras branch	55.5	45.45
	iii) Other off-takes of upper Ganga canal	58.0	47.65
	Total	139.0	114.0

MADHYA PRADESH

LEGEND

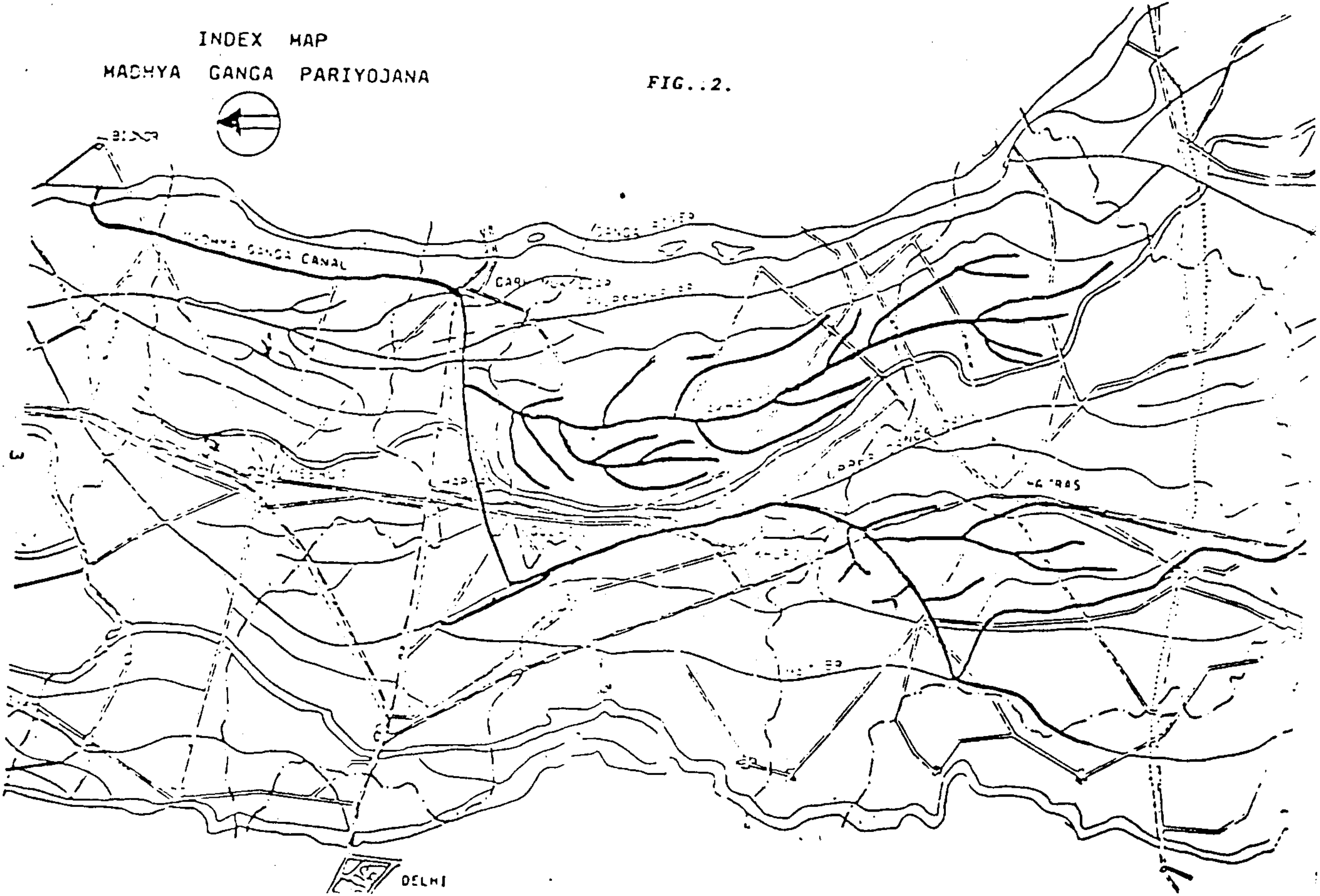
INTERNATIONAL BOUNDARY	- · - —
STATE BOUNDARY	- - - -
DISTRICT HEAD QUARTER	○
UNDER CONST & FRCP F C	•
BARRAGE, DAM	ı

FIG. 1: UTTAR PRADESH IRRIGATION AND POWER PROJECT

INDEX MAP

MADHYA GANGA PARIYOJANA

FIG..2.



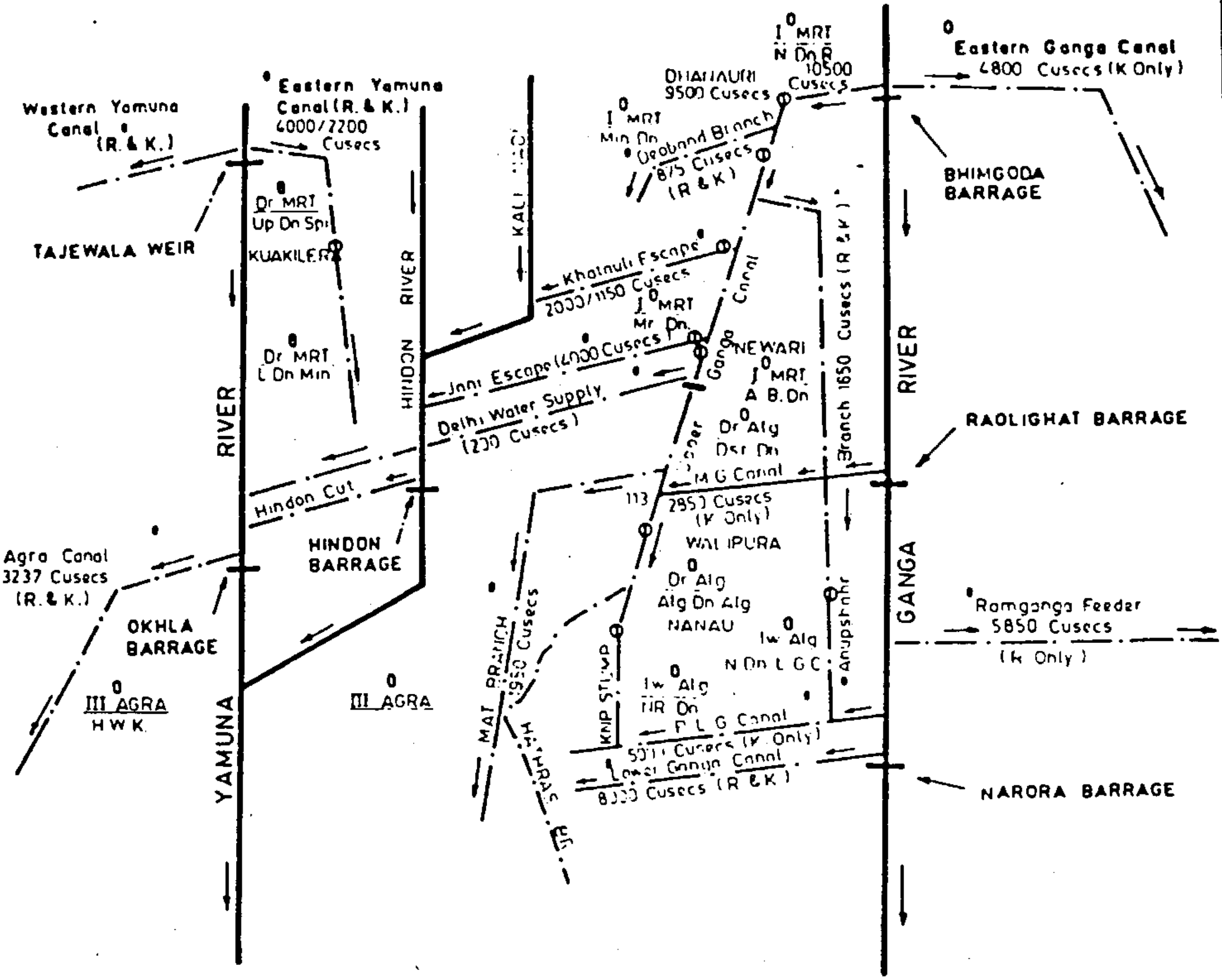
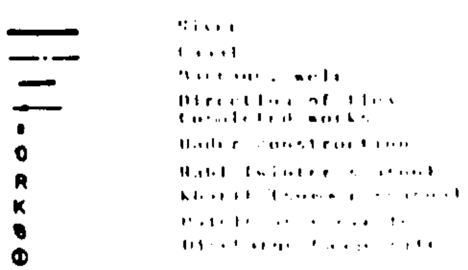

Western Yamuna Canal (R. & K.)
Eastern Yamuna Canal (R. & K.) 4000/7200 Cusecs
TAJEWALA WEIR
Dr MRT Up Dn Spl
KUAKHERA
Dr MRT L Dn Min
RIVER
YAMUNA
Hindon Cut
Agra Canal 3237 Cusecs (R. & K.)
OKHLA BARRAGE
III AGRA H W K.
III AGRA
HINDON RIVER
HINDON BARRAGE
KALI
Khatauli Escape 2000/1150 Cusecs
Jani Escape (4000 Cusecs)
Delhi Water Supply (200 Cusecs)
I MRT N Dn R
DHANAURI 9500 Cusecs
10500 Cusecs
I MRT Min Dn
Deoband Branch 875 Cusecs (R & K)
Ganga Canal
J MRT Mr Dn
NEWARI
J MRT A B Dn
Dr Alg Dsr Dn
M G Canal 2850 Cusecs (K Only)
WALIPURA
Dr Alg Alg Dn Alg
NANAU
Iw Alg N Dn L G C
Iw Alg
KNP STUMP
MAT BRANCH 950 Cusecs
HATHRAS
P L G Canal 5000 Cusecs (K Only)
Lower Ganga Canal 8000 Cusecs (R & K)
Anupshahr Branch 1650 Cusecs (R & K)
Eastern Ganga Canal 4800 Cusecs (K Only)
BHIMGODA BARRAGE
RAOLIGHAT BARRAGE
RIVER
GANGA
Ramganga Feeder 5850 Cusecs (K Only)
NARORA BARRAGE

FIG. 3:

LEGEND



2)	New Command		
i)	Lakhaoti branch	63.00	49.55
ii)	Mat feeder channels	18.50	14.45
	Total	81.50	64.00
	Line Losses	14.00	--
	Grand Total	234.50	178.80

Progress of Works:

The main works of Barrage and main canal have been completed. The main canal was run on trial from head to Km.92 in August 1985. The main canal was again run during the full monsoon from 30 June to 9 Oct 1986 and supplemented waters of Upper Ganga Canal (UGC). The canal is run in Kharif all these years supplementing waters of UGC.

The work on the main Lakhaoti main branch is complete and the distribution system is under construction. The work on Mat branch Feeder canal is in progress.

Research Proposal:

This section provides an indepth picture of the research components as visualized.

Objectives:

The broad objective of this study is to examine various issues related to conjunctive use management of surface and groundwater such as socio-economic considerations, institution and organizational factors, surface water control and regulation, hydrologic and technical aspects of surface water and ground water interactions and interventions, to arrive at a feasible, cost effective management strategy to improve irrigation performence in the region and to develop a monitoring and management information system to support or help short term and long term decisions for operations of such a system in an integrated fashion for sustained productivity and long term stability. The specifics of the objectives that are to be achieved within the time frame are:

1. Assess current ground water conditions in the specific area.

2. Model potential surface water, ground water interactions.

3. Develop a range of future scenarios of irrigation requirement based on socio-economic, agronomic and agricultural practices, and the water availability for a sustained irrigation and agricultural production activity.

4. Simulate groundwater surface water operations and develop management actions to meet these alternative conjunctive use management conditions. This includes institution and organization and decision support systems necessary for implementation of these alternatives.

5. Document techniques and findings to be useful as training modules.

Pilot Areas Identified:

To study the impact of introducing surface water in this ara at present during kharif and in future during rabi as well, three pilot areas representing different combination ofirrigation from surface water and ground water have been selected for detailed studies pertaining to cropping pattern, behaviour of farmers to irrigation water and its inpact on socio-economic conditions and integrated organisational aspects.

The different prevailing situations combining the surface water and ground water are as below:

a) The areas in the command of Lakhauti branch which are being irrigated by grounnd water only extracted by state tubewells and ~~are~~ privately owned tubewells. These areas may get surface water in the coming years, but surface water irrigation has not become available until now.

b) The areas in the command of Lakhauti branch where irrigation both ~~water~~ from ground water i.e.,state tube wells, private owned tubewells and from surface water i.e., canal water ~~is~~ being used.

c) The areas in the command of Upper Ganga Canal which is adjoining the Madhya Ganga Canal areas, where surface water i.e., canal water is being used for long time and ground water extracted by privately owned tubewells is ~~along~~ also being used.

This is most likely situation, which will develop in Madhya Ganga Canal areas in the coming years.

Three pilot areas representing the above situations have been selected as mentioned below.

1) PILOT AREA A, lies in the Bulandshahr-Garh road at a distance of approximately 14 kms. on the left side of the road. This area is the command of State tubewell No. 84, which lies in Kuchechhar Block of Tubewell Division (North) Bulandshahr. Though a distributary passes very close to this area, but no surface water irrigation has been introduced, because the distributary is incomplete in the head reach and has not become operational. Twenty one private tubewells are operating in the vicinity of state tubewell No. 84 and the command of state tubewll has shrunk over the years as the farmers who are having their own tubewells, are not taking water from the state tubewell. In this area ground water is being used for irrigation, extracted from state tubewell and private tubewells. Surface water supplies are not expected during the next two years, as there is a dispute about the forest land acquisition which lies in the head reach of distributary.

2) A PILOT AREA B near village Manikpur on right sideof Bulandshahr - Garh road at the chainage of 18 kms. of Sikarpur distributary has been taken for detailed studies. Surface water

FIG 4 COMMAND AREA MAP OF STATE TUBEWELL NO. 84 KB IN CHARORA VILLAGE OF LAKHAOTI BLOCK

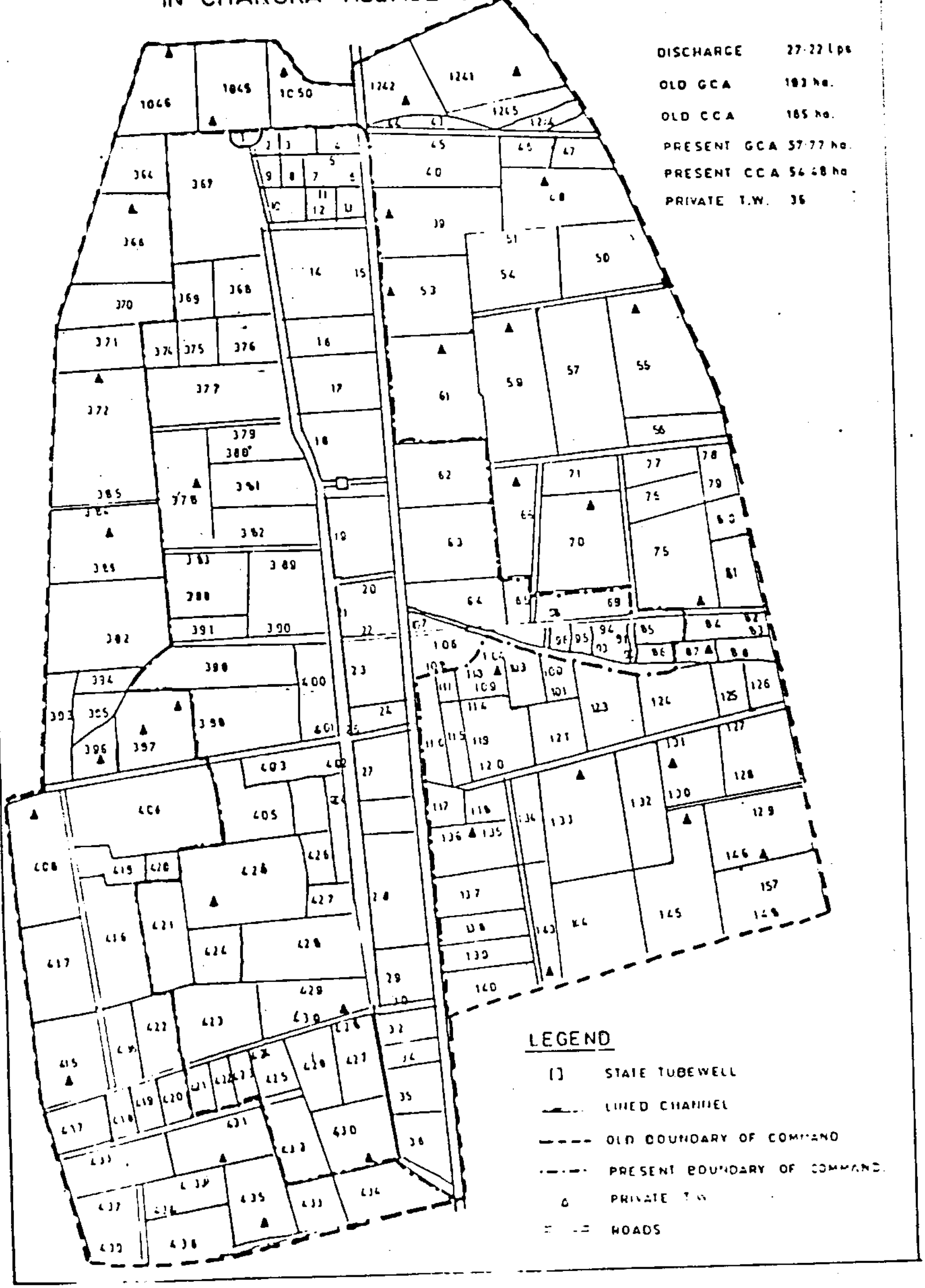


FIG 5 COMMAND AREA MAP OF STATE TUBEWELL NO. 43 J B IN MANAKPUR VILLAGE OF BULANDSHAHAR BLOCK

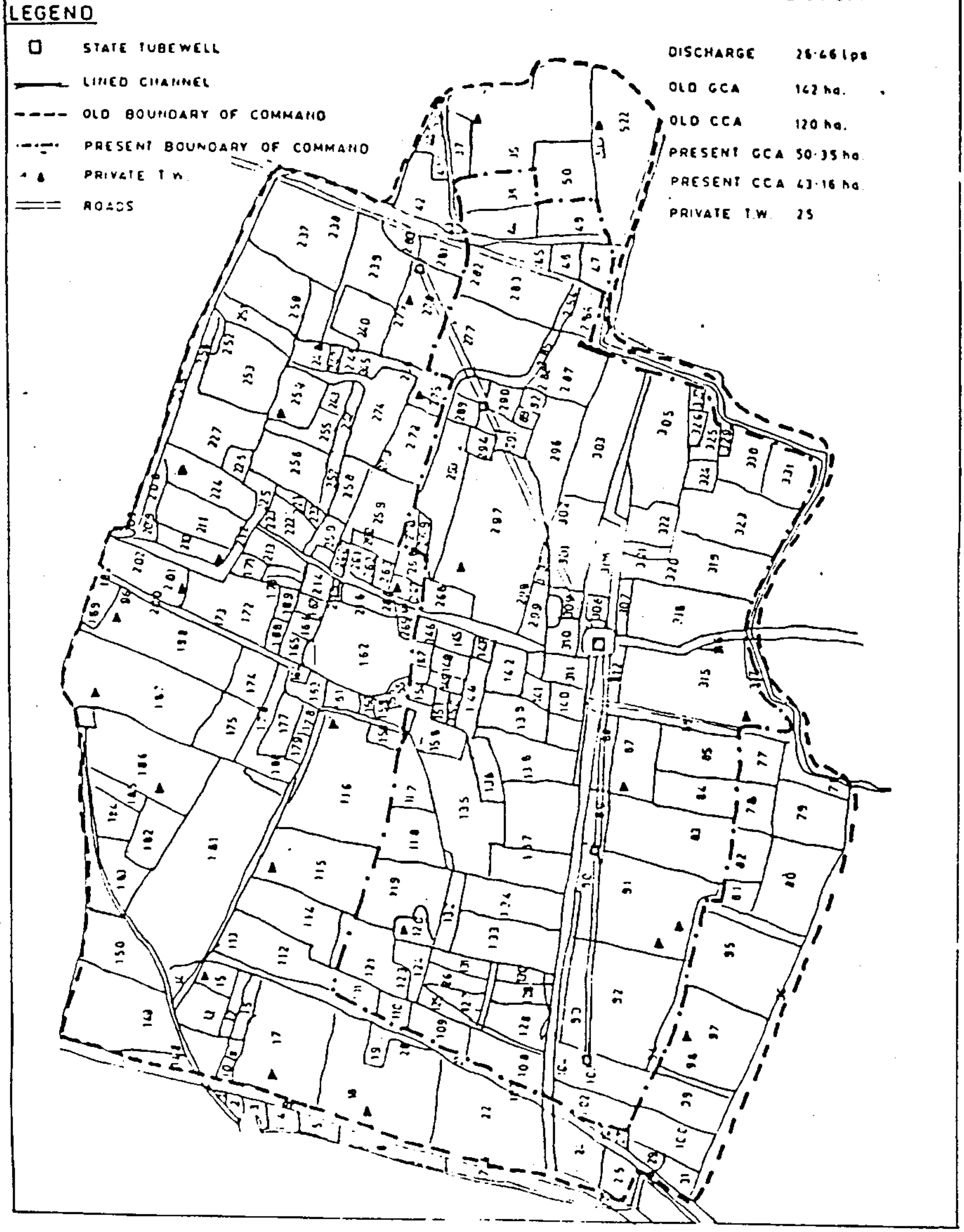


FIG. _ COMMAND AREA MAP OF STATE TUBEWELL NO. 45 K B IN PIPALA VILLAGE OF LAKHAOTI BLOCK

LEGEND

□	STATE TUBEWELL	DISCHARGE	22·50 lps
═══	LINED CHANNEL	OLD GCA	96 ha.
- - - -	OLD BOUNDARY OF COMMAND	OLD CCA	75 ha.
-·-·-	PRESENT BOUNDARY OF COMMAND	PRESENT GCA	11·03 ha.
▲	PRIVATE T.W.	PRESENT CCA	8·61 ha.
══	ROADS	NO. OF PRIVATE T.W.	15

Apart from the above studies carried out, data collection on several aspect have been carried out by both the organizations WALMI - UP and WRDTC, University of Roorkee.

A brief summary of the various studies are given.

TECHNICAL ASPECTS

Implementation of Kriging

A computer program on Geostistical technique using Universal Kriging Approach is implemented and applied to Madhya Ganga Canal command area with the secondary data that was available.

A typical set of groundwater data, such as measured piezometric heads, denoted by Z, consists of observations at a number of irregularly spaced points. Given such a set, a geohydrologist is often faced with estimation problems such as (i) estimating the value of Z at an unmeasured point in the same aquifer (interpolation), such as the estimation of Z at the nodes of a fine grid before using a contouring subroutine ii) estimating the area or volume of water stored in an aquifer (integration) and (iii) estimating the slope of Z at some point (differentiation), such as the calculation of piezometric head gradient, which is required for flow velocity determination.

Geostatistics provides the statistical tools for (i) calculating the most accurate (according to well defined criteria) predictions, based on measurements and other relevant information (ii) quantifying the accuracy of these predictions and (iii) selecting the parameters to be measured, and where and when to measure them, if there is an opportunity to collect more data.

A programme in Fortran is implemented for universal Kriging and has been used to produce ground water contours in the Lakhaoti branch command area. The study area is divided into 80 grid points.

Water Resources Evaluation in Lakhaoti Branch Command

Studies have been conducted to determine sustained yield and to study the behaviour, and pumping pattern of groundwater in the command of Lakhaoti Branch of Madhya Ganga Project. Lakhaoti Branch command is 201560 ha and is bounded by Kali nadi and Nim nadi. The proposed CCA of the branch is 193,000 ha. The area lies in Distt. of Bulandshahr, Ghaziabad and Aligarh.

Ground water of the area is monitored through measurement of water levels in 42 open wells. So far the farmers were entirely depending on the groundwater for irrigation. The crops grown in the area include wheat, sugarcane, maize, bajra, pulses and rice. Depth to water table in the region varied from 6.00m to 16.00m in pre-monsoon of 1987. Average depth to water table in the region varied from 8.8m in October 1984 to 12.20 m in October 1987. Water table variation and monthly average rainfall are shown in Fig.7. The water table in the area has downward trend with an average lowering being about 0.4m per year. In order to evaluate

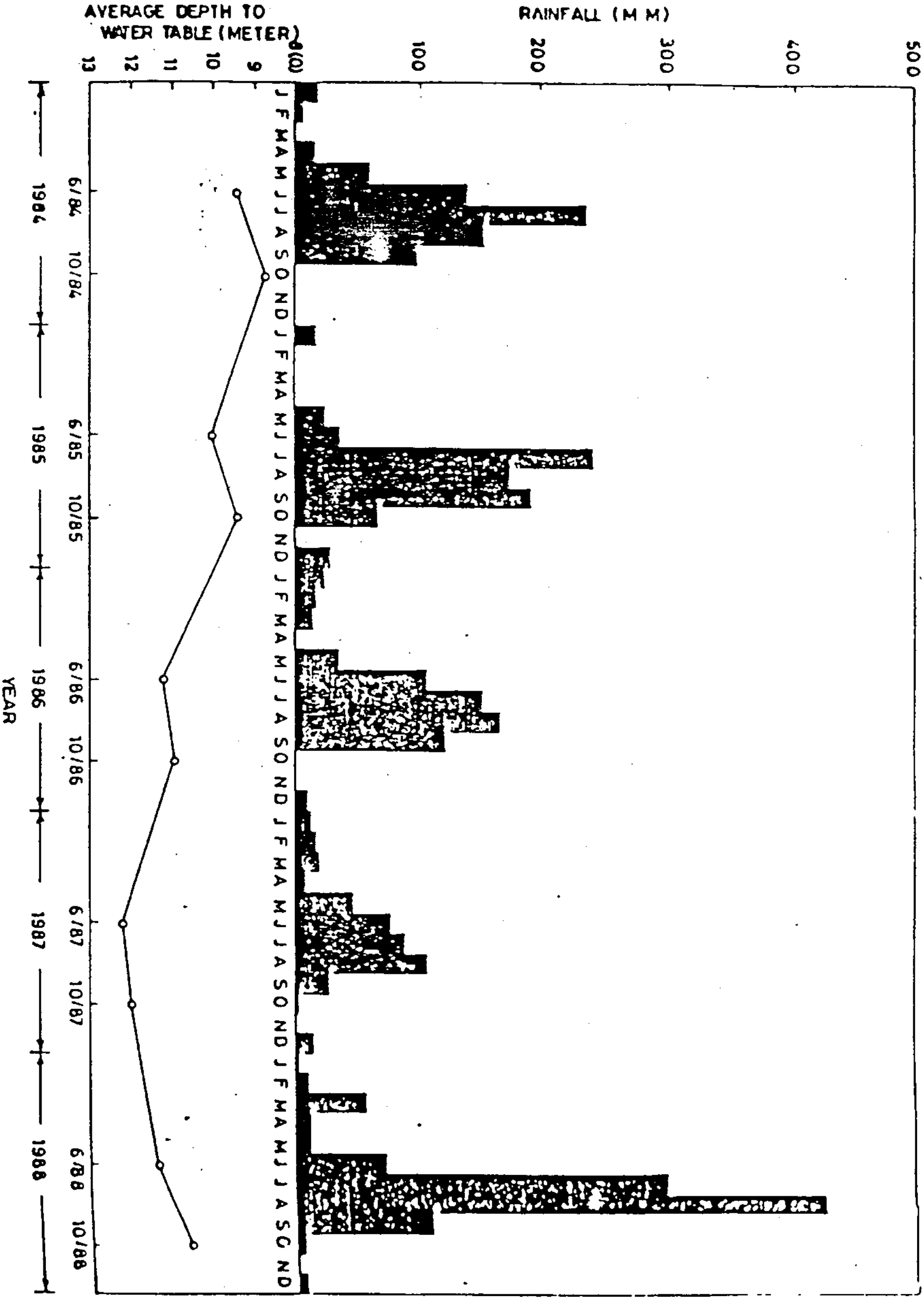


FIG.7: AVERAGE DEPTH TO WATERTABLE FLUCTUATION OF LAKHAOTI COMMAND

the ground water resources and to determine the present use pattern of water resources, water budget of the area have been prepared seasonwise for a period of four years.

The value of specific yield as determined from the data of four non monsoon seasons is consistent and ranges between 0.126 and 0.137. Average value of the specific yield for this this area is 0.13. The rainfall recharge, which is the major contributing to the subsurface reservoir of the area varies from 23.9 to 27.5 percent of the annual rainfall during the four year period from 1984-85 to 1987-88. Average value of rainfall recharge for a normal year can be taken as 25 percent of the annual rainfall. Normal rainfall of the area is 1050 mm. Therefore rainfall recharge for a normal year over the study area of 193000 ha works out to 507 MCM.

Average evapotranspiration from the irrigated area works out to 35.6 cm and 53.8 cm against average consumptive use requirement of 39.7 and 85.0 cm during Rabi and Kharif seasons respectively. Rainfall runoff from the area varies between 45 and 54 percent of annual rainfall.

The study area which is commanded by Lakhaoti Branch will be getting surface water during June to September every year when there is surplus water available in river Ganga. Surface water will be used for Kharif irrigation as well as recharge of ground water. This will help in enhancing the sustained yield of ground water reservoir and in checking downward trend of ground water.

Lakhaoti Branch system will supply 536 MCM of surface water during Kharif season. Out of this, 282 MCM of surface water is expected to go to the underground reservoir through the seepage from irrigation canals and percolation from the irrigation fields. The available canal supplies fall short of the water required for the proposed kharif crops for a period of 7 weeks leading to shortage of 151 MCM. This shortage is to be met from the sub- surface reservoir. The balance of recharged ground water of 131 MCM can be utilised for the non kharif irrigation. Besides this in an average year 507 MCM is contributed from the rain-fall to the sub-surface reservoir. The total amount of 638 MCM of ground water can meet the current demand of 567 MCM (upto 1990) during non kharif season and additional future demand of 71 MCM. This additional surplus water can not only be utilised in future but also raise the water level in the subsurface reservoir leading to reduce pumping cost. Therefore, increased ground water availability will be used to meet the shortfall during kharif and meet water requirement during non-kharif season.

Ground Water Model

The study area commanded by Lakhaoti Branch is bounded by Kali Nadi and Nim Nadi. Since these rivers are not continuous flowing, these can not be taken as equal head or no flow boundaries. The area for ground water was therefore extended upto Upper Ganga Canal, Anup Shahar Branch and Lower Ganga Canal, which can be taken as fixed head boundaries.

Integrated finite difference model representing single layer aquifer ground water flow has been used for simulating ground water system of the area. The study area has 39 observation wells. Ground Water abstraction in the study area is taking place through state tubewells, shallow (private) tubewells, pumpsets and dug wells. Blockwise population of these structures is recorded by the Minor Irrigation Deptt. Total modelled area is 446879 ha.The area has been divided into 98 polygonal nodes (Fig.8) Average area of the nodes is 4560 ha. There are 36 clamped nodes and 62 free nodes.

The model was calibrated nodewise for eight seasons of the four years period from 1984-85 to 1987-88 by adjusting values of parameters through trial and error method until the computed levels matched with the observed levels. The sequence followed was, first modifications were carried out in the value of T, next modifications were made in the values of S and if necessary corrections were made in the values of vertical flows.

The average error between computed and historic levels for the important nodes was 0.056 m and that for all node was 0.05 m. This indicates fair degree of accuracy in the simulationof the model from the final caliberation, the values of the specific yield are found to vary between 5% and 25% with an average value of 14.98%. The values of the transmissibility varies from 0.5 to 5.75 ha/month.

Average rainfall recharge varies from 18.35 to 21.05 percent of the annual rainfall. Recharge from canal seepage and from irrigated fields was 39.5 percent of the total canal input. Since the modelled area is bounded by U.G.C., L.G.C. and Anupshahr branch, the seepage from these canals varies from 10598.4 to 12205.82 ha-m annually. Maximum seepage was found to take place during the years 1986-87 and 1987-88 and that was because of the drought in 1987.

The input from rainfall to the ground water basin varies between 37% to 60% of the total annual input. Lowest value being obtained in 1986-87 which was a drought year with annual rainfall of 36.4 cm.

From the predicted results it was clear that if Lakhaoti branch system is lined the water table will continue to go down progressively. The subsurface inflow to the study area from the adjoining irrigated area will decrease after introduction of the Lakhaoti branch system. The cost of pumping ground water which has been progressively increasing will stabilise after 1992, if Lakhaoti branch is not lined.

Ground Water Balance

The various components of ground water balance for the total modelled area are taken from the output of the final calibration run. It is seen that the recharge factor for rainfall varies from 18% to 21%. The lateral flow from main canals, (UGC, LGC and Anupshahr branch) to the area varies from 10598 ha.m. to 12205 ha.m annually. More lateral flow is observed in the year 1987 and 1988. This because of the depression of the water table level due to the drought in the year 1987. The rate of seepage from the main canals varied from 0.69 to 0.8 $m^3/sec/10^6\ m^2$ with an average value of 0.75 $m^3/sec/^6\ m^2$ of wetted perimeter area.

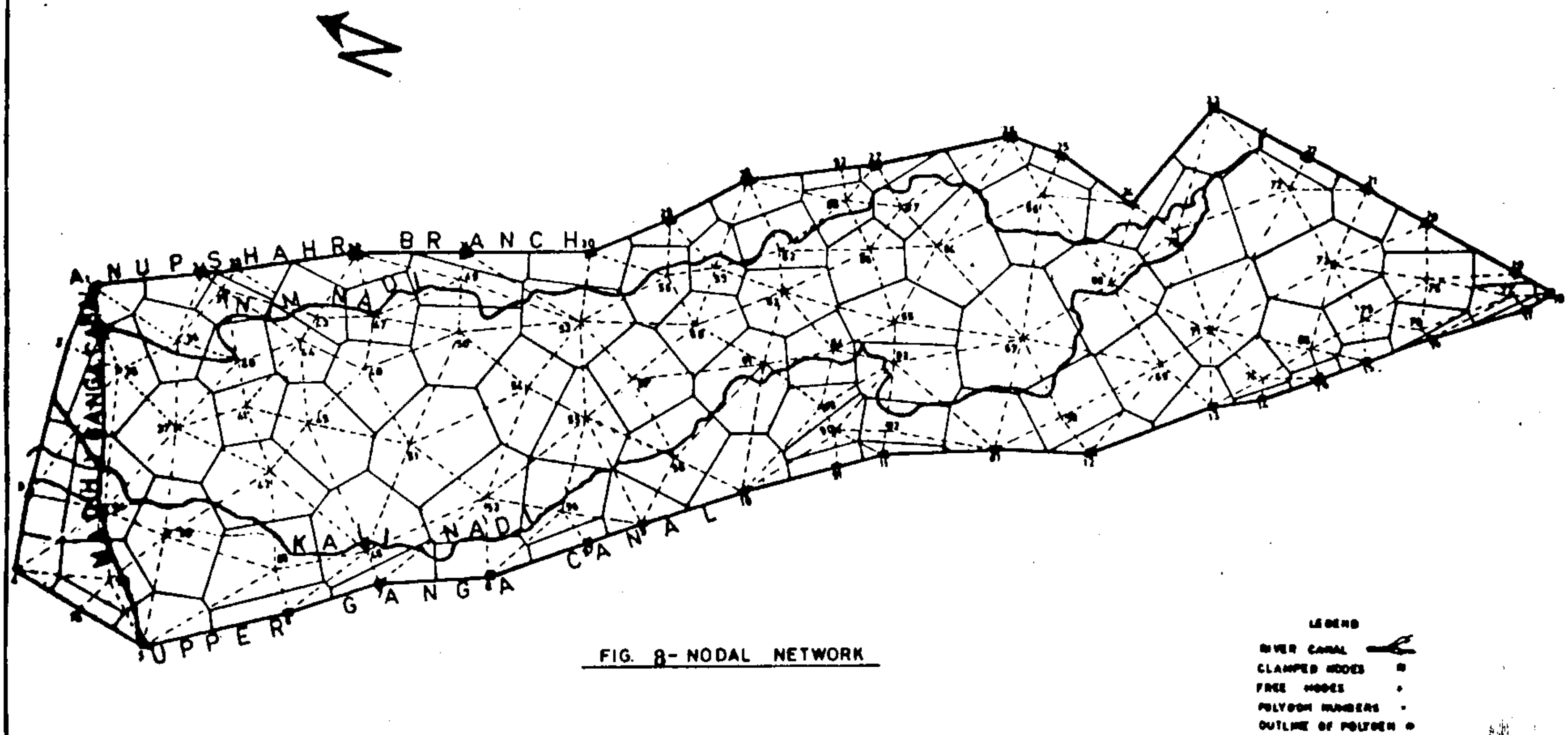


FIG. 8- NODAL NETWORK

The water balance for the modelled area for the Lakhaoti branch command area has also be worked out. A perusal of the the results indicatesthat the total annual recharge to the Lakhaoti command varies between 39670 and 66725 ha m from 1984 to 1988. The minimum recharge has taken place during the year 1987 which was a drought year and maximum recharge has taken place during the year 1988. During the period 1984-1987, there has been mining of groundwater varying between 7253 and 30,000 ha.m. As a result of this there has been progressive lowering in water table during this period. During the year 1988, there has been increase in storage by about 3267 ha.m as it was a relatively wet year. Gross annual pumping has varied between 63,937 and 76927 ha.m. 75 to 80 percent of which has taken place through shallow tubewells and other privately owned minor irrigation structures and the remaining through state tubewells.

The area between East Kali Nadi and Nin Nadi previously served by the state and private tubewells has been taken as the command area for Lakhaoti Branch canal. Surplus monsoon run off of the Ganga river will be utilised for Kharif irrigation in this dry pocket. The cultural command area branch is 193000 hect, and the proposed paddy irrigation is 49550 ha. The length of the branch canal is 72 km while the length of the distributaries and minors is 1030 km.

On full development of Lakhaoti branch irrigation the surface water input into the area will be 53670 ha.m. Out of this about 27000 ha.m. water percolate to subsurface reservoir through canal and field seepage. This additional recharge will check mining of subsurface reservoir and water table will stabilise at a depth of about 12.0 m below ground level. In case the distribution system is lined, the seepage and recharge to the subsurface reservoir will be reduced. Therefore, the progressive lowering in water table will continue. With unlined system, the average water table stabilised at a depth of 12.2 m below ground level. If the canal system is lined the lowering will continue at a rate of 0.3 m per year.

Main Canal Operation

Main systems accomplish two main functions; transfer and distribution. The transfer function includes flow routing, control and regulation of flow along the network. The distribution function involves the amount of water to be delivered at the right time given the overall operation rules and management practices. The operation of the main system may be set up to provide rotating or continuous water supply while such supply strategies yield lower cost system and system easier to manage they may not encourage farming practices which maximize production. Instead, the scheduled on demand water delivery may be used to allow the best water management at the farm level as well as the different linkages of the net work.

i) An updating process of demands in relation to the previous supplies

ii) A process by which operational water losses are minimized

iii) A water transfer function for travel time

Demand Updating: Whenoperating a gravity system, the problem is; How to allocate a given quantity of water to attain an optimum distribution. Facing the limiting water availability, the problem is crucial during the peak periods and demands cannot be satisfied in a timely fashion. The water master is constrained to give water with excess or deficit in order to maintain the mass balance over the system. thus supplies may not fit the demands, in which case command areas react by updating the on coming demands in response to previous supplies. A each time step,the updated demands are considered as the targets to be reached by the model. Based on the assumption that the updated demand of a given time step i is related linearly to the discrepancy between supply and demand of the previous time step i-1, one can write

$$\bar{d}_{i+1,j} - d^{o}_{i+1,j} = \bar{d}_{ij} - s_{ij}$$

for i = 1,2, ..., T

where;

$\bar{d}_{ij}$ and d^{o}_{ij} are the updated and forcast demands respectively of unit command area j during time step i; sij is the supply given to the same command area during the same time step; and T is the optimization time period.

Observing that for time step 1, the updated and forecast demands are equal, and making use of equation (1), the forecast demands may be calculated as -

$$\bar{d}_{i,j} - d^{o}_{ij} = D_{i-1,j} - S_{i-1,j}$$

where Si-1, j and Di-1,j are the total supply ad forecast demand respectively of command area j from time step 1 to i-1.

Water Loss: Water losses are of two kinds; the conveyance water losses and the operational spills. If Qij is the available flow at the command area out let j during time step i, the available flow down stream j-1 is given by the equation

$$Q_{i,j-1} = \rho_{j-1} \left(Q_{ij} - s_{ij} \right)$$

Where ρ_{j-1} is the conveyance efficiency of link j-1 necessary to match the supplies,operational spills are with the manageable discharges. The efficiency of the operation dictates that water losses are to be minimized. The operational water losses eij in link j during the time step i can be calculated as -

$$e_{i,j} = \mathrm{Max} \left(0,\ Q_{ij} - s_{ij} - QL_{j-1} \right)$$

Where QLj-1 is the system capacity of link j-1

Travel Time: Any modification of the flow occuring at the upstream part of the system takes time to be effective at some point downstream. This time may vary from a few hours to several days depending on the geographical distribution of command areas in the system, the hydraulic characteristics of the network, the basic flow and the change in flow produced. This problem involves not only different time references of operational periods from one command area to the another but also the change in the flow characteristics from point to point in the system. A conveyance system operation must include not only the optimal amount of water to satisfy the demands, but also the stabilization of flows within the system. The requisite to minimize transient flow and so to stabilize the hydraulic profile along the canal suggests that regulation and control of system structures should be setup so to get as quickly as possible a steady state flow. One solution to this problem can be obtained by a hydraulic analysis of water transfer in thesystem. Instead, the travel time to each command area outlet will be in put as a constant.

When optimizing water distribution, the objective is to maximize water availability of water from upstream to down stream. If Ri is the release at the head during time step i, taking into account travel time τ_j this flow will reach any command area out let j at time $i + \tau_j$ and lasts the duration of time step. so, if the available flow in link j during time step $i + \tau_j$ is Qij and sij the supply given to unit command area j during this time step, then

$$Q_{i,j-1} = \rho_{j-1} \left(Q_{i,j} - s_{ij} - e_{ij} \right)$$

Where eij are the operational water losses during i. the above equation provides for most complications to be considered. Hoever the index ij is not in standard time reference since i is equal to $i + \tau_j$ It can be shown that

$$ss_{ij} = (1 - A_j)\, s_{ij} + A_j\, s_{i+1,j}$$

$$ee_{ij} = (1 - A_j)\, e_{ij} + A_j\, e_{i+1,j}$$

$$A_j = \tau_j - \text{int}\,(\tau_j)$$

Where int (τ j) is integer part of τ j and ssij and eeij are supplies and operational water losses in the standard time reference.

Model Formulation:

The decision to be taken at each time step is the supply of water to be given to command areas of the system. So the policy should reflect the objective assigned to the operation of the main system model which is to give water supplies as close as possible to the updated demands with the maximum efficiency.

With this regard, the mathematical formulation of the objective function attempts to minimize the discrepancies between supplies and their corresponding updated demands as it also tries to minimize water losses. The resulting objective can be established as ;

$$\text{Min} \sum_{i=1}^{T} \sum_{j=1}^{J} w_j \left((s_{ij} - d_{ij})^2 + e_{ij}^2 \right)$$

Where J is the total number of command areas in the system.

Defining Pij as the returning function we can write -

$$P_{ij} = w_j \left((S_{ij} - D_{ij})^2 + E_{ij}^2 \right)$$

So the objective can be written as

$$\text{Min} \sum_{i=1}^{T} P_i I^t$$

i) $$S_i = \sum_{k=1}^{i} s_k$$

ii) $$E_i = \sum_{k=1}^{i} e_k$$

iii) $$\alpha_{j-1} Q_{i,j-1} = \alpha_j (Q_{ij} - s_{ij} - e_{ij})$$

iv) $$s_i = n_i S_m$$

v) $$s_i + e_i < QO + QS$$

vi) $$Q_i < QL$$

vii) $$(s_i + e_i) \alpha^t = \alpha_{J+1} R_i$$

where I is the vector unit of dimension J with components 1,0 and I^t is its transpose pi, Si, Ei, si, ei, Qi, QL are vectors whose components are pij Sij, Eij, sij, eij, Qij, QLj respectively.

S_m is the vectors whose componentsare S_{mj} the manageable discharge of command area J

QO is the vector of command area out let capacities.

ω is the vector whose components are Wj, the weighting factors of different demand nodes in the system, and

α is the vector and α^t is its transpose whose components are α_j the conveyance efficiency of the system from command area j to the downstram and of the net work given by the equation

$$\alpha_j = \prod_{k=1}^{j-1} \rho_k \quad \text{with } \rho_0 = 1$$

The above model is to be solved by dynamic programming.

Evaluation of Recharge:

For this purpose two different models have been formulated and tried. The first one is based on the Richard's equation for one dimensional flow andthe other one is a Lumped model refered toas the GARDENSOL model. Though the first model is quite comprehensive, the results show that it does not reflect the soil moisture status properly. The later one is simple and reproduces the measured soil moisture fairly well.

SOCIO - ECONOMIC STUDIES

Some Aspects of Socio Economic Studies

A survey to collect base line data on socio-economic conditions in a selected area of Shikarpur distributory under Lakhaoti branch canal of Madhya Ganga project has been carried out. The survey was conducted in 5 villages. The base line data is collected through two sets of questionnaire and by personal interviews. Finally 45 farmers of various categories viz. 15 from marginal, 11 from small, 9 from medium and 10 from large size of land holdings. Based on the data collected, the socio-economic indicators such as family composition, land holdings, housing, food habits, livestock, education etc. are analysed. Agro-economic aspects such as cropping pattern, cropping intensity, crop budget, crop productivity, agricultural income etc. are analyzed. The resource use of various inputs by the farmers is analysed through production function for crops like sugarcane, maize and wheat. Ground water utilisation and performance and economic analysis of private tubewells are evaluated. Factor analysis technique is used for identification of significant socio-economic variables, affecting existing system in the study area. The same technique is also applied to determine important inputs used in agriculture, with regard to crops viz., sugarcane, wheat and maize.

The study area comprising 40 villages of Bulandshahr tehsil and district are included under the command of Shikarpur distributory of Lakhaoti branch of Madhya Ganga Canal project. The total geographical area is 12,616 hectares comprising of culivable waste 1.21 percent, area occupied by roads, villages etc. 10.34 percent, area under tubewell irrigation 82.36 percent and the remaining area under rainfed agriculture. There is no forest land in the area. It was observed that all the villages were connected with excellent net work of roads and had no dearth for infrastructural facilities like marketing, communication, supply of fertilisers and seeds etc. No single farmer had complained about these facilities. The problems expressed by the farmers were mainly finance, water and unemployment.

The family composition of various categories of farmers were tabulated and concluded that the average persons per family was increasing with the land holdings. Illiterates were reported more in marginal size of farmers. However, education level of the farmers was restricted upto high school only. The composition of the farmers was analysed. The marginal farmers consisted the least i.e. 6.5% where as the large farmers were about 50%. Almost all farmers were having houses whether kutchha or pucca. The tubewell owners were reported more in large farmers category. Livestock strength was also recorded high in case of large farmers and less for marginal farmers. Income of the people was derived from agriculture mainly and the auxillary income from maintaining livestock.

Factor analysis is carried out at individual level. It was concluded that the agriculture income was dependent on land holdings and gross sown area and 33.45% variation was explained in the data among these variables. 17.46% variation was explained by the family composition of the farmers. 12.88% variation was explained by food habits. 7.92% variation was explained by source of irrigation (tubewell) and 7.52% variation was explained by education. With this analysis it was conluded that in the study area, the important factors for the individuals were found to be land holdings, family composition, food habits, source of irrigation and education. Hence it was suggested that concentration on these aspects would bring in further development of the study area. While the first three are the personal factors, the variation in the latter two variables viz. source of irrigation and education could be minimised by improving facilities in this sphere. Much improvement could be expected in respect of other variables also due to existance of interdependancy.

While farmer's choice of crop always lay emphasis on maximizing his income, due to scarcity of water resource in the area, the farmers are raising crops according to their primary requirement. This was concluded with the cropping pattern in the kharif season followed by farmers, which revealed that about 22% of the area was under sugarcane, where as the other crops like maize and jowar were raised in more percentage area i.e. 26% and 28% respectively. However, it was recorded that higher percentage area for sugarcane was contributed by the small, medium and large farmers. It was established that the difference in land holdings and availability of water are the important factors for choosing sugarcane crop. However, the other crops like maize and jowar were raised almost equally in proportion to their land holdings.

In rabi season, 2/3 of the area was covered by wheat. Pulses were raised mostly as mixed crop with wheat. Barseem was also raised in about 1/5 of the area.

The existing cropping pattern established that the farmers could raise such of those crops which were needed for their own consumption and for feeding livestock. The farmers expressed that with availability of canal water supply they would prefer to raise sugarcane or paddy. Since it was already proposed to supply water from Shikarpur distributory in kharif season, area under paddy could be improved from the existing 9% to 25% as contemplated. The crop budget in respect of some important crops like sugarcane, maize, arhar, rice and wheat revealed that the farmers were gaining maximum for sugarcane crop and next come wheat, arhar and paddy. The farmers have no benefit in maize except toiling hard for themselves. The farmers reported that they could sell their produce either to private parties or agricultural market yards except sugarcane. Presently majority of the farmers were selling their produce to private parties due to malfunctioning of sugar factory at Bulandshahr. Therefore the new sugarfactory, which is coming up at Bulandshahr may be helpful.

The cropping pattern and crop calender revealed that the farmers were engaged in agricultural operations for most of the time. The farmers expressed that they had very little time left for recreation. Due to double cropping system prevailing in the area, the cropping intensity worked out to be 193%. The farmers are risk if there were failure of winter rainfall. Except sugarcane, the average yield of other crops was reported high. The annual agricultural income per hectare of food crops on average was worked out to Rs. 5587, where as the income per house hold was increased from marginal to large size farmers. The income per hectare was Rs. 8597 for small farmers, which is maximum. The income per hectare for marginal, medium and large farmers was worked out to Rs. 6229, 6025, 5143 respectively. It was concluded that marginal farmers are handicapped for infra structural facilities, where as small farmers some how manage. The medium and large farmers also registered comparatively less income due to diversion of work.

Multiple regression to analyse production function (Cobb Douglas) was carried out for important crops like sugarcane, wheat and maize. The results for sugarcane are that irrigation water and fertilizer components were over utilised. Human and bullock labour and seeds components could be raised to maximize net returns for the farmers. The utilization of irrigation water established the fact that the farmers were more conscious on sugarcane crop.

In respect of wheat except use of urea (fertiliser) all other inputs were found to be significant and positively contributing to increasing returns to scale. It is established that while the irrigation water use is almost at optimal level, the other inputs such as human and bullock labour etc. could be increased.

In respect of maize, the variables like bullock labour, machine charges, fertilizer (urea) and irrigation water can be used more for increasing returns to scale. The other inputs such as human labour, fertilizer (DAP) and seeds were used more than necessary and more use of these inputs would have decreasing returns to scale. The marginal productivity indicated that irrigation water for maize can be raised so that the estimated yield would increase. Factor analysis results revealed that the important variables are fertilizer for sugarcane, urea, seeds and water for maize and fertilizer (DAP) seeds and human labour for wheat.

Ground water table in the study area was declined from 5.5 to 15 m and resulted in high investments for tubewells and increase in pumping costs. However the farmer had so far no alternative except use of ground water for irrigation. It was felt that the farmers would have great advantage, if canal water is supplied to them.

The farmers expressed that they were not looking for incentives for installation of tubewell, but any alternative arrangements or measures to improve the ground water table would facilitate the farmers to carry out agricultural activities. Any laxity on the part of agencies would have disastrous effects on agriculture.

It was concluded that usage of ground water for sugarcane crop was more than necessary and for wheat at optimal level. More water can be used for maize. The present situation revealed that in kharif season, farmers were able to get water for sugarcane crop, whereas water for other crops such as maize was not supplied adequately. Hence improvement of irrigation in kharif season would result in far reaching benefits to farmers. Moreover a change in the cropping pattern could also be anticipated with supply of additional water.

With the introduction of canal system in the area, ground water table would be raised, resulting in lesser pumping costs. In view of this, there is possibility that the subsidies would still be reduced. But on the whole, the supply of electricity should be made adequately and effectively.

Socio Economic Impact of Irrigation

Random sampling was adopted for selecting the farmers in three pilot areas giving proportionate representation which encompasses the sampling, data collection, processing of data, analysis etc. to each category of farmers according to their size of population. The villages selected for the study are Manakpur, Utraloi, Bagalaputhri. In pilot area A and the villages covered in pilot area B are Charora, Nagalakaran and Bhawas whereas in pilot area C only one village i.e. Behlimpura has been covered. Thus finally a sample of 12 farmers in pilot area A,15 farmers in pilot area B, 9 farmers in pilot area C have been selected using the random numbers for achieving the objectives of the study. In pilot area A, state tubewell and private tubewell, irrigation facility is available and in pilot area B, also the state and private tubewell irrigation facilities are available whereas in pilot area C canal and private tubewell facilities are available. The randomly selected farmers have been categorised as marginal, (less than one ha.), small (1 to 2.5 ha.), medium (2.5 to 4 ha.), and large (above 4ha). Finally in pilot area B there are 4 marginal, 6 small 3 medium and 2 large farmers which have been selected for the study and in pilot area C, 4 marginal, 3 small, 1 medium and one large farmers have been selected for the study. Likewise in pilot area A there are 2 marginal, 6 small, 3 medium and 1 large which have been finally selected for achieving the objective of the study. A pre-structured and pretested schedule/questionnaire was used for collection of the required data for which an intensive survey method has been adopted, which means that repeated visits were made to interview the selected farmersfor collection of the required data. Also 20 unirrigated farmers were selected which have been considered as a `control unit'.

The study revealed that the average operational holding of the selected farmers in pilot areas A,B and C is 2.16, 2.06and 1.32 hectares respectively. However,the average area under pilot area A,B and C for different crops shows that maize and sugarcane occupied on an average the largest area followed by sorghum. Further the study revealed that the area irrigated by private tubewells is largest as compared to the area irrigated by canal. A close analysis revealed that the area irrigated by private tubewells is much larger than the area irrigated by state tubewells in pilot area A and B whereas in pilot area C the area under canal is more than the private tubewells.

Further it is seen that the average area under maize crop in pilot area B is 0.58 hect. and sugarcane aea on an average is 1.02 hect. and private tubewells irrigated 2.04 ha. whereas 1.14 hect. is irrigated by state tubewells. In pilot area C the area under sugarcane is 1.00 hect. followed by maize i.e. 0.49 hect. Canal irrigated 1.00 hect. and private tubewells irrigated 0.48 hect. On the basis of the size of holding, it is seen that in case of marginal farmers, maize occupied 0.32 hect. on an average and sorghum occupies 0.39 hect, out of which private tubewells irrigated 0.80 hect. and state tubewells irrigated 1.33 hect. but canal irrigated only 0.50 hect. However, in case of small farmers the average area under sugarcane is 0.45 hect. followed by arhar (i.e. 0.34 hect). and maize (0.31 hect). Canal irrigated as much as 0.43 hect. whereas private tubewells irrigated 1.16 hect. and state tuebwells 1.30 hect. But in case of medium farmers the area under maize is 1.15 hect. But in case of medium farmers the area under maize is 1.15 hect. followed by sugarcane i.e. 1.00 hect. and sorghum 0.56 hect. Private tubewells irigated 2.80 hect. and state tubewells 1.20 hect. Canal could irrigate only 0.66 hect. The large farmers on an average could take 0.71 hect. maize and sugarcane 1.6 hect. followed by sorghum (i.e. 0.5 hect). Of the total irrigated area in case of large farmers, canal irrigated 4.08 hect, whereas private tubewells and statetubewells irrigated 4.50 and 1.20 hectares. Similarly in pilot area A sugarcane an maize are the most important crops which occupied 1.08 hect. and 0.88 hectare on an average. Sorghum occupied the 3rd place. Private tubewells irrigated 1.78 hect. whereas state tubewells irrigated 1.55 hect.

The Cropping Pattern determine the levels of production which inturn, determine the level of farm out-turn. In view of this fact, cropping pattern in respect of each pilot area for the selected farmers has been studied. The analysis shows thatthe most important crops in pilot area A are mize, sugarcane, arhar, vegetables, paddy and green fodder. in pilot area B, the important crops are again maize, sugarcane, green fodder and paddy. Also a similar trend is observed in pilot area A and C. Out of these crops in pilot areas A,B and C maize and sugarcane occupied the first position followed by green fooder, and arhar. It may be seen that in pilot area C the canal and private tubewell irrigation facility is available to farmers. Therefore, the farmers have cultivated maize and sugarcane in larger area. However, a close analysis reveals that in pilot area A and B it is sugarcane crop which is predominantly cultivated by the farmers which shows their liking and preference. Since the tubewell irrigation is costly as compared to canal irrigation, therefore the farmers may be motivated to grow more sugarcane and paddy if canal irrigation facility is created in pilot area A and B.

The average yield of the selected irrigated and unirrigated farms has also been studied and it is observed that the average yield of irrigated maize, sugarcane and other crops is comparatively higher than the unirrigated maize, sugarcane and other crops. The higher yield per hect. incase of irrigated crops is partly due to irrigation facility and partly due to improved seeds, fertilisers and other resource application.

The study also revealed that the farmers having irrigation facility used improved varieties of seeds and applied fertilisers and pesticides. There has also been an intensive use of machinery/capital and the human labour use which has been instrumental in pushing up the farm income. The farmers having irrigation facility in pilot area A,B and C also have rationally used the farm resources.

The analysis revealed that the human labour utilisation for production of sugarcane is much higher than vegetables, sorghum and maize in pilot area `A'. Similarly in pilot area B and C human labour requirement on an average has been much higher in case of sugarcane than maize an sorghum which shows that human labour requirement for production of sugarcane is much more than any other crop which is probably due to that sugarcane is a commercial crop and takes about 10 to 11 months whereas maize and sorghum take 4 to 5 months. Based on size of holding it is seen that a marginal farmer needs much human labour for production of all the crops as compared to small, medium and large. This is on account of that the marginal farmers put all their labour for crop production and in case of the large and medium farmers it is seen that they could use equipment and machinery for carrying out the agricultural operation which saved the use of human labour.

SOIL AND AGRONOMY STUDIES

A Study of Crop Husbandry in Lakhoti Command

This Study is aimed at:

i) Conducting the irrigability and drainability survery in the command

ii) Classification of agro-climatic condition of the area

iii) Analysing the production potential of crops in the command

iv) To record the impact of irrigation sources on the crop husbandry in the command.

Crops predominantly grown in the command area are sugarcane, wheat, redgram, maize, sorghum, berseem and mustard. The study consisting of four main treatments; viz. government tubewell irrigated; private tubewell irrigated; canal irrigated and tubewell (s) + canal irrigated; subtreatments viz. Sorghum (fodder) (Sorghum vulgare); Maize (zeamays); Redgram (cajanus cajan) and sugarcane (saccharum officinerum) was undertaken during kharif 1990-91. These could not be any replication of the main treatment but the subtreatments were replicated thrice. Thus whole experimental set up consisted 48 observational plots. Procedure adopted in selecting the sites and analysis of data viz. physico-chemical condition of soil, land features, agroclimatic condition, crop production potentials and cultural practices.

The physico-chemical condition of the soil and land features of all the plots observed indicated that the areas surveyed bear characters which enable it to be classified as Irrigability and Drainability class I. Some notable characteristic feature are described below:

a)	Textural soil dept	very deep
b)	Textural class of root zoane soil	sanddy loam
c)	Cumulative infiltration (cm/minute)	$I=1.61t^{0.68}$
d)	Water holding capacity	195mm/m
e)	Presence of gravel kankar etc.	Nil
f)	Problem of erosion	Nil
g)	Problem of salinity or alkalinity	Nil
h)	Presence of hardpen in rootzone	Nil
i)	Depth of water table	10 - 15 m
j)	General slope	0.0375%
k)	Presence of natural outlet	available

While identifying the agroclimatic zone of the area it was observed that at 75% dependability of weather conditions the potential evapotranspirative demand of the area was 1456 mm/year agains the annual rainfall of 323 mm. For about 10 months the mean temperature is 10° C. . Thus the area falls in semi Dry sub Tropic Agro climatic zone.

Analysing the biomass productivity it is observed that the area bears a good potential of producting biomass of about 120 t/ha/year. The biological efficiency however of most of the crops under observation varied between 4-10% only.

The impact of irrigation sources on the cultural practices was quite significant. Crops in the private tubewell comands were timely sown and good care was given to them. On the other hand uncertainity prevailed in Government Tubewell and canal irrigations, therefore, cultural operations had to be synchronised with the availability of water only. Crops in the commands of Government Tubewell and canal were found to face more water stress as compared to that in Private Tubewell commads.

INSTITUTIONAL AND POLICY ASPECTS

Ground Water Exploitation and its Regulation

Ground water in the study area is declining at the rate of 0.5 to 0.65 every year and it has gone down by more than 3 m in the last five years. Almost all tubewell owners have lowered their tubewell at least once within the last five years. The distance between two wells in the study area is even less than 100 m and within 150 to 200m, there are two or sometimes three wells. Farmers feel that due to close spacing of wells their discharge has reduced considerably. If the surrounding tubewell in the vicinity are already running the tubewell will not lift water. The basic cause of overcrowding of the wells is the poor and uncertain electric supply. Inadequate recharge due to poor rainfall is also another cause. However, farmers are sowing very limited intensive water using crops such as rice.

There are four constraints that determine the feasibility of action that might be taken to cope with the depleting water table. To succeed adjustments must be - (a) Technically feasible (b) Financially viable, and (c) Legally permissible, (d) Socially acceptable. The efficacy and desirability of various approaches to prevent over exploitation of ground water has been discussed with farmers and their concern and views ascertained. The questionnair included questions; to determine farmers awareness and understanding of ground water depletion and its associated problems; and to indicate degree of preference for 20 adjustments to ground water depletion. The adjustments are categorised into five groups; user practices. Management policies, financial disincentives, technological fixes and others as shown in Table 1. Five adjustments related lto conservation and water management practices that could be carried out by irrigators. Five adjustments represented possible management policies. They included various forms of regulating or allocating water use that could be administered by project agency. Four adjustments involved financial incentives/disincentives and two were technological fixes and three were placed in "Other" category.

Preferences were measured on a scale of 1 to 5; 1 marked prefer; 3 was labled neutral and 5 was labeled dislike. Table shows the preference score of each adjustment and percentage of respondents preferring each adjustment. Preference scoreswere computed by summing the individual scoresand dividing by the total number of respondents. Thus the scores are estimated means.

8 adjustments received score of 11.6 or less indicating relatively a strong preference. Four of the most favoured are in user conservation category, two in technological fixes and two in others Category i.e. encourage water conservation law and use education. At least 76 percent farmers preferred each of these items. More than 90% like user conservation practices and technological fixes,except "Return to Dry Land Farming" in former category which has been disliked by more than 88% farmers. All the management policies has preference score more than 3 indicating dislike. "Offer govt. depletion insurance" item under financial policies had relatively neutral preference score of 3.06 with approximately equal number of people preferring and disliking.

In six adjustments there was a marked preference difference among various categories of farmers. The estimated means of their preferences areshown in Table 2. Large farmers has relatively strong preference for increasing spacing between the wells and are approximately neutral for prohibiting new irrigation wells. Marginal farmers had some degree of preference for offer Govt. depletion insurance and large are almost neutral. Small and marginal farmers has also neutral response for "Limiting kinds of crops irrigated".

Table - 1

Category and adjustments	Mean*	Prefer (%)	Neutral (%)	Dislike (%)
User Conservation Practices				
(a) Improve irrigation efficiency	1.0	100	-	-
(b) Employ conservation tillage practices	1.18	91	9	-
(c) Periodically check well efficiency	1.12	97	-	3
(d) Grow hybrid plants using less water	1.36	91	-	9
(e) Return to dry land farming	4.69	3	9	88
Management Policies				
(f) Increase spacing between irrigation wells	3.48	36	3	61
(g) Prohibit new irrigation wells	4.15	21	-	79
(h) Establish water quota	3.9	27	-	73
(i) Limit hours/day of pumping	3.9	27	-	73
(j) Limit kinds of crops irrigated	4.21	15	9	76
Financial Policies				
(k) Charge for water permits	4.33	15	3	82
(l) Tax irrigated agriculture	4.33	15	3	82
(m) Offer govt. depletion insurance	3.06	48	-	52
(n) Govt.increasing energy cost	4.63	9	-	91
Technolgocial Fixes				
(o) Recharging G.W. through unlined canals	1.0	100	-	-
(p) Build small recharge dams	1.18	91	9	-
Others				
(q) Encourage water conservation laws	1.6	76	18	6
(r) Use education	1.24	88	9	3
(s) Continue existing method	3.36	31	21	48

NOTE: 1: much prefered; 3: neutral

Table 2

Estimated Means showing preference Differences Among Various Categories of Farmers on Controversial Adjustments

Category and adjustment	Small, marginal farmers	Medium farmers	Large farmers
(a) Increase spacing between the wells (management)	4.2	3.8	2.0
(b) Prohibit new irrigation wells (Management)	5.0	3.93	3.25
(c) Establish water quota (Management)	3.8	3.66	4.5
(d) Limit hours/days of pumping (Management)	3.8	3.66	4.5
(e) Limit kinds of crops irrigated (Management)	3.2	4.6	4.75
(f) Offer govt. depletion in-surance (financial)	2.6	3.4	3.0

NOTE: 1: much prefer; 3 neutral; 5 dislike

In formulating policy to ensure adequate management of Madhya Ganga Aquifer, the legitimate concern of all water users will need to be respected if workable programs are to be instituted.

Ground Water Development

Agricultural production in study area is based almost entirely on ground water. Goverment programmes and policies have influenced largely the development of private tubewell in this region. Minor irrigation department helps farmers in drilling but almost 90% of the surveyed wells were installed by the private drillers, however the demand of farmers for this service exceeds the ability of department to do so. Other institutions directly involved are Gramin Vikas Bank and other Banking institutions. At present the average disbursement of loan is 12000/- Rs. per tubewell against the weighted average cost of Rs.25000/- tubewell. In case of marginal and small farmers Government offers 33-1/2% subsidy. Of the farmers interviewed 50% of small and marginal farmers have tubewell and 85% of these have installed with Government assistance, in case of medium farmers 80%, have tubewell and 30% have installed with government assitance, and in case of large every farmer own tubewell and 22.5% have sought government assistance. As a financial institution, lending policies are selective, no farmer with holding size less than 0.8 ha can apply for assitance and they also do not consider loans to co-operative or similarily organised groups. these two realities have curtailed access of marginal farmers to Banks' credit facilities. The mode of finance is cashor in the form of motor/engine, pumpset, fitting material etc. Electricity is at flat rate Rs.33/- H.P.

Of course, public programmes have encouraged the development of private tubewell but procedure for getting loan are very tedious and officials involved are highly corrupt. Influential and rich farmers and those who have contact have access to government programmes.

Government does not render any technical advice to farmers. Decision regarding type, make of pumps and prime mover are influenced by local mechanics. Mostly centrifugal pumps are used and are driven by electrically operated motors. Farmers face variety of technical difficulties including reduction in discharge over time, failure of centrifugal pumps, impeller blades and valves , burned out motors. Spare parts are easily available and repairs are locally done.

The survey conducted revealed that only 50% of small and marginal farmers have tubewell and almost all large farmers own it. Well owned by co-operatives are very small (5 to 6%). Partially due to fact that pulic programs have done little to encourage joint ownership and partially due to farmers distrust of cooperatives. Distribution is skewed towards large scale land owners. Reasons analysed are; it is not financially viable when holding size falls below minimum, as primary source of returns to farmer must come from his own land; Installation costs are high; To secure credit at least farmer must have 2 acre of land & cost are relatively inelastic when compared to capacities.

Existing Ground Water Scenerio :

In the study area, ground water markets by private tubewell owners is existing and water is commonly sold, but it represents fraction of total ground water pumped. Major obstacles preventing ground water markets are highly erratic and irregular electric supply and as ground lwater is fast depleting, so every year there is reduction in discharge of tubewell and now it takes more time to irrigate own land and number of hours left for sale areshrinking. On an average marginal and small farmers supplied water to 3 farmers, medium to 2.2 farmers ad large to 1.7 farmers per tubewell respectively. Own area irrigated of marginal farmers is 0.9 ha and large farmers is 3.75 ha. per tubewell respectively. The marginal and small farmers aresharing water atan average of 1.5 ha. while large farmers 0.75 ha per tubewell respectively. Monopoly enjoyed lby WEM owners varies from moderate to high. For a 5 H.P. Tubewell, cost of supplying water comes out to be 3.3 Rs./hr and the existing market rate is 4 to 6 Rs./hr. The difference between average value of output of seller and buyer is approximately 20%, which indicates that water markets in study area are inefficient. Ground water markets have enhanced capacity utilisation of WEM, as owners are pumping 2.25 times more water than they could have pumped otherwise.

There is a great need to make ground water markets competitive and efficient, so that more benefits accrue to non-WEM owners and even the landless.

Regarding the form of ground water markets lfarmers strongly favoured lthat some bussiness man or industrialist shouldrun the water companies, over other arrangements as public tubewell and community tubewell, with Government regulating control over prices andensuring equitable distribution of water guided kby certain norms. Community tubewell arrangement was least favoured.

The measures suggested to improve the electric infrastructure should be looked into. As farmers khave demanded separate quota for agriculture on the pattern of industry, so that possibility of providing a separate alternate source of energy has been worked out. Theunit cost of energy is lowest in case of lthermal plant li.e. 1.25 Rs./unit and highest in case of gas turbine i.e. 1.52 Rs./unit. As hydro cost arounds 0.9 Rs./unit & is the cheapest, so if the hydel department does not have sufficient supply to meet lthe demand then the steam plant for the area is second best choice.

Ground water in the study area is declining at .5 to 0.65 m every year. There is over crowding of wells and within radius of 150 to 200 m there are2 to 3 wells. So far all direct and indirect measures adopted by government have not yielded any results. Distinct preferences for coping with the ground water depletion emerged from the study. Farmers as a whole place much greater value on improving "User Conservation Practices". However, there was strong opposition to use of financial incentives and disincentives to deal with ground water depletion except offer government depletion insurance", which attracted neutral response. Among technical fixes, "Build Small Recharge Dams land Unlined Canals" won greatest favour. Other adjustments "Encourage water Conservation Laws were also highly preferred".

The results agree with actual practices. There is an active effort to increase substantially the irrigation efficiency. There is also a strong support for water storage, ground water recharge and water conservation. Efficiency and conservation are the consensus assurances to ground water depletion in the study area. The legitimate concern of all water users will need to be respected, if workable programmes are to be instituted.

As present ground water is the only source of irrigation government policies and programmes have encouraged the development of private tubewells, but officials involved are corrupt and procedures tedious. No governmental agency renders any sort of technical advice, except in rare cases they helped in boring. Farmers are facing variety of technical difficulties including reduction in discharges over time, failure of centrifugal , pumps-impeller blades.

Analysis of Ground Water Cost and Optimum Design of Wells

Large scale development of ground water calls for optimum design of wells which would deliver water at the minimum cost. The effect of various parameters on the unit cost of pumped water should also be determined to arrive at the optimum design.

The cost of pumping water from groundwater reservoir comprises fixed cost and recurrent/variable cost. The fixed cost include the initial cost of exploration, drilling well assembly, installation and development while variable costs include those of energy, establishment, maintenance and operation charges. The fixed cost depends on factors such as depth and thickness of the aquifer, diameter and length of screen and casing pipe, design discharge, depth of the water level and drilling cost which depends on the hydrogeological conditions.

From the study the following conclusions have been made:

i) Optimum capacity of wells have been determined as follows:

(a) For deep wells: It is in the range of 80 lps to 100 lps

(b) For shallow wells: Optimum well capacities between 10 - 15 lps.

ii) Optimum diameter and well depth has been determined as follows:

(a) Deep Wells

Well Capacity (lps)	Optimum Diameter (mm)	Well Depth (m)
40	23	85
70	25-28	110-120
80	28-30	115-121
100	33	127
140	35	157
170	40	165
200	45	172

(b) Shallow Wells

Well Capacity (lps)	Optimum Diameter (mm)	Well Depth (m)
5	65	23
6	80	22
8	100	25
9	100	24
10	100	26
12	125	28
14	125	31
15	125	33
16	125	35
18	150	33
20	150	37

iii) Optimum Entrance Velocity:

The optimum entrance velocity for deep wells is found to be less than 0.02 m/s and for shallow wells it is in the range of 0.0175 to 0.0225 m's.

iv) The unit cost of pumped water decreases with the increase in the value of transmissibility.

v) The unit cost of pumped water decreases with the increase in the value of the storativity of the aquifer.

vi) The unit cost of pumped water decreases with the increase in the annual running hours.

It is seen from the results of the analysis that the unit cost of pumped water by shallow wells of 10 lps capacity with 500 and 1000 annual running hours works out to be Rs. 184 and Rs.124 for 1000 m^3 respectively.

The unit cost of pumped water by deep wells of 70 lps and 100 lps capacity with 3000 annual running hours work out to Rs.138 and Rs.133 per 1000 m^3 respectively. Similarly the unit cost of ground water pumped through augmentation wells works to Rs.453.7 per 1000 m^3 with well of 100 lps capacity and continuous running duration of 168 hours (annual operation hours = 3000). It is therefore seen that the unit cost of pumped water works out to cheapest by shallow provided it is working for 1000 hours annually.

Surface and Ground Water Allocation

Conjunctive use management require allocation of surface and ground water such that the net benefits from the various crops are maximised subject to technical constraints and to satisfy the socio-economic requirements. Surface water should be allocated to areas where it can be supplied at lower cost as well as it should help in recharging unconfined aquifer to raise the water table. Thereby reducing cost of pumping. On the other hand ground water should be pumped in the regions where depth to water table is small and cost of pumping will be less.

For optimal allocation of surface and ground water the study area has been divided into ten zones. For each zone the cost of providing surface water has been worked out. For this both the fixed cost and recurring cost have been determined for all the ten zones. Cost of pumping ground water will depend upon the total head and other design parameters of wells and hydrgbeological conditions. For this study the cost of pumping has been adopted as computed for 10 lps capacity well which is found to be the optimum capacity.

For this study nine crops which are presently grown in the area or likely to be adopted have been taken into consideration. Water requirement of these crops and their net benefits have been calculated. Objective function of the model is to maximise the net benefits from the crops less cost of providing surface and ground water. This is subject to the constraints that the crop water requirement is satisfied by available surface and ground water. Pumping in all the zones is limited to the available pumping capacity, and area under all the crops in each zone is limited to the area available for cultivation. In addition some crop constraints have been introduced to satisfy socio-economic requirements of the area. Ground water simulation model has been used to determine the effect of pumping and recharge due to

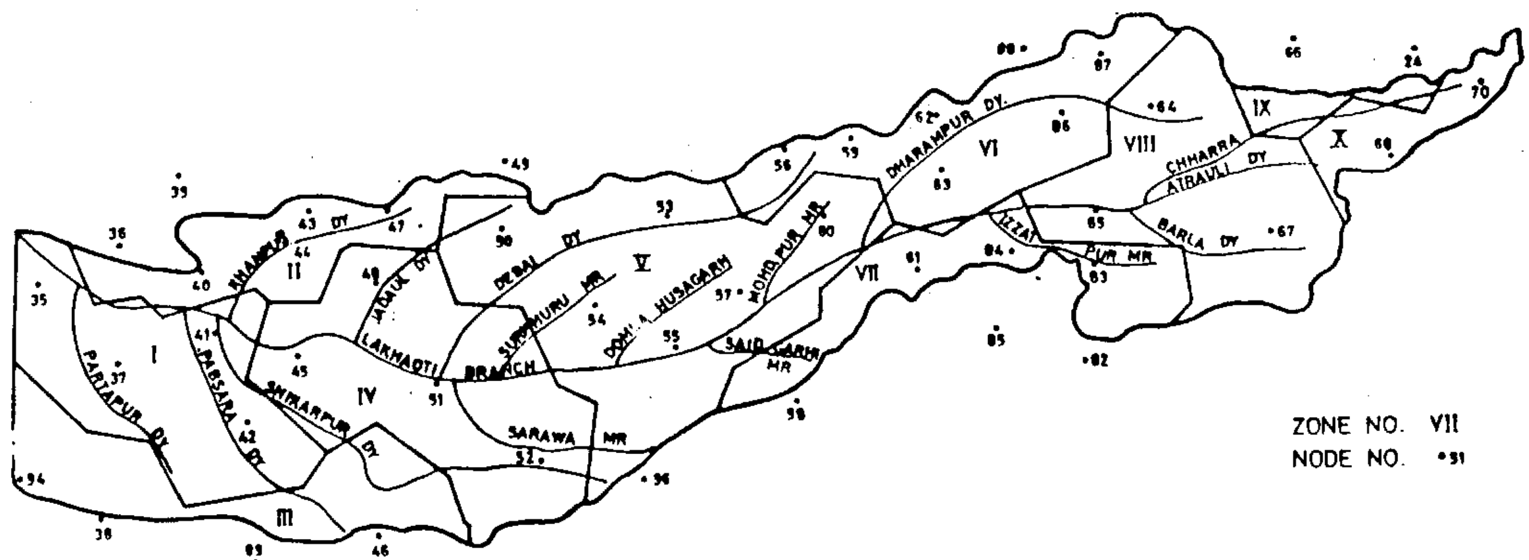


FIG. 9-VARIOUS ZONES OF STUDY AREA WITH DISTRIBTION SYSTEM

rainfall, seepage from canal distribution system and field seepage. Linear programming package was used for determining the allocation of surface water and ground water to various zones and integrated fiinite difference model was used to simulate the ground water system and to determine the ground water level in various zones.

A number of trial runs were made to determine the optimum allocation of surface and ground water and crops to be grown in the various zones. In the final run in addition to other constraints, an additional constraint was introduced to have an equitable distribution of available surface and ground water. The results of the final run are given in Table 3.

It is observed that more surface water is allocated for zones 1,4 and 5 where depth to water table is more (about 14.0 m). The cropping intensity is about 94% (45% in kharif + 49% in Rabi).

Water Table Behaviour

Ground water model was used to determine the water table behaviour for the optimal cropping pattern and distribution of surface and groundwater and for the existing cropping pattern with the modification that 10 percent of the existing area under maize will shift to rice after the introduction of surface water. The computed water levels in various zones have been worked out. A perusal of the computed water levels table indicates that in the zones where table is more than 10 metre below ground level will rise due to higher allocation of surface water. After 10 years period water table will stabilise at a depth ranging between 6.6 and 9.9 m below ground level except in zone 6. This will result in overall reduction in the requirement of energy for pumping ground water. Weighted average depth for water table and cost of pumping unit volume of ground water during next ten years have been worked.

If the present cropping pattern is continued with 10 percent of area shifting from maize to rice due to introduction of surface water, the water table will continue to deplete as the ground water draft will be still exceeding the sustained yield. The cost of pumping unit volume of ground water during next 10 years have also been worked out.

Implementation Aspects of Conjunctive Use Plan

Implementation of conjunctive use requires unified control and retgulation of surface and ground water. Since surface water distribution is controlled by the State Irrigation Department, its supply to the various zones can be regulated by the Irrigation Department. In the absence of legislation on the development and pumpage of ground water, it is difficult to regulate and control pumpage of ground water in the various zones of the study area. Therefore, ground water pumpage has to be regulated through other methods. Some of these are indicated below:

i) For optimal conjunctive management of both surface and ground water, associations or cooperative societies of the

Table : 3 RESULTS OF EIGHTH COMPUTER TRIAL

Zone No.	1	2	3	4	5	6	7	8	9	10	Total
Area (Ha.)	24503	13324	10579	32948	41358	20678	14176	26357	2359	6724	193006
W/Level m.bgl	14.1	9.5	7.7	14.0	11.5	10.0	8.5	12.7	5.3	10.0	
AREA UNDER VARIOUS CROPS											
Rice	3576.5	1332.4	1057.9	4809.7	5405.4	2067.8	1417.6	2635.7	235.9	672.4	23211
Potato	490.0	266.0	212.0	659.0	827.0	413.0	283.0	527.0	47.0	135.0	3859
Wheat	3920.0	3403.4	2700.4	5271.0	7926.9	5280.2	3620.9	6729.7	603.2	1714.0	41170
Arhar	1715.0	933.0	740.0	2306.0	2895.0	1447.0	992.0	1845.0	165.0	473.0	13511
Mustard	1225.0	666.0	529.0	1647.0	2068.0	1034.0	709.0	1318.0	118.0	338.0	9652
Berseem	1225.0	666.0	529.0	1647.0	2068.0	1034.0	709.0	1318.0	118.0	338.0	9652
Guar	245.0	133.0	106.0	329.0	414.0	207.0	142.0	264.0	24.0	68.0	1932
Sugarcane	2940	1599	1269	3954	4963	2481	1701	3163	283	807	23161
Maize	2450.0	1332.0	1058.0	3295.0	4136.0	2068.0	1418.0	2636.0	236.0	672.0	19301
PERCENT AREA UNDER VARIOUS CROPS											
Rice	14.60	10.00	10.00	14.60	13.07	10.00	10.00	10.00	10.00	10.00	
Arhar	7.00	7.00	6.99	7.00	7.00	7.00	7.00	7.00	6.99	7.03	
Potato	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.99	2.01	
Wheat	16.00	25.54	25.53	16.00	19.17	25.54	25.54	25.53	25.57	25.49	
maize	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	9.99	
Mustard	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.03	
Berseem	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.03	
Guar	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.01	
Sugarcane	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	
SURFACE WATER ALLOCATION (Ha-m)											
JUN	587.2	0.0	0.0	789.6	8.8	0.0	0.0	0.0	0.0	0.0	1386
JUL	1375.5	563.1	447.0	1849.7	2131.1	873.8	599.1	1113.8	99.7	284.2	9337
AUG	1375.5	563.1	447.0	1849.7	2131.1	873.8	599.1	1113.8	99.7	284.2	9337
SEP	1437.5	606.7	481.7	1933.1	2246.0	0.0	76.4	1200.2	0.0	0.0	7982
OCT	0.0	0.0	0.0	1271.4	364.2	0.0	0.0	0.0	0.0	0.7	1636
Total	4775.7	1732.8	1375.8	7693.6	6881.2	1747.6	1274.5	3427.9	199.4	569.2	29678
GROUND WATER ALLOCATION (Ha-m)											
JAN	784.3	552.5	438.6	1054.5	1453.7	857.4	587.9	1092.8	97.9	278.8	7198
FEB	784.3	552.5	438.6	1054.5	1453.7	857.4	587.9	1092.8	97.9	278.8	7198
MAR	1159.6	822.5	652.8	1559.2	2155.0	1276.2	875.1	1626.6	145.7	414.6	10687
APR	973.3	594.6	472.0	1308.8	1710.2	922.8	632.7	1176.2	105.3	299.9	8196
MAY	477.2	259.5	206.0	641.7	805.5	402.7	276.1	513.3	45.9	131.0	3759
JUN	0.0	296.6	235.5	0.0	958.9	460.3	315.5	586.7	52.5	149.7	3056
JUL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
AUG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
SEP	0.0	0.0	0.0	0.0	0.0	941.6	569.1	0.0	107.4	306.4	1924
OCT	945.5	423.3	336.1	0.0	1138.1	656.9	450.4	837.4	74.9	213.2	5076
NOV	478.4	260.1	206.6	643.2	807.5	403.7	276.7	514.6	46.0	131.7	3768
DEC	834.8	603.6	479.1	1122.4	1563.2	936.6	642.2	1193.8	106.9	304.5	7787
Total	6437.3	4365.2	3465.2	7384.4	12046	7715.4	5213.5	8634.1	880.6	2508.5	58650
Depth S/W (m)	0.195	0.130	0.130	0.234	0.166	0.085	0.090	0.130	0.085	0.085	
Depth G/W (m)	0.263	0.328	0.328	0.224	0.291	0.373	0.368	0.328	-0.373	0.373	
Tot.Depth (m)	0.458	0.458	0.458	0.458	0.458	0.458	0.458	0.458	0.458	0.458	
NET BENEFITS (Million Rs.)											
Gross Receipt	68.02	39.00	30.97	91.46	116.89	60.53	41.50	77.16	6.91	19.69	552.13
S/W Cost	16.29	6.46	5.00	26.39	23.69	7.98	5.36	15.81	1.01	3.20	111.18
G/W Cap.Cost	2.63	1.60	1.22	3.00	4.63	2.87	1.87	3.42	0.29	0.93	22.46
G/W O&M Cost	12.08	6.21	4.34	13.77	19.49	11.40	6.94	15.05	0.90	3.70	93.87
Net Benefits	37.02	24.74	20.41	48.31	69.08	38.28	27.33	42.88	4.71	11.86	324.63
COST OF ALLOCATION OF WATER (Rs.per Ha-m)											
TotalCost S/W	1958.8	2135.5	2085.1	1970.7	1979.2	2612.0	2414.0	2643.7	2885.1	3208.3	
TotalCost G/W	3508.3	2890.8	2657.4	3490.9	3156.2	2965.5	2766.8	3325.6	2340.0	2958.8	

farmers may be formed. Such Associations/Societies may be formed for each distributary and a confederation of the Societies may also be formed for the management of water resources at the level of Lakhaoti Branch Command. The confederation could also be entrusted with the distribution of electricity within the command of the branch. Gradually, the confederation could be entrusted with collection of water and electricity charges and maintenance of these facilities.

ii) In the absence of above unified control, the ground water pumpage could be regulated through control over power supply for the tubewells. The ground water pumpage cost to the farmers much higher than the surface water price charge to them. Inequitable distribution of surface water will cause resentment among the farmers, in the zones wgere surface water supply is relatively less. Therefore, the farmers required to depend on ground water for irrigation will have to be compensated by subsidising the ground water pumpage through subsidised power supply. For the above management pattern, it is advisable that for each zone there is an independent distributary and power feeder so that these can be regulated, according to the conjunctive use plan for the zone.

iii) Third alternative is to develop the ground water in the area through State controlled wells. These wells could be used to augment the canal supply and canal distribution system be used for distribution of both surface and ground water conjunctively. This set up can control pumpage of ground water and supply of surface water in various zones of the command.