IWMI-TATA WATER POLICY RESEARCH PROGRAM

ANNUAL PARTNERS' MEET 2002

Innovations in Conjunctive Water Management

Artificial Recharge in Madhya Ganga Canal Project

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and
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Contents

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Introduction

All over the world, regions having sustainable ground water balance are shrinking fast. Three problems dominate ground water use: depletion due to overdraft; water logging and salinization due mostly to inadequate drainage and insufficient conjunctive use; and pollution due to agricultural, industrial and other human activities. In regions of the world, especially with high population density, the most common symptom of consequences of ground water over development is secular decline in water tables. In 1999 the water table under Beijing fell by 2.5 meters (8ft). Since 1965, the water table under the city has fallen by some 59 meters or nearly 200 feet, warning China's leaders of the shortages that lie ahead as the country aquifers are depleted (Brown, 2001).

Growing ground water scarcity and alarming declines in ground water levels in many developing countries indicate that ground water policies in most of these countries are failing to protect life's most vital resource Nearly 1.5 billion people rely on ground water as their sole source of drinking water (Shah et. al 2000). Some of this water comes from deep sources that are isolated from the normal runoff cycle, but much ground water comes from shallow aquifers that draw from the same runoff that feeds freshwater ecosystems. Over drafting of ground water sources can rob streams and rivers of a significant fraction of their flow whereas pollution can render aquifers unfit for human use and degrade water quality in adjacent freshwater ecosystems.

Ironically, at the heart of all these problems of ground water depletion are the unique advantages that ground water has and the opportunity this offers for increasing irrigated agricultural productivity. Evidence in India suggests that crop yield/m3 on ground water- irrigated farms tends to be 1.2 to 3 times higher than on surface-water-irrigated farms (Dhawan 1989,176). Also in view of its amenability to poverty-targeting, ground water development has become the central element in livelihood creation programs for the poor in developing countries of Asia and Africa (Shah 1993; Kahnert and Levine 1993; and Calow et al. 1997)

As problems of ground water depletion and its deleterious consequences- have surfaced in different parts of the world, a variety of responses have been forged to mitigate or reverse these. The standard reasoning is that even after constructing 800,000 big and small dams around the world, the reservoirs can capture and store no more than a fifth of the rainwater, the bulk of the remainder still running off to the seas. India has built more than its share of the world's dams but 1150 km3 of its rainwater runoff still goes to the seas annually in the form of "rejected recharge"

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(INCID 1999). If a fraction of this could be stored underground by artificial recharge, ground water supplies could be enhanced significantly. But this requires active aquifer management where planned draw down of the water table in the pre-monsoonal dry months is an important element of the strategy for enhancing recharge from monsoonal rainwater as well as from irrigation return flows.

Some successful recharge experiments with imported water have been reported in literature (Fariz and Hatough - Bouran 1996;Llama et al 1992; Keller et al 2000); Although these experiments are successful, long-distance transport of large quantities of water is often problematic besides being expensive. In many parts of the world, especially in South Asia, increasing stress is being placed on in site rainwater harvesting and recharge. India has begun to take rainwater harvesting and ground water recharge seriously at all levels. These are at the heart of its massive Integrated Watershed Development Program, which provides public resources to local communities for treatment of watershed catchment areas and for constructing rainwater-harvesting and recharge structures. This paper examines an on-going, large scale experiment being carried out by the Government Of Uttar Pradesh to artificially recharge excess river water in an area which is being irrigated with ground water, and evaluates its performance with respect to its suitability in similar hydrogeological regions and its economic viability.

Background

The western part of Indo Gangetic Plains (IGP) receives rainfall ranging between 650 and 1000 mm, most of which occurs in the three months(June to October) of monsoon period. Out of this, an amount of approximately 200 mm naturally recharges ground water aquifers which by itself is not sufficient to raise a rabi (winter) crop. While there is fairly high river flows during the monsoon season, the dry seasonal river flows during the non monsoon season drop down to a very low level. As per existing water rights most dry weather flows are fully allocated to upper Ganga and lower Ganga canals with very little to spare for additional irrigation. One way to raise a winter crop is to store and make use of excess river flows of the monsoon season. In this flat alluvial terrain, no surface storage dam can be built in view of non-availability of suitable places for constructing such dams. Moreover, escalating cost of construction of storage reservoirs and stringent environmental requirements needed to construct such reservoirs prohibit construction of storage reservoirs for augmenting rabi season irrigation. However, subsurface storage can be made use of wherever possible. One option is to divert monsoon flood water through unlined earthen channels and grow paddy and other kharif crops. Seepage from unlined canals and irrigated fields can increase recharge to the ground water reservoirs and augments rainfall recharge. This augmented recharge would make additional water available for irrigating rabi crops. This concept was put in to practice by the Government of Uttar Pradesh (UP) in Madhya Ganga Canal Project (MGCP) which is located in between upper and lower Ganga canal commands.

Upper Ganga Canal (UGC) command comprising one million hectares are irritated about 400 thousand hectares of surface water. Out of this, paddy irrigation occupies only 60 thousand hectares (Dhawan, 1987). A considerable portion of the command, especially lying between Kali nadi and Nim nadi and between Aligarh drain and Karwan nadi were dependent solely on groundwater for irrigation. Madhya Ganga

Canal Project was formulated for utilizing surplus monsoon flow of the Ganga river for intensification of paddy irrigation in the UGC command through construction of canals for kharif irrigation only. The MGCP comprises a barrage across river Ganga at Raolighat, about 75 km downstream of barrage at Haridwar (the off-take of upper Ganga canal) which will divert 234 m3/sec water in a 115 km long feeder canal named Madhya Ganga Canal. This canal will feed existing UGC system and a newly constructed system called Lakhaoti Branch Canal with a head discharge of 64 m3/sec.

The International Water Management Institute (IWMI) in collaboration with Roorkee university, Water and Land Management Institute (WALMI,UP), and Irrigation Department (UP) undertook a research study in 1989-91 in Lakhaoti branch canal to investigate the impact of conjunctive use of surface water on the ground water regime. A mathematical model was prepared to simulate the ground water system which was calibrated with historic data and a conjunctive use model was used for allocation of available surface and ground water in space and time such that benefits from various crops were maximized (WRDTC, 1993). This study indicated that the water table will get stabilized at a depth ranging between 7 and 12 meters below ground level after 10 years of canal operation. The subsurface inflow into the area which was estimated to be about 11500 ha.m. per year in 1988 was expected to go down to 6300 ha.m. per year. The cost of pumping was also expected to go down to about Rs.1600 per ha.m. Without introduction of the canal water average water table in the year 2000 would have gone down to about 18 m. below ground level. According to the groundwater balance as obtained from the model studies, the total groundwater recharge would range between 68,300 and 77,300 ha.m. including lateral flow. Much of these model results could not be verified with field data since operation of kharif channel started only in 1988.

IWMI after a lapse of nearly 10 years went back to MGCP in the year 2000 to find out and document how diversion of surplus Ganga water during kharif season has affected the groundwater regime, land use, cropping pattern, and the cost and benefit of agricultural operations. A series of field visits were undertaken to discuss with implementing agencies to see whether they would provide the necessary data for evaluation and to get the perception of farmers about the efficacy of operation. For the present analysis, only Lakhaoti Branch Canal was considered. The specific objective of this study is to explore the possibility whether kharif channels and paddy growing during kharif is a viable option for artificial recharging, groundwater stabilization and increasing farmers' net benefit in similar geohydrologic settings in India.

Study Area

Lakhoti Branch command area, a part of Madhya Ganga Canal Project covers an area of 205.6 thousand hectares in the districts of Ghaziabad (3.8%), Bulandshahr (71.4%) and Aligarh (24.8%) in the western Uttar Pradesh and is bounded by Kali nadi and Nim nadi drainage channels (Figure 1). These drainage channels mainly drain monsoon rainwater during rainy season and are mostly dry during non-monsoon season. Monsoon discharge ranged between 8,868 ha.m in 1993 and 27,597 ha.m in 1998, whereas non-monsoon discharge ranged between 2,688 ha.m in 1993 and 12,450 ha.m in 1998. The average groundslope of the area is only 0.375% in longitudinal direction from north to south with very little erosion hazard. The soils are made up of recent unconsolidated fluvial formation comprising sand, silt, clay and kankar with associated beds of gravel, extending to a thickness of roughly 2,500 to 3,000 meters. Geologically the sediments are favourably embedded for the occurrence of groundwater in the major portion of the area.

Monthly rainfall data was collected for 14 stations in and around the area from IMD (1999) and average monthly rainfall for the study area from 1984-85 to 1997-98 was calculated from the values generated at a grid spacing of 2 km from the randomly located rain gauge stations using Kriging method. The minimum annual rainfall for the study area was 38 cm in the year 1987 and the maximum was 102.1 cm in 1997. The average annual rainfall for the study area for this period was 77.9 cm. The monsoon rainfall varied between 22.6 cm and 88.3 cm whereas non-monsoon rainfall varied between 6.6 cm and 21.9 cm. The number of rainy days (days with rainfall more than 2.5 mm) are 33. The heaviest rainfall in 24 hours is 451 mm.

May is generally the hottest month with the mean daily maximum temperature of about 41^{0}C. January is generally the coldest month with the mean daily maximum temperature of about 21^{0}C. During monsoon, humidity is relatively high, often exceeding 70 percent while it becomes less than 20 percent during summer. Monthly average meteorological data of Bulandshahr district is given in **Table 1**.

Table 1: Monthly average meterological data of Bulandshahr district

Month	**Rainfall (mm.)**	**No. of Rainy days**	**Temperature (^oC)**		**Relative Humidity (%)**		**Sunshine Hours**	**Wind velocity (km./day)**
			Max	Min.	Max.	Min.		
Jan	12.7	1.7	22.5	5.0	90.7	80.1	8.2	98.2
Feb	25.3	1.6	25.4	6.7	88.6		8.6	118.3
Mar	12.7	1.1	31.2	11.6	78.1		8.5	122.8
Apr	8.8	0.9	38.0	16.5	87.3	76.5	9.1	149.5
May	11.9	0.8	41.3	21.3	85.0	66.6	9.9	187.5
Jun	55.2	3.6	41.7	23.5	82.5	59.5	7.1	243.3
Jul	209.3	8.8	36.9	24.1	85.0	63.3	6.4	196.4
Aug	196.4	8.9	35.3	24.2	90.5	74.6	6.0	136.2
Sep	123.9	5.3	34.9	22.1	91.6	77.1	7.6	118.3
Oct	9.9	1	33.8	16.6	89.6	76.5	9.3	96.0
Nov	2.1	0.2	27.7	10.5	86.9	74.6	9.1	87.0
Dec	10.3	0.7	23.9		86.4	77.3	8.2	98.2
			5.4		89.0			
					78.1			

The study area has soils of sandy loam type in texture and granular in structure. Clay percentage is about 6 percent. Thickness of the fertile soil is more than two meters. Average infiltration rate is about 2.6 cm/hour. The dry bulk density is 1.53 gm/cm3. Ph of the soil is 7.9 and EC is 1.42 mhos/cm. There is no salinity problem in the area. Average hydraulic conductivity is 0.7 m/day.

The groundwater reservoir beneath the plain is the potential source for providing irrigation to the water short and needy areas. Exploratory drilling in this area indicates that the thickness of the alluvium varies between 379 m and 700 m. Depth to water levels in the wells generally ranges up to 12 m below ground level. There are a number of deep and shallow wells in the area with discharges of shallow wells (depth < 50 m) ranging between 6 and 15 lps whereas discharges of deep wells ranges between 25 and 45 lps. A perusal of the geological cross-sections indicates that water bearing formations in some wells are as low as 30 percent of well depth. Interspersed clay lenses make the aquifer to exist in unconfined to semi-confined conditions.

Pumping tests indicate that the deeper aquifers are leaky and confined with coefficient of transmissibility varying between 484 and 683 m^2/day with strainer length varying between 10 and 25 m. The value of coefficient of storage varies between 0.0009 and 0.004. The shallow aquifers have coefficient of transmissibility ranging between 167 and 1,1917 m^2/day. The value of specific yield varies between 0.05 and 0.2 with the weighted average value of 0.15.

Measurements of PH, EC and TDS of groundwater show 7.79, 313 mhos/cm and 653 mg/liter, respectively. The values of SAR range between 5.67 and 7.53 and the sodium soluble percentage between 62.6 and 69.5. The value of residual sodium carbonate range between 0.75 and 3.46 me/liter. The water samples of the area fall in C_2S_1 class as per US salinity laboratory classification and are considered to be good.

The land use data for the years 1985-86 to 1995-96 are given in Table 2. The table indicates that the net sown area has varied between 81.8 and 83.48 percent of reported area. Gross sown area has varied between 137.15 and 146.20 percent of the reported area. The cropping intensity (gross sown area/net sown area) has ranged between 1.69 and 1.78. The irrigation intensity (gross irrigated area/gross sown area) has ranged between 85.95 percent in 1986-87 and 95.52 percent in 1993-94.

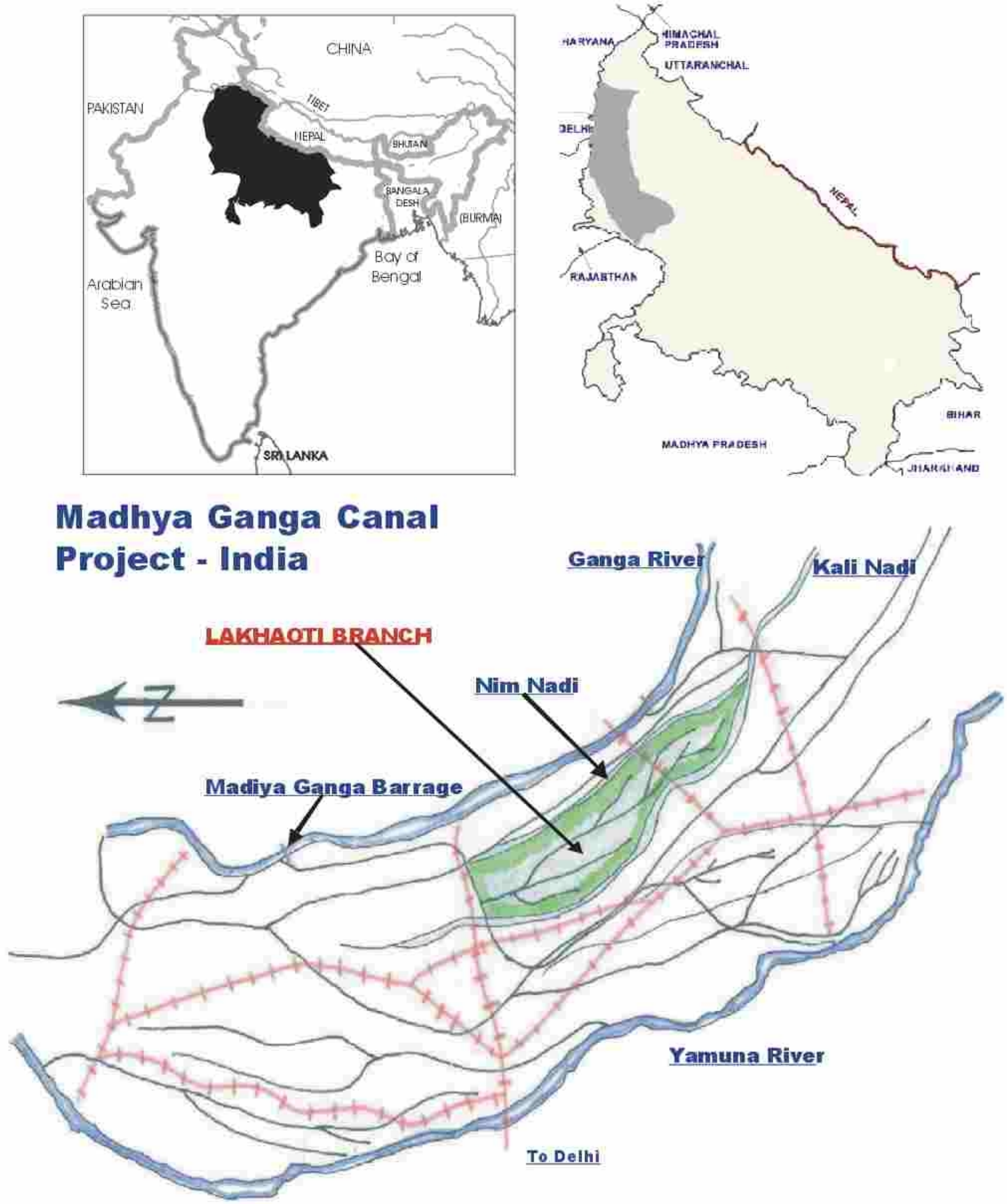
Average cropping pattern from 1987-88 to 1995-96 indicates that during kharif, major crops grown are maize (29.9 to 37.6%), sugarcane (12.5 to 14.9%), oil seed 6.9%, fodder (11.9 to 14.8%), paddy (1.5 to 2.4%), and other kharif crops (3.1 to 14.8%). During rabi season, wheat (51.4 to 59.7%) and barley (6.6 to 7.9%).

Before introduction of canal irrigation in 1987, the source of irrigation in the study area was primarily groundwater. Groundwater was pumped through state tubewells, private tubewells, and persian wheels in dug wells. Annual groundwater draft has varied between 95,382 ha.m in 1985-86 and 84,737 ha.m in 1989-90. Total withdrawal of groundwater in the area was exceeding the recharge and therefore water table was declining and going down progressively.

Lakhaoti Branch Canal

Lakhaoti Branch Canal commands an area of 193,000 ha and the proposed paddy irrigation is 49,500 ha. Head discharge of the branch canal is 64 m^3/sec. Length of branch canal taking from MGC at 82.43 km is 72 km. Length of distribution channels of various capacities is 1,030 km. In the head reach Lakhaoti Branch has a bed width of 35 m, water depth 2.25 m, bed slope 15 cm/km. At tail where discharge is 20 m^3/sec, bed width reduces to 14 m and water depth to 1.56 m. Canal water input into the area has varied between 27,202 ha in 1988 to 64,301 m in 1996. All main canals and distribution systems are unlined earthen canals.

Figure 1 Index Map of Madhya Ganga Canal Project



Ground water levels

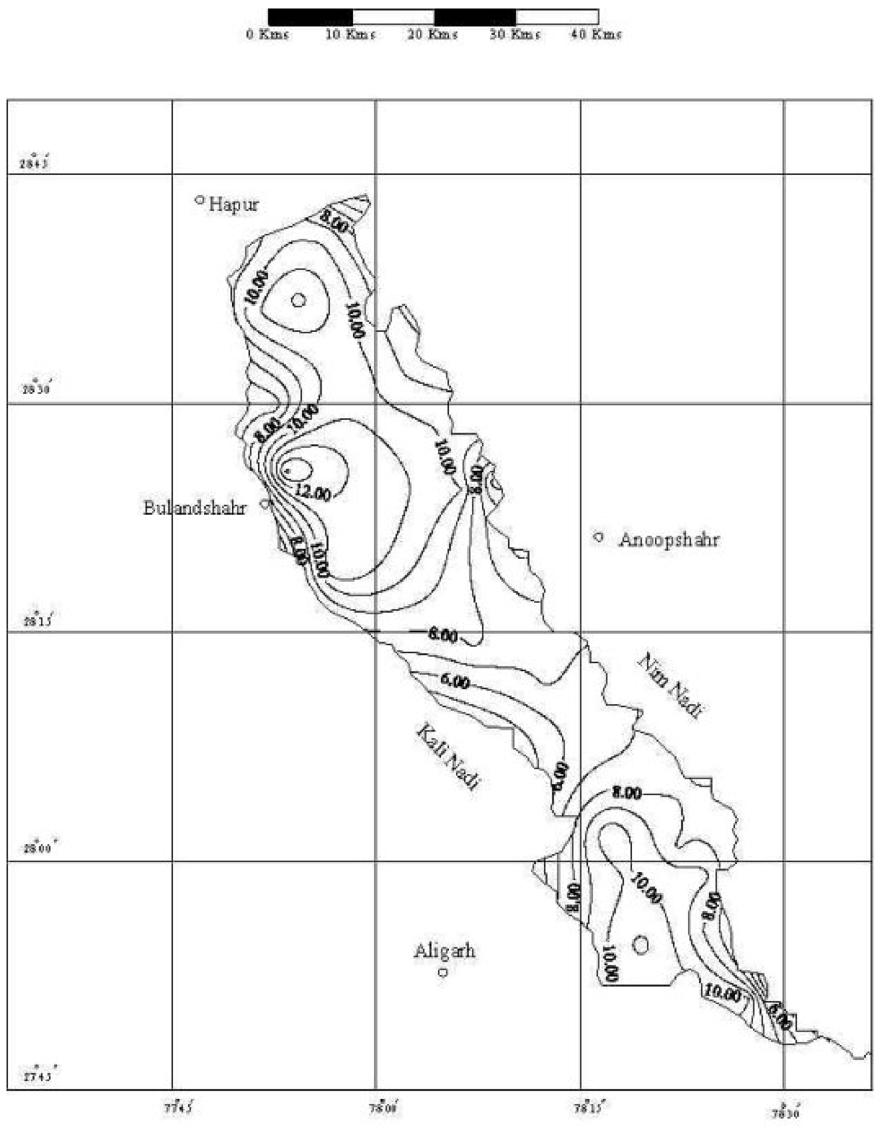
Plots of water table depth below ground level and water table elevation contours (computed against a chosen datum) were prepared to study respectively the behavior of water table and its slope in space and time. A program designed to take irregularly spaced data and convert it to regularly spaced form to create a surface representation was used. Using Kriging interpolation method, and data from 102 irregularly located observation wells, a regularly spaced grid at 2km spacing was created and ground water elevations were computed and smoothed using a smoothing option.

Water table depth below ground level and water table elevation contours for the years 1984 and 1998 (post-recharging period) are shown in Figs.2 and 3. A perusal of Figure 2 indicates that water table depth below ground level ranged between 6 and 14 m. in pre-monsoon of 1984. Deeper water table depth of 12 m. was mostly confined to a limited area farther away from the branch canal. During the post monsoon of 1998, the upstream potion of the command recorded a water table depth ranging between 2 to 10 m below ground level except in small pockets in the downstream portion where it was up to 12 m. The water distribution system in the lower reaches is not yet completed. Once this is completed and water is allowed for irrigation, water table will rise in this reach also. Water table elevation contours in the pre- and post-monsoon of 1998 show that water table in general slopes from north to south in the direction of branch canal flow and inward from drains on either side of the study area boundary. Water table along the boundaries of the study area has been higher than the middle portion of the area in the initial years (Fig.3). However, in the subsequent years, the gradient from the drains towards the central portion of the study area was either negligible or negative as seen in Figure 4.

Table 2: Land use Pattern Of The Study Area (Hect.)

Landuse						Year						
	85-86	86-87	87-88	88-89	89-90	90-91	91-92	92-93	93-94	94-95	95-96	Average
Reported area	214934	215356	215950	215945	215070	217725	214547	211373	211348	211265	211280	214072
Forest	3376	2862	2477	2647	2653	2549	2562	2562	2531	2435	2435	2644
Culturable waste	3656	3435	3621	3679	3726	3418	3603	3528	3580	3755	3531	3594
Current fallows	4771	5057	5093	4899	4546	3318	3198	3201	2812	2107	1879	3716
Other fallows	5531	3926	3897	3724	3886	4482	4070	4426	4279	4697	5086	4364
Not available for cultivation	5536	5623	5548	5268	4663	4840	4277	4856	4947	4113	4190	4896
Land put to non agr. Uses.	16649	16934	17602	17945	18986	17971	17456	16524	16430	16627	16681	17255
Pastures & grazing	581	553	543	520	518	559	537	538	532	545	548	543
Misc. crops & trees	555	555	552	535	542	650	618	609	609	616	570	583
Net sown area	175824	176453	176659	176747	177682	179568	176296	175118	175615	176369	176380	176610
Area sown more than once	134863	138376	138400	119418	130876	126632	128407	125205	124055	125703	129821	129250
Gross sown area Total	310707	314850	313519	296180	308557	306203	304702	300323	297625	302130	306318	305556
Rabi	148650	149038	151776	142598	140596	145898	154708	149867	147157	142770	147018	147279
Kharif	145230	149932	143436	130711	146478	145393	135869	136367	138424	278817	145287	154177
Summer	16261	15908	15918	21228	21453	14431	14105	13939	14021	14000	14507	15979
Net irrigated area	168914	171619	171501	150400	169517	172653	173545	164192	159359	163810	159741	165932
Gross irrigated area	267830	270626	287085	264680	280863	283956	282910	281683	284291	281540	287597	279369

Figure 2 - Water Table Depth Below Post monsoon 1984



Water Table Depth Below Post Monsoon 1998

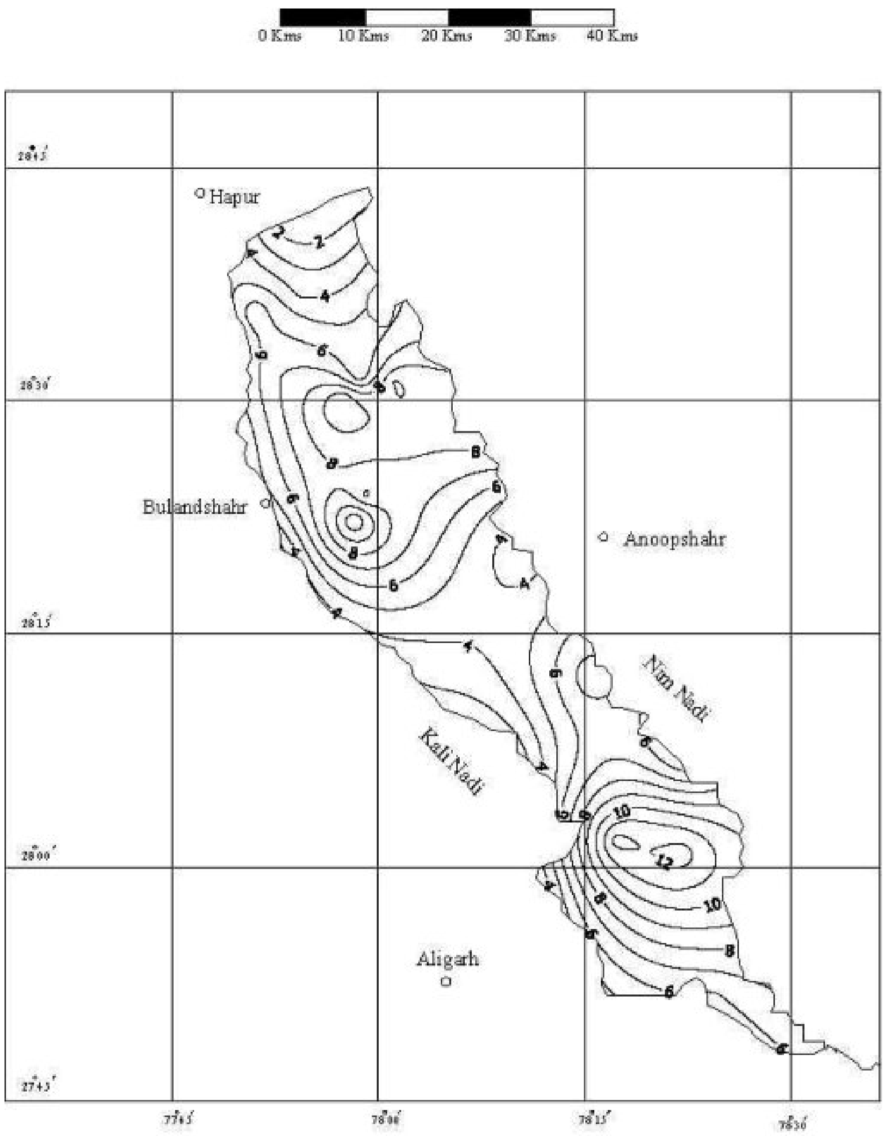
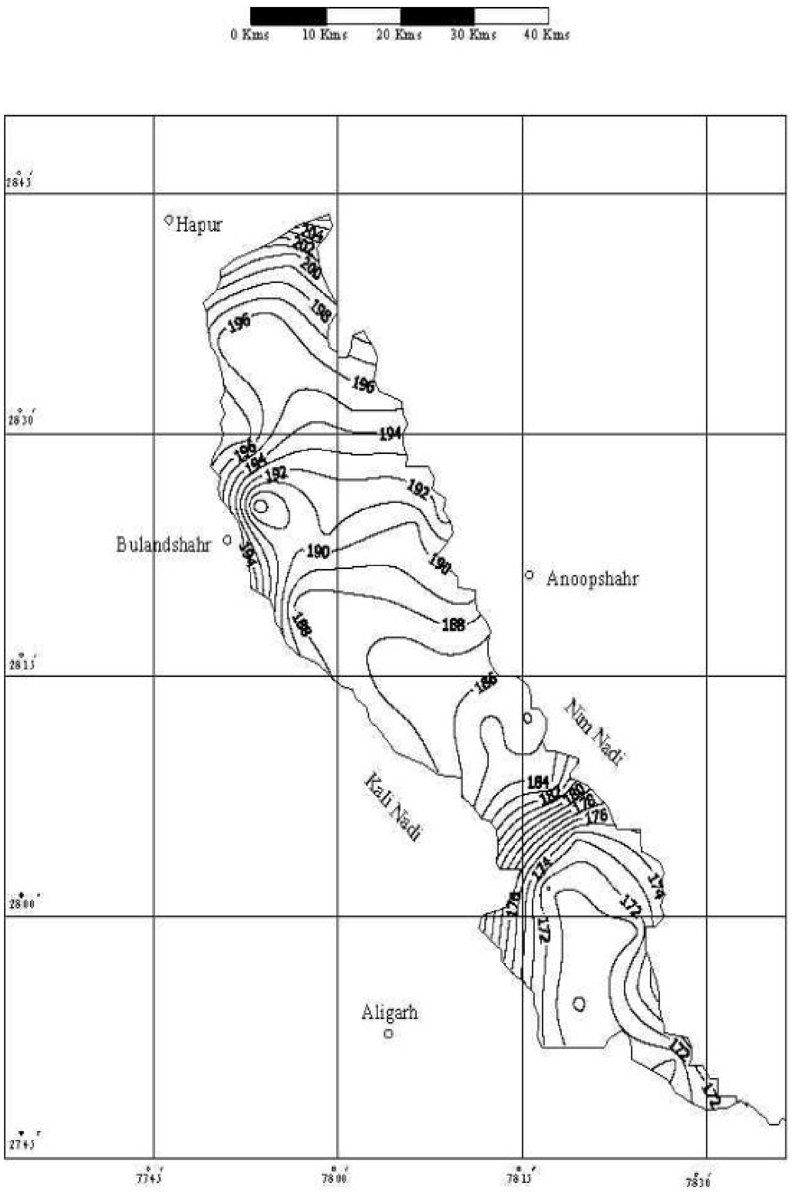


Figure 3: Water Table Elevation Contours (m) Post Monsoon 1984



Water Table Elevation Contours (m) post monsoon 1998

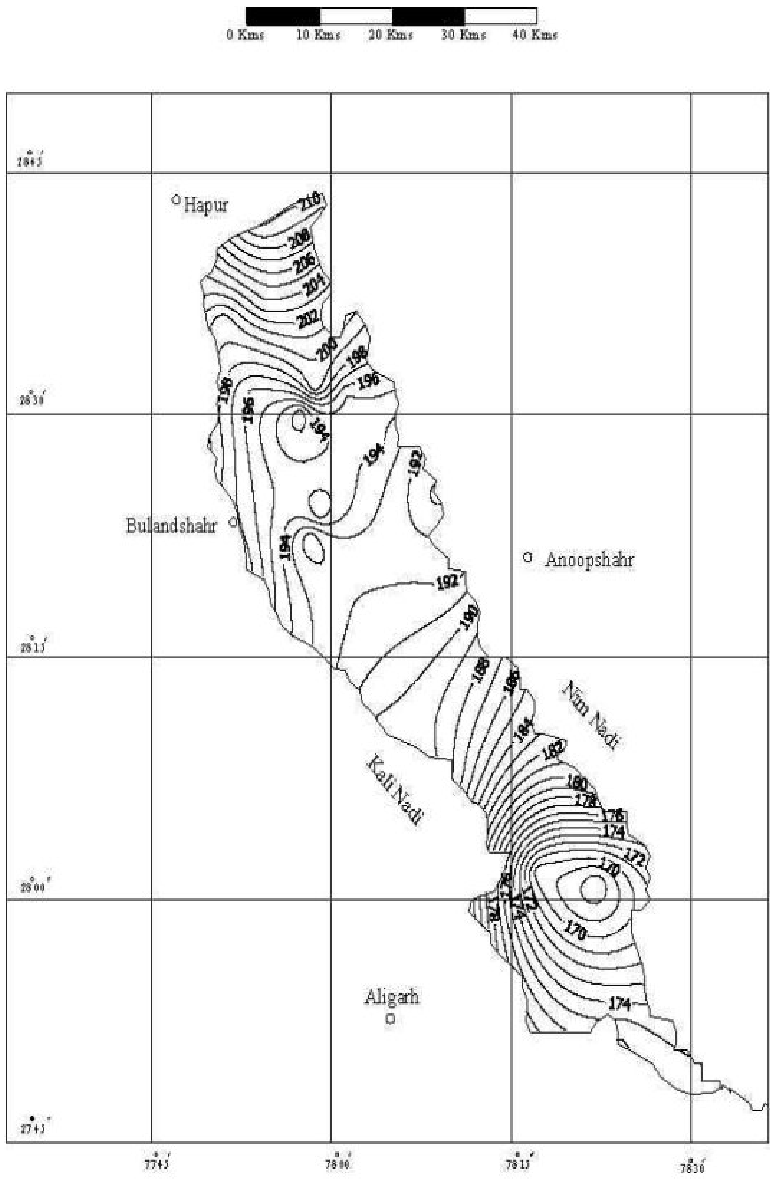
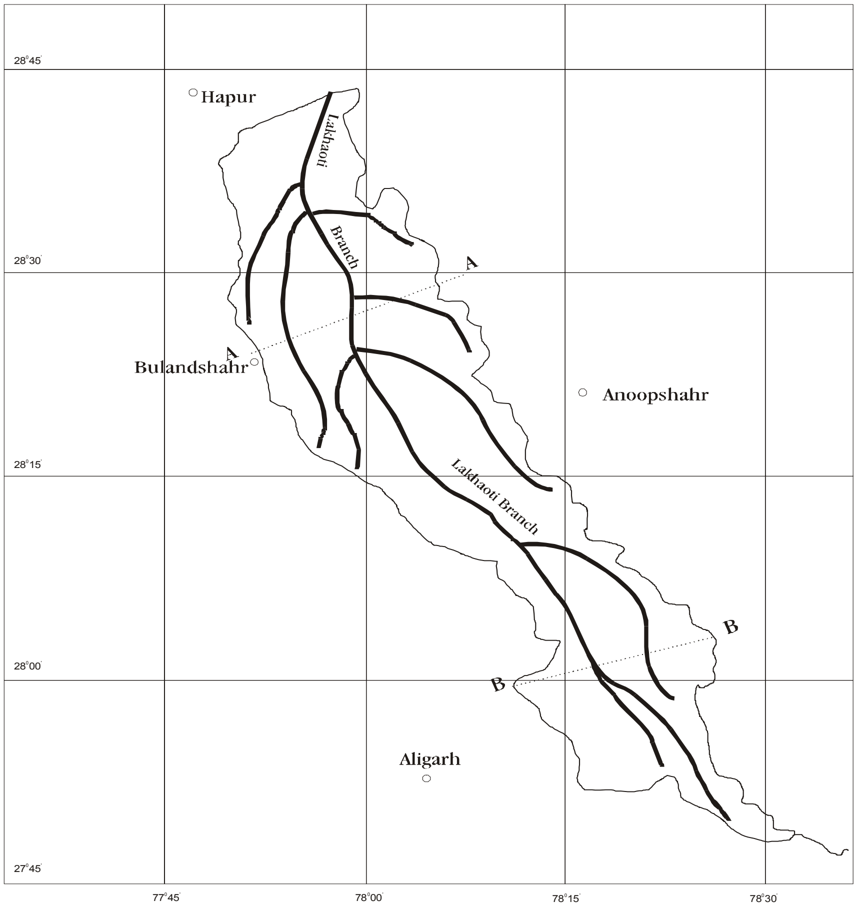
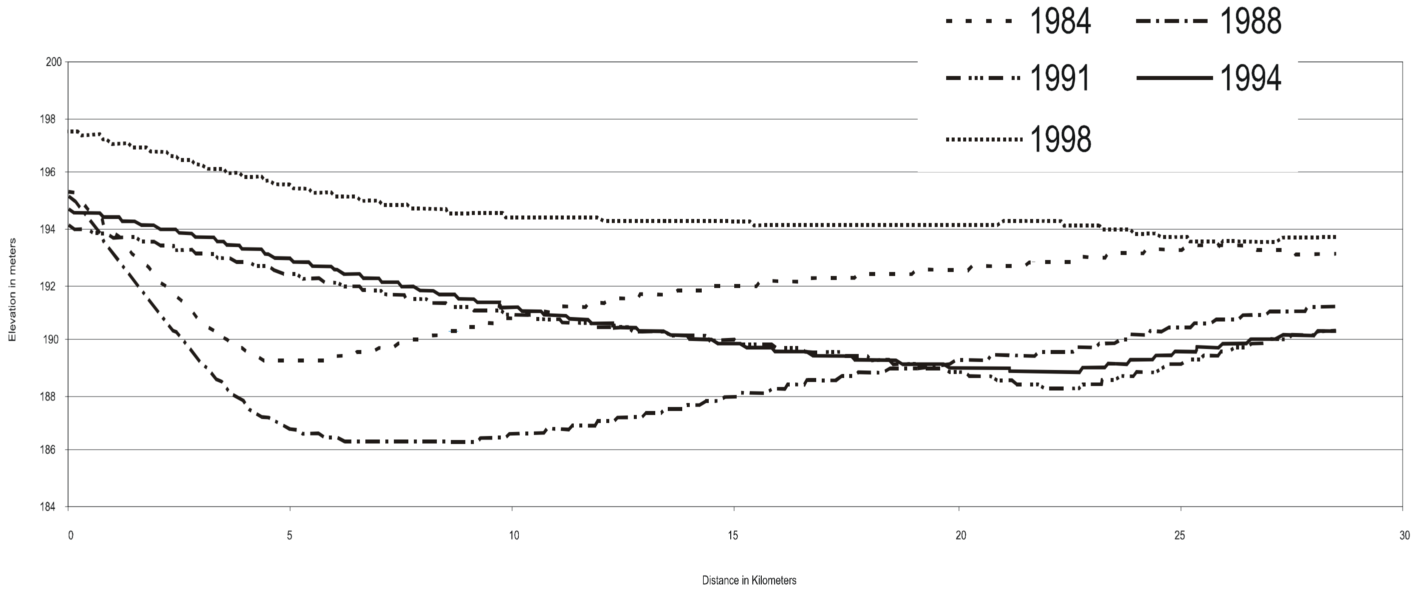


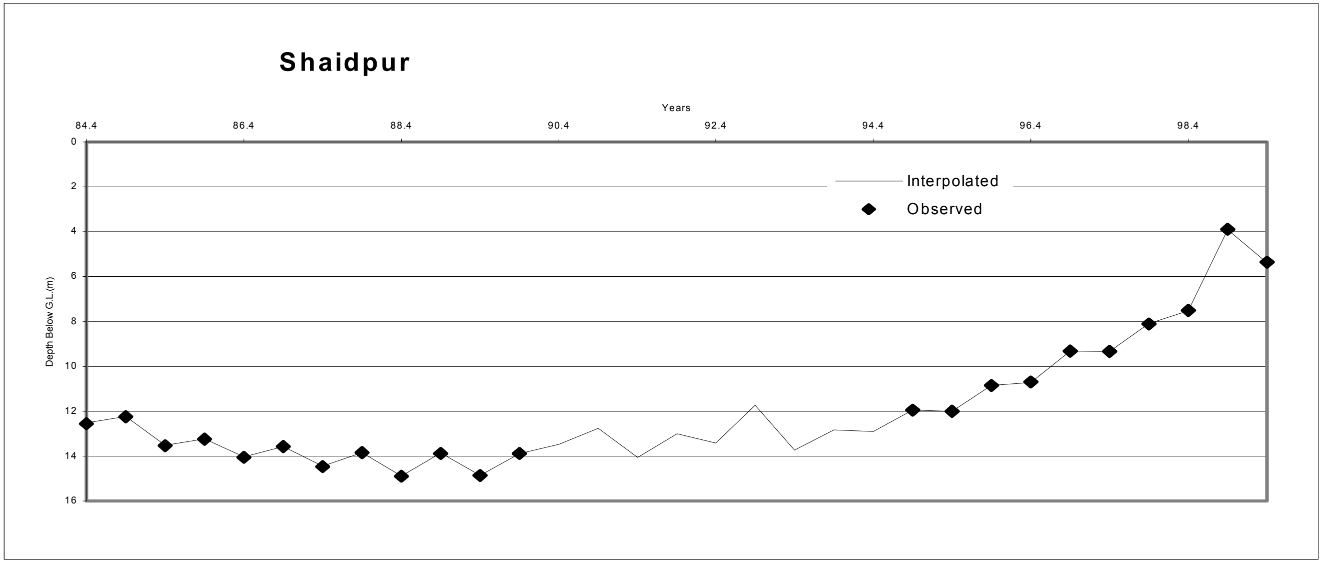
Figure 4 - Post Monsoon Water Table Elevations

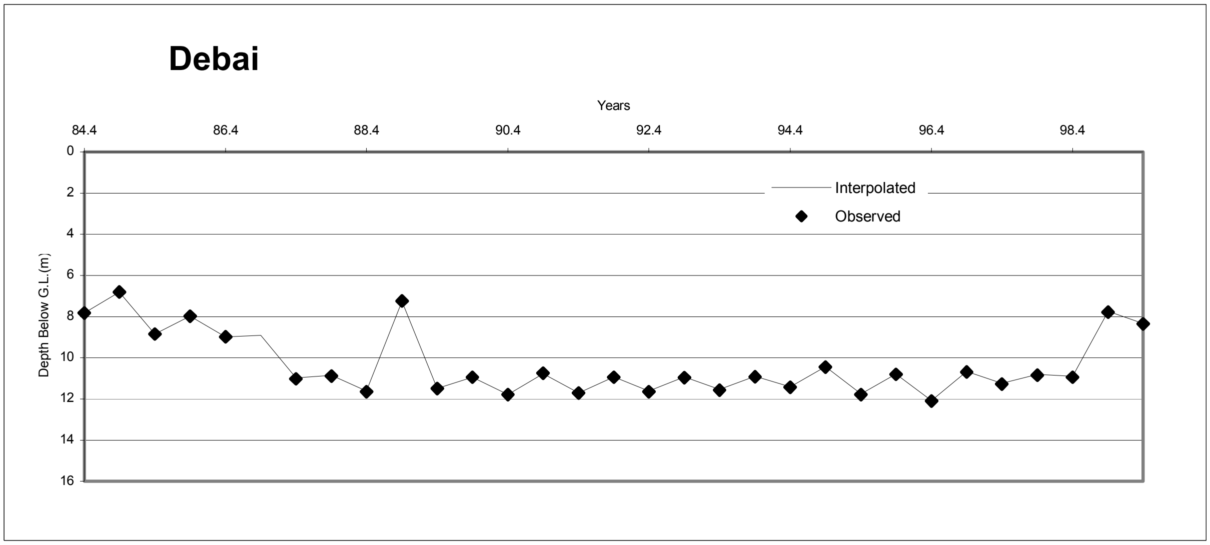



Section along A-A

Post Monsoon Water Table Elevations

Figure 5 - Hydrograph – Villages Shaidpur and Debai

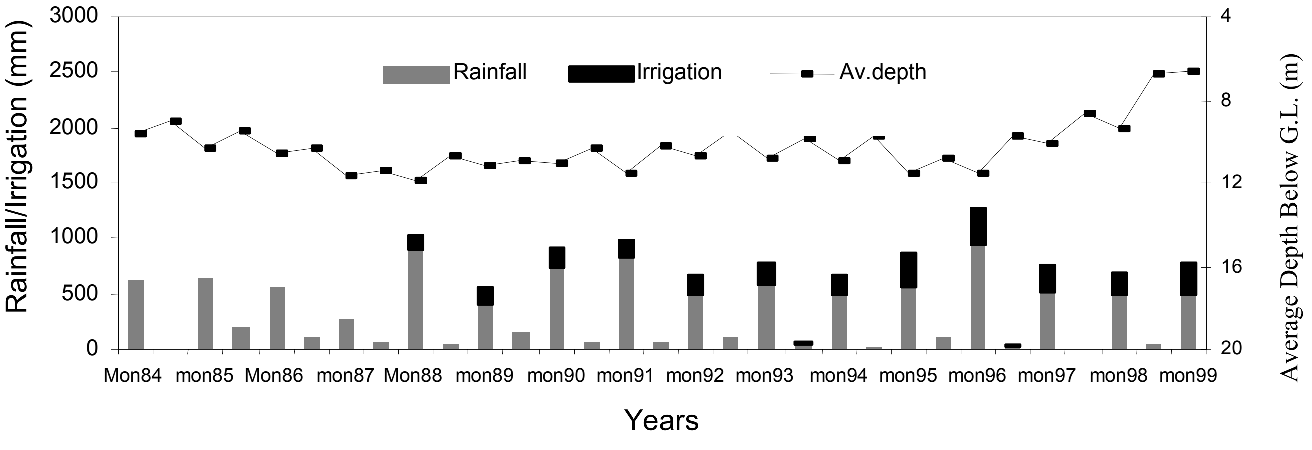




Ground water hydrographs were prepared for 5 observation wells located from head to tail along Lakhaoti branch canal . A typical plot of hydrographs for head reach and tail reach villages is shown in Fig 5. A perusal of the hydrograph at Shaidpur (a head-reach village) indicates that water table went down progressively up to 1988 and started rising from 1989. It has progressively gone up since then. During the last few years, even during non-monsoon season lowering in water table was little. In some years during non-monsoon water table has gone up which indicates that pumping has been less than recharge from canal seepage and field seepage. Canal water supply has not only arrested the lowering of water table but also helped to raise the water table in an incremental fashion over the years. On the other hand, water table at village Debai (a tail end village) has been going down up to 1990, then it was nearly constant up to 1997, and has risen since then. This indicates that tail reach area has taken longer time than head reach area in responding to canal water recharge primarily because much of the canal water is used in the upstream reach due to inadequate infrastructure for water distribution in the tail reach.

Figure 6 shows the hydrograph of average water table depth below ground level (averaged over the total command area) along with rainfall and canal water input. It indicates that in general water table shows downward trend up to 1988 after which it starts rising due to canal water input up to 1994. Between 1995 and 1996, water table went down in some locations. This may be due to less rainfall in 1994 and 1995 and consequently less canal water input. The water table has again shown an upward trend during 1997 to 1999 due to increased rainfall during 1996 and larger canal water input. The average water table in the command went down from about 10 m in 1984 to 12 m below ground level in1988. From then on, it started rising and went up to 6.5 m below ground level in 1999.

Fig 6: Average Depth to Water Table, Irrigation and Rainfall



Water Balance

A study of water table behavior gives an idea about the response of ground water system. But to know why a system behaves in a particular fashion, we need to quantify various recharging and discharging components through a water balance.

A hydrologic budget is a quantitative statement of balance between the total water gains and losses of a basin, for a chosen period and is expressed as follows:

$P= E+R+U+DSw+DSg+DSs$

Where P= Precipitation
E= Evapotranspiration
R= Stream run off
U= Subsurface underflow
DSw = Change in surface water storage
DSg= Change in ground water storage
DSs= Change in soil moisture storage

In the present study, the area commanded by Lakhaoti Branch, which is a doab between Kali nadi and Nim nadi, has been taken. The entire study area is well controlled on the boundary and considered as a single unit for water balance purposes because of its more or less similar geohydrologic considerations; however, spatial variations in the values of various parameters were considered and average values determined for the area. Water balance was prepared on a seasonal basis since most of the recharge to ground water takes place during monsoon season. The water balance study was conducted from 1984-85 to 1997-98, covering three years before the canal started operation and several years after its operation started.

Using modified Penman method and the data available at Bulandshahr observatory; crop water requirements were determined for the various crops grown in the area on monthly basis. Effective rainfall for various crops has been estimated from average monthly evapotranspiration and mean monthly rainfall. Monthly and seasonal values of net irrigation requirement (NIR) for various crops are computed taking into account water requirement for land preparation and deep percolation from paddy fields. Field irrigation water requirement (FIR) has been determined by using appropriate field application efficiency for ground water and canal water use.

Weighted average rainfall for monsoon and non-monsoon seasons from 1984 to 1997 were determined using monthly rainfall data available for 14 raingauge stations in and around the study area. Rainfall recharge is estimated from the water table fluctuation data using specific yield (Sy) obtained from non-monsoon season water balance (WRTDC1993).

Canal water inflow data was available from Madhya Ganga Division, Hapur from 1988 onwards. Weekly average daily discharge data was used to compute weekly/monthly/ seasonal canal water input. Annual canal water input in ha.m from 1988 to 1997 is given in Table 3.

Table 3: Lakhaoti Branch Canal input and Irrigated Area

Year	Canal Input (Ha-m)			Irrigated area (Ha)				Water Depth (m)
	Monsoon	Non Mon soon	Annual	Paddy	Sugarcane	Others	Total	
1988	27202	0	27202	83	470	698	1251	21.7
1989	28816	0	28816	341	642	1909	2892	10.0
1990	37393	753	38146	500	860	2239	3599	10.6
1991	32742	1594	34337	1237	1120	4365	6722	5.1
1992	36990	0	36990	2379	1391	4002	7772	4.8
1993	40995	4308	45303	3020	1358	7189	11567	3.9
1994	36835	0	36835	2535	1589	10543	14667	2.5
1995	58385	0	58385	5073	2743	19684	27500	2.1
1996	62015	2286	64301	6270	3312	27526	37108	1.7
1997	49575	2054	51629	8394	2425	24979	35798	1.4
1998	35342	372	35713	8668	1142	12173	21983	1.6
1999	45944	2109	48053	10419	1388	14032	25839	1.9

Crop wise irrigated area data for the command is available for the years of water balance. Water requirement for the canal-irrigated area was worked out. Field irrigation requirement which includes seepage from irrigated fields and percolation losses from paddy fields was worked out for the total canal irrigated area. Percolation losses from paddy fields was assumed at the rate of 6mm/ day. For field application in canal irrigated area, an application efficiency of 70 % for canal water was assumed. It was also assumed that on an average 80 % of this loss would reach the ground water reservoir. Canal water input minus gross field irrigation requirement should account for conveyance losses through branch and distribution system including field channels.

Canal water use balance (Chawla, 2000) indicates that in the initial years of canal operation, conveyance losses were high. Those got gradually reduced as distribution system became ready and farmers started using water for irrigating crops from the canal water. The irrigated area has increased from 1251 ha in 1988-89 to 35798 ha in 1997-98. This is still less than the proposed paddy irrigated area of 49500 ha. Maximum paddy irrigated area was 14 419 ha. in 1999-2000.

Ground water balance has been prepared for 14 years starting from 1984-85 to 1997-98 (Table.4.). From the balance it is seen that rainfall recharge ranges between 15 and 30 % of the rainfall, canal seepage between 43 and 78 % of the canal input, field seepage from canal irrigated areas ranges between 27 and36 % of gross irrigation requirement. Canal seepage has started accruing from1987-88 when canal was run for the first year for irrigation. Subsurface inflow has been taking place from adjoining areas due to lowering of water table in the study area. Maximum value of subsurface inflow was 9188 ha.m in 1986-87 when water table was low. It became 4600 ha.m in 1997-98 due to rise in water table in the study area. On the basis of ground water balance, it is found that on an average rainfall recharge is 23 % of the annual rainfall. In a normal year, rainfall recharge would be 37000 ha.m. and canal seepage including field seepage would contribute about 32000 ha.m. Seepage from Madhya Ganga canal proper is estimated to be around 800 ha.m. Thus the total recharge without considering lateral inflow would be 69800 ha.m. Gross pumping for irrigation could be 88400 ha.m with net pumping of 66300 ha.m.

Table 4 : Ground Water Balance

		Recharge											**Change**	**Error**
Year	**Season**	**Rain fall**	**Canal Seepage**		**Return Flow**			**Lateral flow**	**Total**	**Discharge Withdrawal**			**in Storage**	
			MGC	**Lakhaoti**	**Canal**	**G.W.**	**Municipal**			**Irrigation**	**Municipal**	**Total**		
84-85	Monsoon	29669				3375	678	2668	36390	13500	1355	14855	21630	-95
	NonMon	2428				15750	1016	3668	22862	63000	2033	65033	-42360	189
	Annual	32097				20100	1694	6336	60227	77500	3388	80888	-20730	69
85-86	Monsoon	39434				5750	691	2637	48512	23000	1382	24382	24000	131
	NonMon	8084				15000	1036	4326	28446	60000	2073	62073	-33525	-102
	Annual	47518				20750	1727	6963	76958	83000	3454	86454	-9525	29
86-87	Monsoon	25041	817			6000	704	3650	36213	24000	1409	25409	10665	139
	NonMon	4790				17250	1057	5538	28635	69000	2113	71113	-42340.5	-138
	Annual	29831	817			23250	1761	9188	64848	93000	3522	96522	-31675.5	1
87-88	Monsoon	12329	817	17600		9250	718	3897	44611	37000	1437	36500	8137.5	-26
	NonMon	4572				8500	1077	4985	19135	34000	2155	35000	-15837	-28
	Annual	16902	817	17600		17750	1796	8882	63746	71000	3591	71500	-7699.5	-54
88-89	Monsoon	49831	817	21290	160	6500	732	3567	82897	26000	1465	27465	55500	-68
	NonMon	3741			17	12875	1098	4779	22511	51500	2197	53697	-31050	-136
	Annual	53572	817	21290	177	19375	1831	8346	105408	77500	3662	81162	24450	-204
89-90	Monsoon	18321	817	21868	441	10550	747	3460	56204	42200	1493	43693	12420	90
	NonMon	8510			32	8250	1120	5195	23107	33000	2240	35240	-12330	197
	Annual	26832	817	21868	472	18800	1867	8655	79310	75200	3733	78933	90	287
90-91	Monsoon	20511	817	28355	594	7120	761	3523	61682	35600	1523	37123	24525	34
	NonMon	2638		580	40	15925	1142	4740	25065	63700	2284	65984	-40740	-179
	Annual	23149	817	28935	634	23045	1903	8263	86747	99300	3807	103107	-16215	-144
91-92	Monsoon	39665	817	23033	1270	7875	776	3275	76712	31500	1552	33052	43845	-186
	NonMon	5349		1319	64	9250	1164	3963	21108	37000	2329	39329	-18360	139
	Annual	45014	817	24352	1334	17125	1941	7238	97820	68500	3881	72381	25485	-46
92-93	Monsoon	32141	817	24961	2025	7450	791	2472	70657	29800	1583	31383	39225	49
	NonMon	4437			67	15750	1187	3638	25079	63000	2374	65374	-40200	-95
	Annual	36578	817	24961	2092	23200	1979	6110	95737	92800	3957	96757	-975	-46
93-94	Monsoon	25220	817	26518	2685	8950	807	2875	67872	35800	1614	37414	30405	53
	NonMon	3116		3120	92	15250	1210	3955	26744	61000	2421	63421	-36795	118
	Annual	28335	817	29638	2778	24200	2017	6830	94616	96800	4035	100835	-6390	171
94-95	Monsoon	29712	817	25695	2646	7425	823	2742	69860	29700	1646	31346	38565	-50
	NonMon	2087			125	20000	1234	4271	27718	80000	2468	82468	-54720	-31
	Annual	31800	817	25695	2771	27425	2057	7013	97578	109700	4114	113814	-16155	-81
95-96	Monsoon	16977	817	33984	5139	12000	839	3708	73464	48000	1678	49678	23775	11
	NonMon	6669			229	13160	1258	4242	25558	47000	2517	49517	-24135	176
	Annual	23646	817	33984	5368	25160	2097	7950	99022	95000	4195	99195	-360	188

96-97	Monsoon	39014	817	33074	6586	9200	855	2966	92512	36800	1711	38511	54000	2
	NonMon	2530		958	306	5500	1283	3977	14555	22000	2566	24566	-10125	114
	Annual	41544	817	34032	6892	14700	2138	6943	107067	58800	4277	63077	43875	115
97-98	Monsoon	32051	817	21414	7693	6088	872	2136	71071	24350	1744	26094	44970	7
	NonMon	1042		912	263	8250	1308	2524	14300	33000	2616	35616	-21450	134
	Annual	33093	817	22326	7957	14338	2180	4660	85371	57350	4361	61711	23520	140
Municipal Supply includes domestic and industrial requirement														

Hydrologic Balance

A hydrologic water balance computed for 11 years (1986-86 to 1995-96) (Chawla, 2000) shows that:

- Rainfall input in this period has ranged between 64815 ha.m (1987-88) and 184301 ha.m. (1988-89). Average rainfall input was 143290 ha.m against normal value of 106000 ha.m.
- Canal water input ranged between 22000 ha.m. (1987-88) and 58385 ha.m (1995-96) against planned input of 63632 ha.m.
- Lateral inflow in this period has ranged between 9188 ha.m. (1986-87) and went down to 4660 ha.m in the year 1997-98.
- Total water input in to the study area from 1985-86 to 1995-96 has ranged between 93967 and 220869 ha.m with an average value of 180877 ha.m.
- During this period, evapotranspiration has ranged between 93321 and 153 400 ha.m. with an average value of 127 788 ha.m.
- Change in storage has ranged between –31676 and +25485 ha.m. with an average value of –3524 ha.m.
- Run off from the area has ranged between 8075 (1987-88) to 86 456 ha.m. (1992-93) with an average value of 56 630 ha.m.

Benefits of Groundwater Recharge and Farm Budget

Before the introduction of canal irrigation, Lakhaoti Command was dependent entirely on groundwater. Lakhaoti Branch, which is a kharif channel, supplies irrigation water in the monsoon season to irrigate the proposed area of 49,500 ha under rice. Additional benefits of the Lakhaoti Branch unlined system is recharging groundwater reservoir. Farmers continue to use recharged groundwater for rabi irrigation.

Before introduction of Lakhaoti Branch Canal, excessive pumping of the groundwater had lead to progressive lowering of the water table and increased cost of pumped groundwater. After the introduction of Lakhaoti Branch Canal, the groundwater level has risen and consequently the cost of pumping has reduced. Average cropping pattern with and without Lakhaoti Branch is given in Table5. Cost of cultivation, gross and net benefits of major crops are given in Table 6. In this calculation, the cost of irrigation is worked out assuming that canal water is not introduced. As a result of this, water table would have gone down to about 18 m below ground level. Due to introduction of canal, average depth to water table has risen to 6.5 m. Cost of pumping is therefore Rs. 2,700 per ha.m as compared to that of Rs. 4,500 for 18 m depth of water table below ground level (Chawla 2000).

Table 5: Average Cropping Pattern in Percent

Crop	Average Cropping Pattern in Percent	
	Without Canal	***With Canal***
Paddy	2	15
Bajra	10	10
Maize	35	20
Sugarcane	13	15
Oil Seeds	6	-
Other Kharif	5	5
Fodder	15	15
Wheat	60	60
Barley	10	10
Peas/Gram	7	7
Potato	3	3

Table 6: Farm Budget, With and Without Canal

Crops	Yield Quintal /ha	Gross receipts	Without Canal				With Canal			
			Cost of cultivation	Net benefit	Weightage	Weighted average	Cost of Cultivation	Net benefit	Weightage	Weighted average
		18000								
Rice	22/35	21000*	15400	2600	0.02	50	13200	7800	0.15	1170
Maize	20	9000	7100	1900	0.35	660	6600	2400	0.20	480
Bajra	20	8000	7050	950	0.10	100	6150	1850	0.10	185
Sugarcane	600	43000	23400	9600	0.13	2550	21100	21900	0.15	3285
Fodder (K)				1500	0.20	300		1500	0.20	300
Total Kharif					0.80	3660			0.80	5420
Wheat	35	17000	11000	6000	0.60	3600	10200	68`00	0.60	4080
Barley	35	17000	10700	6300	0.10	630	9800	7200	0.10	720
Potato	200	50000	18000	32000	0.03	960	17300	32700	0.03	980
Peas/Chana	20	15500	10000	5500	0.07	390	9250	6250	0.07	440
Total rabi					0.80	5580			0.80	6220
Total Annual					1.60	9240			1.60	11640

*Gross receipts for rice without canal = Rs.18000/hect.
Gross receipts for rice with canal = Rs.21000/hect.

Weighted average net income per hectare for kharif and rabi seasons without canal would work out to about Rs. 3,600 and Rs. 5,580 respectively. Thus annual income per hectare would be Rs. 9,240. With canal water, water table has gone up resulting in reduction in the pumping cost and with completion of distributary system the area under paddy and sugarcane would go up to 15 percent each. Average net income per hectare would go up to 11,640 per hectare – an increase of 26 percent. Additional benefit of kharif channel is conjunctive use of surface and groundwater. The farmers would continue to pump groundwater for irrigation during rabi crop season and also to supplement canal water during kharif season. Farmers who have lowered their groundwater structures have raised the position of their pumps due to rise in water table.

Lakhaoti Branch command distribution system including minors and watercourses are still incomplete due to which water has not reached the entire command area. Canal supplies are, therefore, not used in an efficient manner. There is considerable scope for improving management of the system for achieving optimal and conjunctive use of water resources. However, talking to farmers located at head, middle and tail of distribution systems, all agree uniformly that there is a definitive advantage in kharif channel diversion; but they also agree that while head enders benefited more, tail- enders do get benefit but not to the extent of head- enders. The greatest benefit according to farmers is that they need not lower their pump set periodically to reach within the suction lift of their pumps.

Discussion of Results

The Lakhaoti Canal was run on trail basis in 1987 and has been in operation since 1988. Canal water input has increased from 27,202 ha.m in 1988 to 64,301 ha.m in 1996. Irrigated area has increased from 1,251 ha in 1988 to 37,108 ha in 1996. Paddy irrigated area has increased from 83 ha in 1988 to 10,419 ha in 1999, which is still less than planned area of 49,500 ha for paddy. Irrigated area of sugarcane increased from 2470 ha in 1988 to 3,312 ha in 1996. Average depth of diverted canal water over canal irrigated area has varied from 21.94 m in 1988 to 1.44 m in 1997. It has again increased to 1.62 and 1.86 m in the years 1998 and 1999 respectively. According to the cropping pattern obtained in the area, average water depth of diverted water over the irrigated area should be about 1 m. Hence, there is considerable scope for improving management of the system so as to achieve the planned irrigated area under paddy and to ensure that the water is distributed to entire command. Construction of minors and provision of outlets have to be completed. Even distribution of water by warabandhi has to be enforced. Aerial distribution of water table indicates that more water so far has been supplied to the head reaches where water table has risen due to seepage water. In the upper reaches, water table in 1998 has risen above its position in 1984. In the lower reaches water table continued to go down up to 1993 and has started rising thereafter. Water table position is still below 1984 position in some areas in the lower reaches.

Benefit of canal in recharging groundwater reservoir has been significant. The total cost of canal water at canal head (capital cost + operation and maintenance cost at 1990 prices) works out to Rs. 3,162/ha.m. On the other hand, cost of groundwater pumping varies between Rs. 2,565 to Rs. 3.230 per ha.m for depth to water table of 6 m and 10 m, respectively. Actual cost of surface water at field will be higher depending on its location due to seepage losses. Additional advantage of Lakhaoti Branch has been reduction of pumping cost. According to mathematical model simulating groundwater system, without canal water input water table would have gone to an average depth of about 18.4 m. This would have not only increased the cost of pumping but would have made it necessary to deepen the wells and lowering pumping set. The cost of pumping with water table at about 18.4 m would have been Rs. 4,650/ha.m. However, with the canal water input average water table depth is 6.5 m. The cost of pumping groundwater at this water table position is Rs. 2,650 per ha.m resulting in saving of Rs. 2,000/ha.m. For an annual pumping of 90,000 ha.m, the saving in pumping cost would be Rs. 180 million per year. About 70 kwh of energy is spent in lifting one ha.m of water per meter of lift. Energy saved for saving of 12 m lift would be 840 kwh/ha.m. Therefore, annual saving of energy would be 75.6 million kwh due to introduction of Lakhaoti Branch.

Economic benefits to individual farmers in addition to saving in cost of pumping would be increased production, better cropping pattern, better operational conditions and saving in time for other activities. The benefits are due to increase of paddy area from 2 to 15 percent and sugarcane from 13 to 15 percent. Net benefits per hectare increased by about 26 percent. Due to operation of canal in kharif season only, the farmers are forced to adopt conjunctive use of surface and groundwater. Water table therefore are maintained at reasonable depth and water logging condition did not develop.

Canal water use balance indicates that in the initial years, canal water was not used very efficiently. However, it recharged the groundwater reservoir. Conveyance losses were estimated to be about 98 percent of canal water input in 1988, which went down to 48 percent in 1998. There is scope for further reducing the conveyance losses. Field water application losses have ranged between 1 and 19 percent of canal water input.

Groundwater use balance indicates that calculated gross irrigation requirement in most of the years ranged between 90 and 110 percent. Rainfall recharge has ranged between 16 and 30 percent of the annual rainfall.

Due to lowered water table position as compared to adjoining areas, subsurface inflow has taken place into the study area. It has increased from 6,336 ha.m per year in 1984-85 to 9,188 ha.m in 1986-87 but reduced to 4,660 ha.m in 1997-98.

Water demand for domestic use (2,397 ha.m in 1997-98) and industrial uses (1,797 ha.m in 1997-98) are also met from recharged groundwater.

The Indo- Gangetic plain, which was waterlogged in the early 1950's is now facing the problems of declining water table, especially in the fresh ground water zones of Punjab and Haryana. A network of surface drains constructed to control water logging and floods during that period are not now put to frequent use and could be utilized for artificial ground water recharge. The surface drainage system cuts across the canal irrigation network. Surplus canal water during rainy season, combined with low crop water requirement period, offers a possible source of water for recharge through the existing canal and surface drainage systems. The surplus canal water should be regulated in such a way that the releases matches the seepage loss in the drain section. Experiments carried out by Khepar et al., (2000) indicate that recharge capacity of a drain is increased by about three and a half times with the provision of check structures at suitable intervals as compared with groundwater recharge under natural flow conditions. Khepar et al., (2000) have developed a model to determine canal water releases ensuring no runoff at the outfall of the drain both under natural flow conditions and with check structures. Since much of supply channels are used in a rotational water distribution under warabandi system, there is a great opportunity to use these supply channels in conjunction with drainage channels with suitable check and control structures to conserve excess rain water during kharif season.

Concluding Remarks

Several methods of artificial recharge of groundwater have been tried out and being implemented in India. But for the climatic and hydrogeologic conditions existing in the Indo-Gangetic Plain, unlined kharif irrigation system such as Lakhaoti Branch appears to be the best arrangement for recharging the subsurface reservoir. Lakhaoti Branch system is a good example of storing monsoon flow in the subsurface reservoir without construction of dam. Also, operation of canal water supply only during kharif season has certain specific advantages in that the available water is supplied in one season only; Due to copious supply during kharif farmers switch over to crops such as paddy and sugarcane which allows flooded water in the fields to get recharged underground aquifers and pump it during rabi season; since farmer's have to pump water from underground which costs money, water use is efficient and productivity of water goes up. By proper pricing of electricity and ground water use regulations, equity and efficiency in water use can be achieved. Combining surface canal and drainage systems as vehicles for recharging has even greater advantage.

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