GROUNDWATER DEPLETION IN THE CANAL COMMANDS OF BARI DOAB

By

Muhammad Saeed[1] and Muhammad Nasim Khan[2]

Abstract

This study was carried out in irrigated areas of Indus Basin. The main objective of this study was to identify areas of groundwater depletion and suggest measures for sustainable use of groundwater. Under this study, the data of depth to watertable in all canal commands of Bari Doab was collected and analysed. The data related to canal supplies, rainfall and depth to watertable have been summarized in this paper. To collect the depth to watertable data, observation wells have been installed / established in the study area by SCARPs Monitoring Organization (SMO), WAPDA. Area represented by one observation well works out as 4215 ha for CBDC, 9852 ha for LBDC, 2056 ha for Depalpur Canal, 10023 ha for Pakpattan Canal, 8725 ha for Sidhnai Canal and 10610 ha for Mailsi Canal.

Average canal deliveries to Bari Doab during the period 1967-76 were 13.435 MAF per year which increased by 10% during the period 1977-00 and reduced by 3% during 2001-09. Canal supplies during Rabi (2001-09) significantly reduced by 18% as compared to 1967-76 level. To overcome this shortage of canal water, farmers used groundwater which resulted in decline of groundwater table in the area with the passage of time.

The data of areas under different depths to watertable for Bari Doab indicates that area under shallow watertable (0-150 cm depth) during 2006-10 has vanished/reduced to minimum as compared to the previous periods, while area under deeper watertable (> 600 cm depth) has increased significantly during this period. It can be due to less canal supplies, particularly during the drought period (1999-2002) because farmers pumped more groundwater to meet their crop water requirements.

The watertable data indicates depletion of watertable at the rate of 15 to 49 cm per year in lower reaches (middle/tail) of Bari Doab Canal Commands.

1. INTRODUCTION

Pakistan has a large network of irrigation system. It has supported the needs of increasing population over the years. Canal water supplies have recharged the aquifer and created a groundwater resource in the command areas. Continued abstraction and extensive exploitation of groundwater has resulted in depletion of groundwater table in

---

1. Senior Engineer, Drainage, International Waterlogging and Salinity Research Institute (IWASRI), WAPDA, and PhD Scholar, Centre of Excellence in Water Resources Engineering, University of Engineering and Technology, Lahore, Pakistan.

2. Dirctor, Drainage, International Waterlogging and Salinity Research Institute (IWASRI), WAPDA, Near Muhammadpura Village, Raiwind Road. P. O. Thokar Niaz Baig, Lahore, Pakistan.

fresh groundwater areas. Lateral and vertical movement of brackish groundwater has deteriorated the groundwater quality in fresh groundwater areas.

International Waterlogging and Salinity Research Institute (IWASRI), under umbrella of Water and Power Development Authority (WAPDA) conducted this research study to identify areas where groundwater aquifer is depleting rapidly and the areas where groundwater recharge potential exists due to groundwater depletion in different canal commands of Bari Doab.

1.1 OBJECTIVE

The main objective of the paper is to understand groundwater table behaviour in the Indus System Irrigated Areas of Bari Doab.

2. DESCRIPTION OF CANAL COMMANDS

2.1 SALIENT FEATURES OF CANALS

Central Bari Doab Canal, Lower Bari Doab Canal, Depalpur Canal, Pakpattan Canal, Sidhnai Canal and Mailsi Canal are the major source of irrigation water in Bari Doab which derives their flows from Chenab and Ravi Rivers. Salient features of Bari Doab Canals are given in Table 1.

Table 1 Salient Features of Bari Doab Canal Commands

Sr. No.	Canal	Barrage/Reservoir/ Supply Channel	Designed Discharge (cfs)	GCA (ha)
1	Central Bari Doab Canal	BRBD Link Canal	2560	333000
2	Lower Bari Doab Canal	Balloki Barrage	7000	798000
3	Depalpur Canal	CBDC	2283	183000
4	Pakpattan Canal	Sulemanki Barrage	6594	431000
5	Sidhnai Canal	Sidhnai Barrage	4315	349000
6	Mailsi Canal	Sidhnai-Mailsi-Bahawal Link Canal	5262	435000

(DMP, 2005)

2.2 CANAL DELIVERIES

Historic average canal withdrawals from Indus River System during Kharif and Rabi seasons for Bari Doab are summarized in Table 2 alongwith percent increase or decrease of withdrawal for each canal during the periods 1977-2000 and 2001-2009 as compared with the period 1967-1976.

Table 3 indicates average annual canal deliveries to Bari Doab from Indus Basin Irrigation System during 1967-76 were13.435 MAF (8.539 MAF in Kharif and 4.896 MAF in Rabi) which increased by 10% during 1977-00 and reduced by 3% during 2001-09. Rabi supplies during 2001-09 significantly reduced by 18% as compared to 1967-76.

This shortage of canal water was met with by pumping groundwater by the farmers which resulted in lowering of watertable in the area. Delta of individual canal water has been calculated on the basis of annual canal deliveries and area under each canal, in terms of feet and centimeters / millimeters (Tables 4 & 5).

Table 2 Average Canals Withdrawal for Bari Doab

Season	Average Canal Withdrawals (MAF)			Percent Change Over 1967-76	
	1967-76	1977-00	2001-09	1977-00	2001-09
CBDC					
Kharif	0.721	0.768	0.802	7	11
Rabi	0.569	0.61	0.504	7	(-)11
Annual	1.301	1.379	1.306	6	1
LBDC					
Kharif	2.539	2.779	2.709	10	7
Rabi	1.88	2.092	1.592	11	(-)15
Annual	4.418	4.871	4.301	10	(-)3
Depalpur Canal					
Kharif	0.54	0.543	0.503	1	(-)7
Rabi	0.104	0.131	0.066	26	(-)36
Annual	0.645	0.673	0.569	4	(-)12
Pakpattan Canal					
Kharif	2.014	1.997	1.982	-1	(-)2
Rabi	1.117	1.27	0.785	14	(-)30
Annual	3.132	3.267	2.767	4	(-)12
Sidhnai Canal					
Kharif	1.269	1.293	1.199	2	1
Rabi	0.708	0.898	0.478	27	(-)32
Annual	1.977	2.191	1.677	11	(-)15
Mailsi Canal					
Kharif	1.456	1.617	1.822	11	25
Rabi	0.518	0.856	0.563	65	9
Annual	2.002	2.472	2.385	24	19

Note : Negative sign shows decrease in canal withdrawals.

Table 3 Average Canal Withdrawals for Bari Doab

Season	Average Canal Withdrawals (MAF)			Percent Change Over 1967-76	
	1967-76	1977-00	2001-09	1977-00	2001-09
Kharif	8.539	8.996	9.018	5	6
Rabi	4.896	5.857	3.988	20	(-)18
Annual	13.435	14.853	13.006	10	(-)3

Note: Negative sign shows decrease in canal withdrawals.

Table 4 Delta of Individual Canal Water Based on GCA of Bari Doab

Canal	Kharif	Rabi						
	MAF	MA	ft	cm	MAF	MA	ft	cm
CBDC	0.802	0.823	0.974	29.702	0.504	0.823	0.612	18.666
LBDC	2.709	1.971	1.374	41.893	1.592	1.971	0.808	24.619
D. Canal	0.503	0.452	1.113	33.919	0.066	0.452	0.146	4.451
Pakpattan	1.982	1.065	1.861	56.724	0.785	1.065	0.737	22.466
Sidhnai	1.199	0.862	1.391	42.396	0.478	0.862	0.555	16.902
Mailsi	1.822	1.074	1.696	51.708	0.563	1.074	0.524	15.978

Table 5 Average Canal Withdrawals per Unit of GCA in Bari Doab

GCA = 6.247 MA

Season	Average Canal Withdrawals (2001-09)		
	MAF	Per Unit of GCA	
		Ft	mm
Kharif	9.018	1.444	44.00
Rabi	3.988	0.638	19.46
Annual	13.006	2.082	63.46

2.3 RAINFALL

There are three meteorological stations of Pakistan Meteorological Department (PMD) in the canals command area, namely Lahore, Sahiwal and Mulatan, where the Indus system irrigated areas of Bari Doab are lying. Annual rainfall for Lahore, Sahiwal and Multan stations is given in Table 6. Maximum annual rainfall for Lahore, Sahiwal and Multan was 750.81, 553.00 and 300.50 mm during 2006, 2007 and 2005, respectively. Minimum annual rainfall for Lahore, Sahiwal and Multan was 372.20, 237.00 and 119.20 mm during 2009, respectively.

Mean (2005-09) annual rainfall is *609.90, 378.96 and 216.66 mm for Lahore, Sahiwal and Multan stations, respectively (*Table 6). No significant increasing or decreasing trend is found.

Table 6 Annual Rainfall for Lahore, Sahiwal & Multan Stations in Bari Doab Area

Year	Lahore	Sahiwal	Multan
	Rainfall (mm)		
2005	652.2	311.10	300.50
2006	750.80	372.20	154.10
2007	660.30	420.60	262.00
2008	614.00	553	247.50
2009	372.20	237	119.20
Five Year Mean	**609.90**	**378.96**	**216.66**

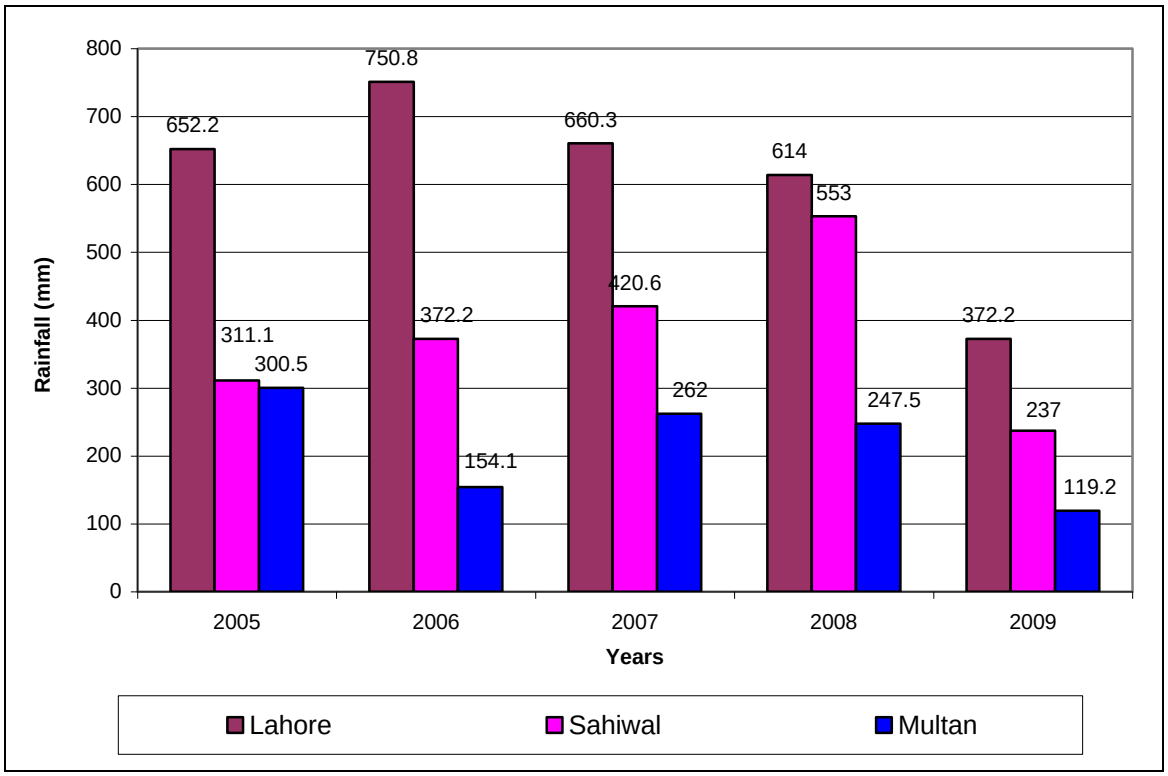

Figure 1 Rainfall at Different Sations of Bari Doab

3. WATERTABLE FLUCTUATIONS

3.1 WATERTABLE MONITORING AND DATA RECORDING BY SMO

SMO, WAPDA, Lahore is responsible for bi-annual monitoring of watertable for canal commands of Bari Doab - Punjab. For this purpose, funds are made available by the Government of Pakistan. Historic data of individual wells were collected from SMO, Lahore. Individual observation well data of many wells is available since 1981.

3.2 AREA UNDER DIFFERENT DEPTHS TO WATERTABLE

SMO collects DTW data under the following ranges:

(i) 0-90 cm

(ii) 90-150 cm

(iii) 150-300 cm

(iv) 300-450 cm

(v) 450-600 cm

(vi) > 600 cm

3.2.1 Watertable in Central Bari Doab Canal Command

Figure 2 shows five years average percent areas under various watertable depths for post-monsoon period in CBDC. As evident, area under 0-150 cm watertable depth during the period 2006-10 has decreased as compared to the previous periods, while area having watertable depth between 450-600 cm and > 600 cm has increased during this period.

3.2.2 Watertable in Lower Bari Doab Canal Command

Figure 3 shows five years average percent areas under various watertable depths for post-monsoon period in Lower Bari Doab Canal. The results show that area under watertable depth 0-150 cm during the period 2006-10 has decreased over the previous periods while area under watertable depth > 600 cm has increased during the period 2006-10.

3.2.3 Watertable in Depalpur Canal Command

Figure 4 shows five years average percent areas under various watertable depths for post-monsoon period in Depalpur Canal. As evident, area under 0-150 cm, 150-200 cm and 300-450 cm watertable depth during the period 2006-10 has decreased as compared to the previous periods, while area having watertable depth > 600 cm has increased significantly during this period.

3.2.4 Watertable in Pakpattan Canal Command

Figure 5 shows five years average percent areas under various watertable depths for post-monsoon period in Pakpattan Canal. As evident, area under 150-300 cm, 300-450 cm and 450-600 cm watertable depth during the period 2006-10 has vanished / decreased to minimum as compared to the previous periods, while area having watertable depth > 600 cm has increased significantly during this period.

3.2.5 Watertable in Sidhnai Canal Command

Figure 6 shows five years average percent areas under various watertable depths for post-monsoon period in Sidhnai Canal. As evident, area under 150-300 cm, 300-450 cm and 450-600 cm watertable depth during the period 2006-10 has vanished / decreased to minimum as compared to the previous periods, while area having watertable depth > 600 cm has increased significantly during this period.

3.2.6 Watertable in Mailsi Canal Command

Figure 7 shows five years average percent areas under various watertable depths for post-monsoon period in Mailsi Canal. As evident, area under 150-300 cm, 300-450 cm and 450-600 cm watertable depth during the period 2006-10 has vanished / decreased to minimum as compared to the previous periods, while area having watertable depth > 600 cm has increased significantly during this period.

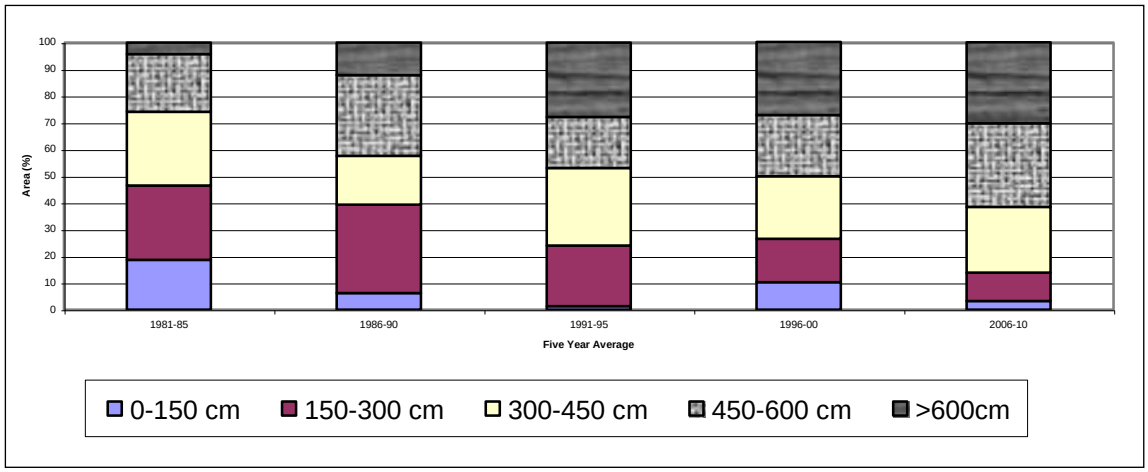

Figure 2 Post-Monsoon Watertable in Central Bari Doab Canal Area

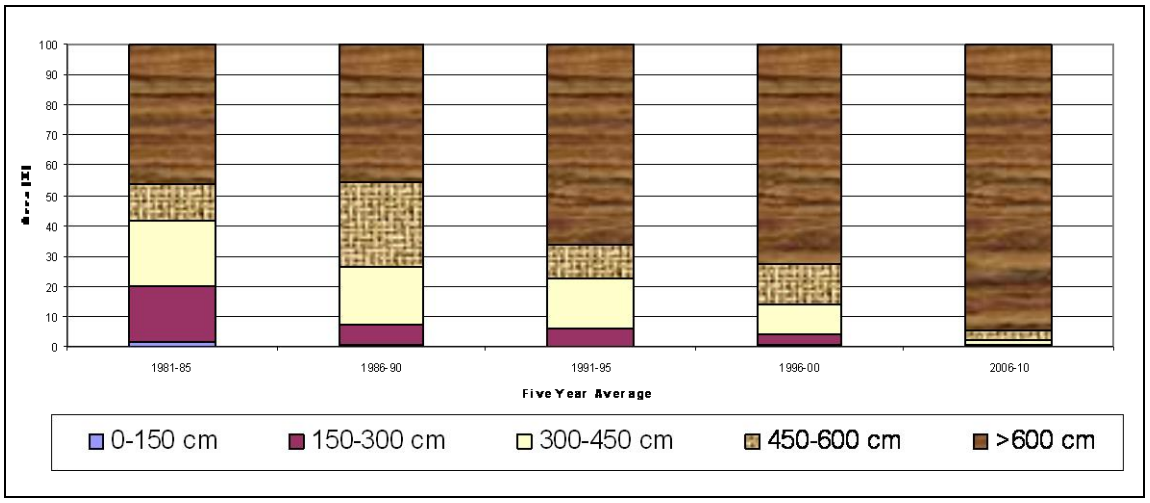

Figure 3 Post-Monsoon Watertable in Lower Bari Canal Area

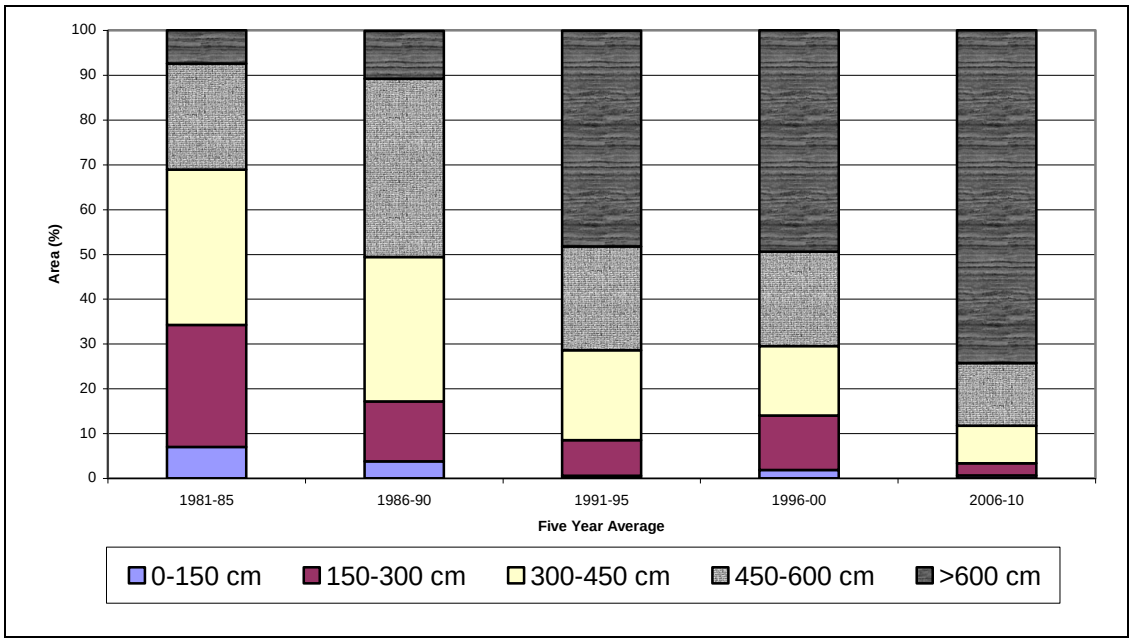

Figure 4 Post-Monsoon Watertable in Depalpur Canal Area

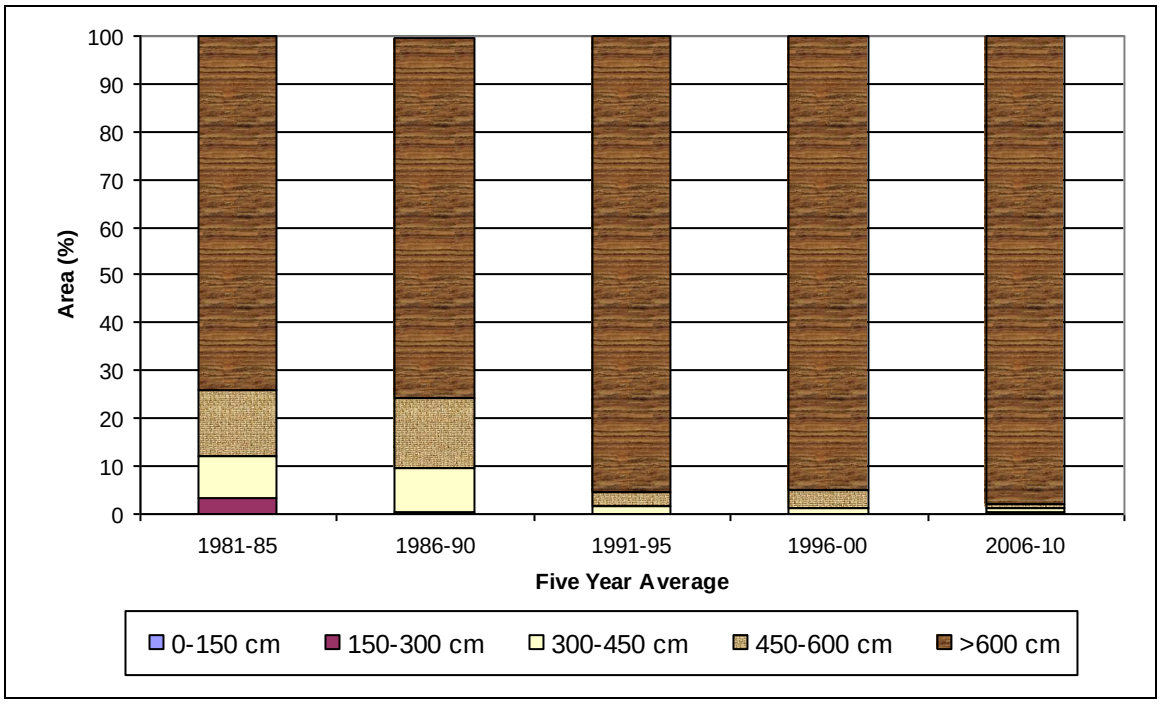

Figure 5 Post-Monsoon Watertable in Pakpattan Canal Area

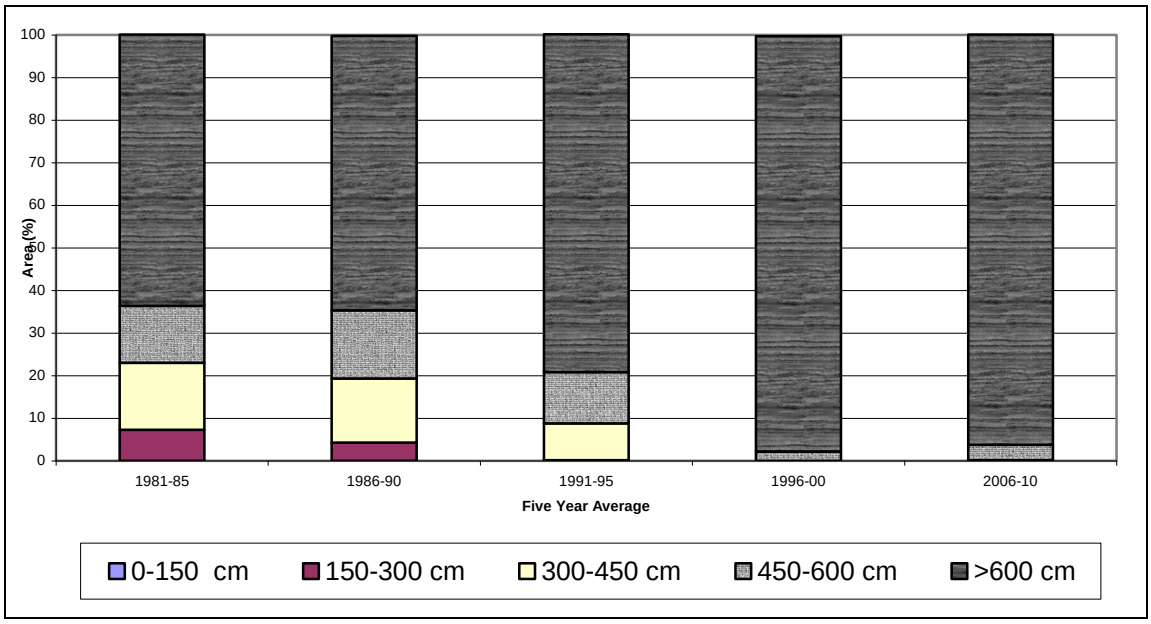

Figure 6 Post-Monsoon Watertable in Sidhnai Canal Area

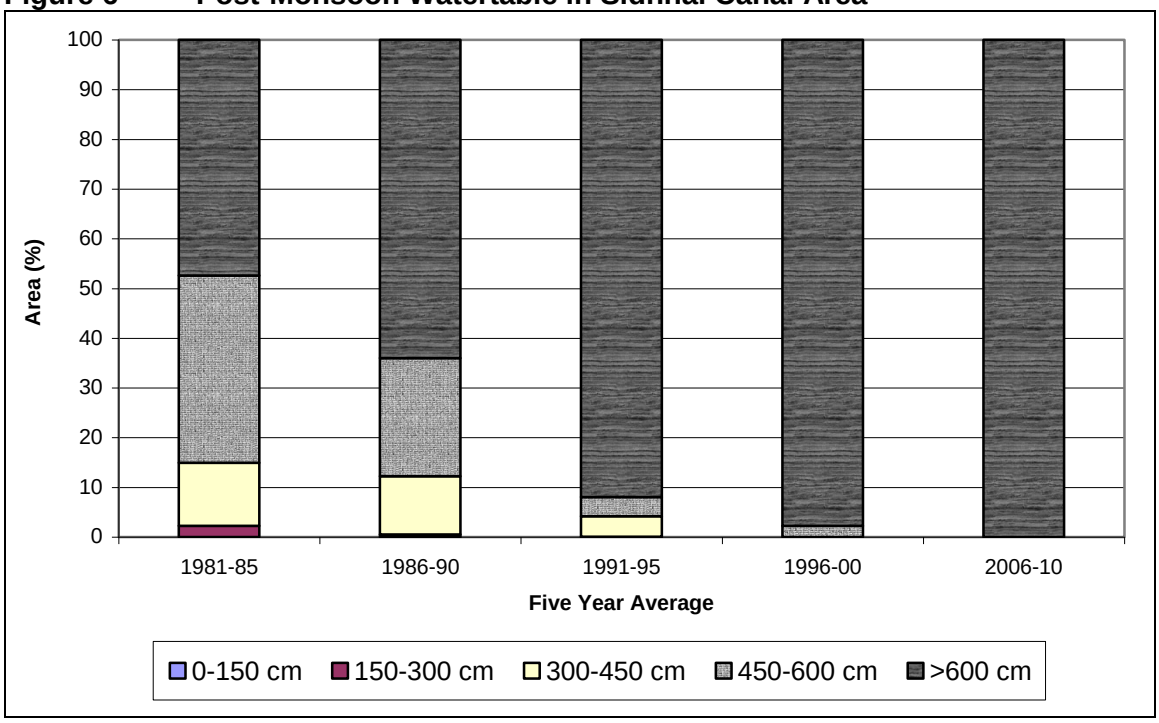

Figure 7 Post-Monsoon Watertable in Mailsi Canal Area

3.3 HISTORIC WATERTABLE DEPLETION AND RISE

3.3.1 Methodology

(i) Historic data of depth to watertable (DTW) for the canal commands of Bari Doab, Punjab Province, was collected from SMO, WAPDA.

(ii) The data was analysed for the selected observation wells located in head, middle and tail reaches of the individual canal commands.

(iii) To achieve accuracy of the results, data of only those observation wells was considered for analysis which did not involve too much data gaps.

(iv) Average DTW, alongwith 5-year moving average, were taken to analyse the data for head, middle and tail reaches of the canal commands.

(v) Mean values of post-monsoon depth to watertable for the first and last year of measurements were compared.

(vi) Total depletion/rise of watertable for the entire period of measurements, was worked- out by subtracting last year mean value of watertable depth from the initial/first year mean value.

(vii) Annual rate of depletion/rise of watertable was calculated by dividing the total depletion/rise of watertable over the total years of observations.

3.3.2 Watertable Fluctuations along Canal Commands

Analysis has been carried out keeping in view the criteria shown as under:

Depletion Rate (cm/year)	**Category**
< 10	Low Depletion
10 – 20	Medium Depletion
20 – 30	High Depletion
> 30	Very High Depletion

3.3.2.1 CBDC (Central Bari Doab Canal)

The results are based on the depth to watertable data of total 9 selected observation wells (4 located in head, 2 in middle and 3 in tail reach of the canal). Watertable depth (mean of pre and post-monsoon observations) in the first observation during 1987 was 415, 429 and 479 cm, respectively in head, middle and tail reach of CBDC (Table 7). In the last observation (2009), the watertable dropped to 1104, 658 and 523 cm in the respective reaches. The pertinent results reveal maximum drop of 690 cm of watertable over a period of 23 years in head reach of the canal command. The rate of depletion per year works out as 30 cm in head and 15 cm in middle reach which falls under the category “Medium to High Depletion”. The groundwater hydrographs also show the declining trend of watertable which is more prominent for the head reach (Figures 8 to 10).

Table 7 Watertable Fluctuations in Head, Middle and Tail Reaches of CBDC (1987 to 2009)

S. No.	Reach	Reading at Start (cm)	Final Reading (cm)	Difference (cm)	Period (year)	Dep/Rising (cm/year)
1	Head	414.53	1104.14	689.61	23	29.98
2	Middle	428.55	657.91	229.36	15	15.29
3	Tail	479.04	523.34	44.3	23	1.93

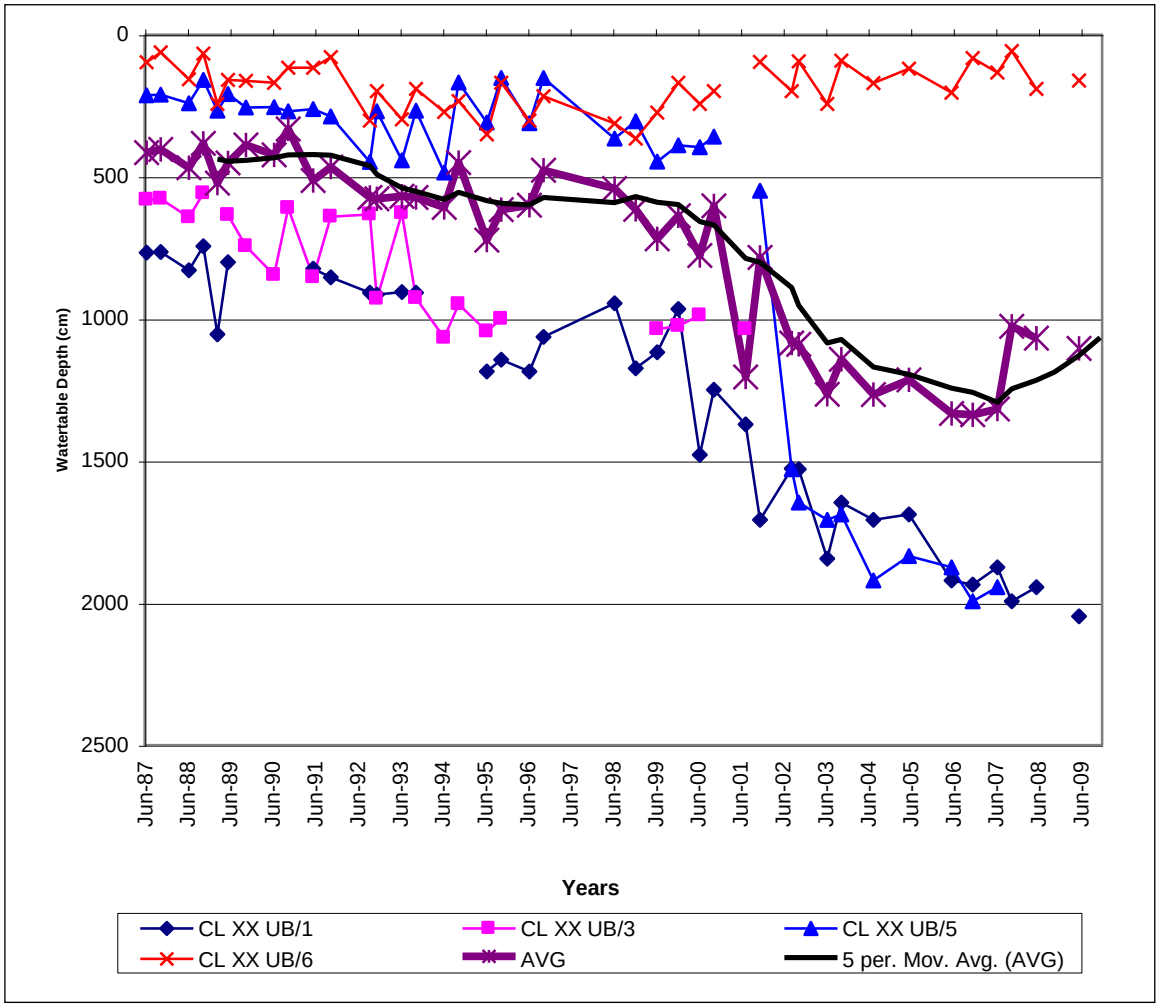

Figure 8 Watertable Fluctuations Along CBDC-Head Reach

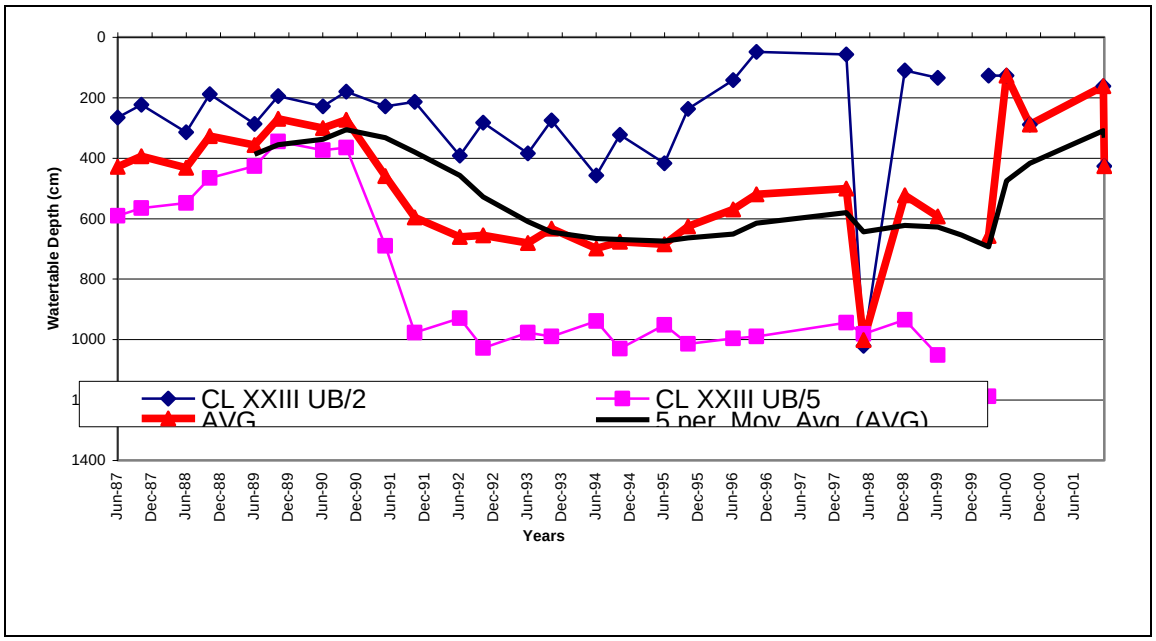

Figure 9 Watertable Fluctuations Along CBDC-Middle Reach

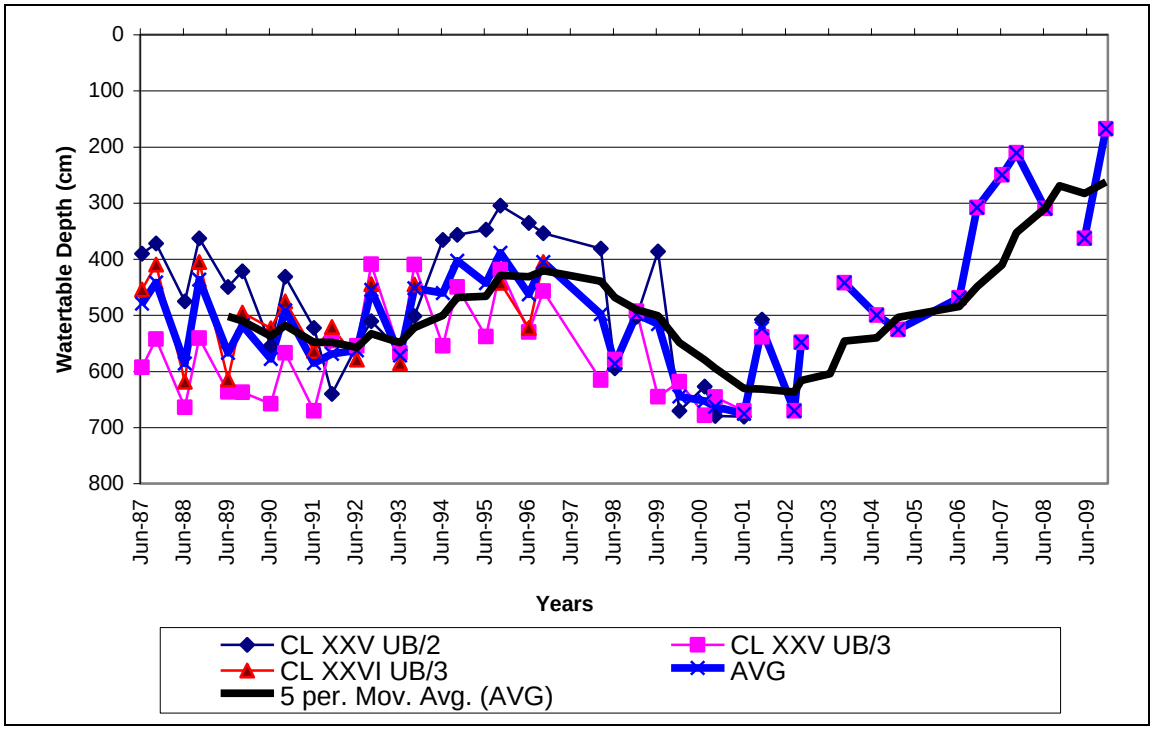

Figure 10 Watertable Fluctuations Along CBDC-Tail Reach

3.3.2.2 LBDC (Lower Bari Doab Canal)

The results are based on the depth to watertable data of total 13 selected observation wells (5 located in head, 5 in middle and 3 in tail reach of the canal). Watertable depth (mean of pre and post-monsoon observations) in the first observation during 1987 was 484 & 491 cm, respectively in head and middle reaches while for the tail reach, the first observation was recorded during 2002 as 1042 cm (Table 8). In the last observation (2009), the watertable dropped to 1027 and 1293 cm in middle and tail reach, respectively. The pertinent results reveal maximum drop of 536 cm of watertable over a period of 23 years in middle reach of the canal command. The rate of depletion per year works out as 23 cm in middle and 11cm in tail reach which falls under the category "High to Medium Depletion". The groundwater hydrographs also show the declining trend of watertable which is more prominent for the middle reach (Figures 11 to 13).

Table 8 Watertable Fluctuations in Head, Middle and Tail Reaches of LBDCCanal (1987-2009)

S. No.	Reach	Reading at Start	Final Reading (cm)	Difference (cm)	Period (year)	Dep/Rising (cm/year)
1	Head	484.33	326.14	-158.19	23	-6.88
2	Middle	490.67	1027.22	536.55	23	23.33
3	Tail	1042.26	1293.37	251.11	23	10.92

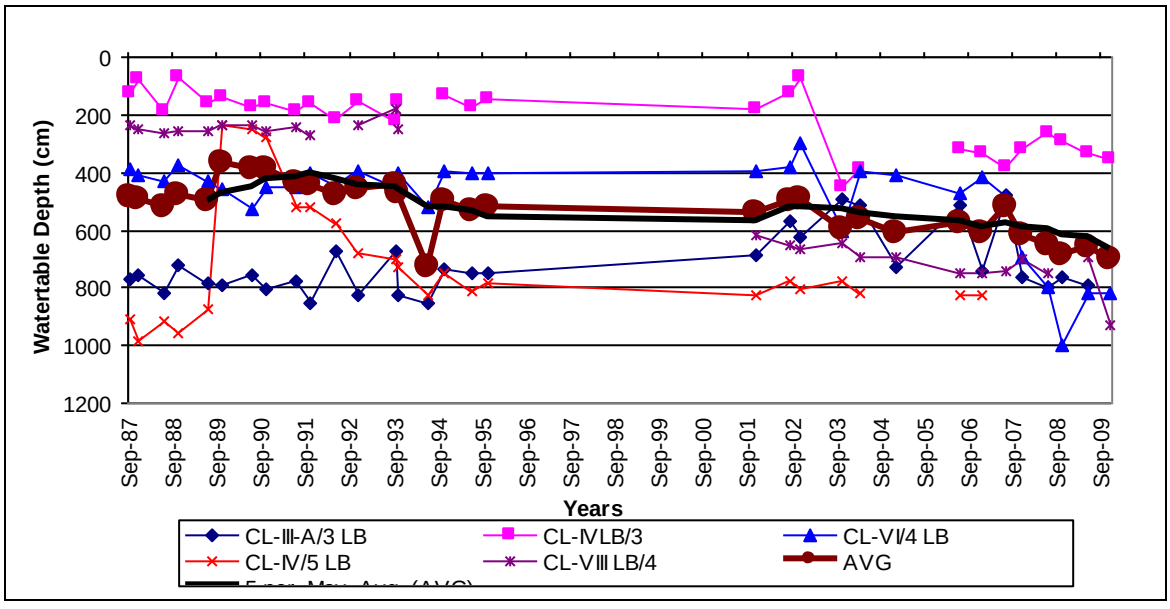

Figure 11 Watertable Fluctuations along LBDC-Head Reach

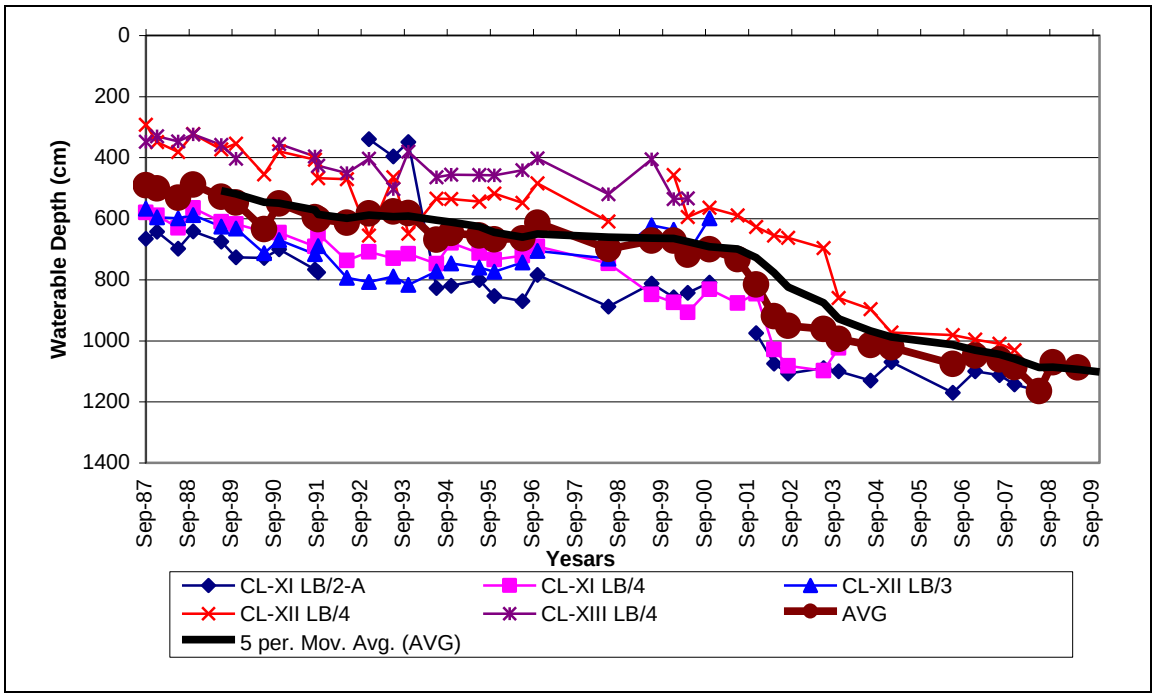

Figure 12 Watertable Fluctuations along LBDC-Middle Reach

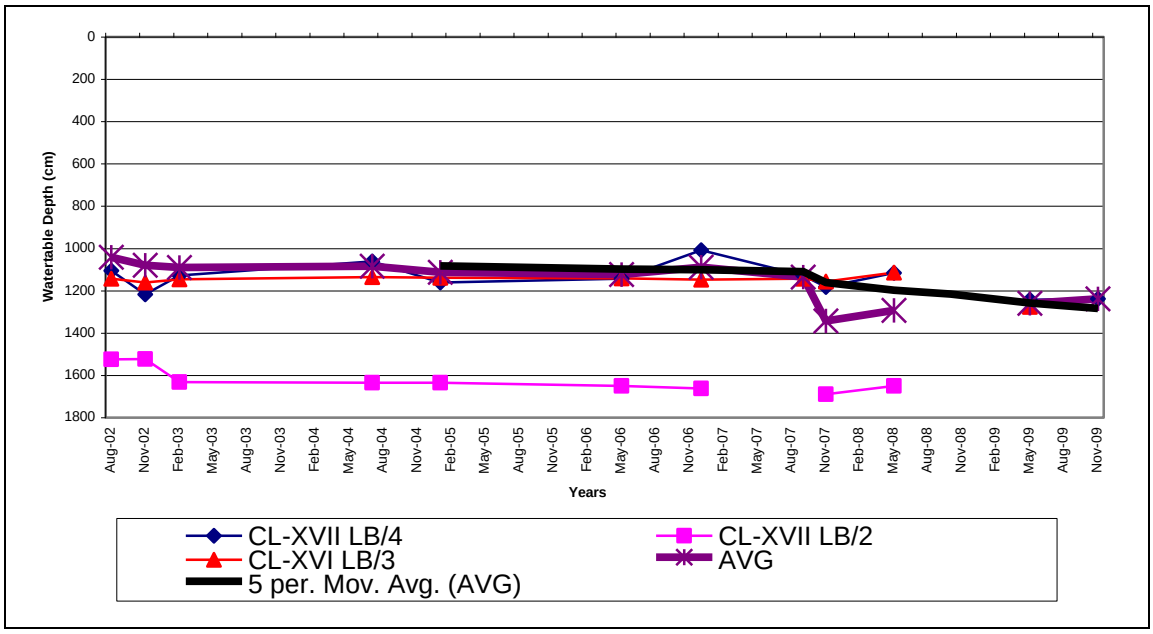

Figure 13 Watertable Fluctuations along LBDC-Tail Reach

3.3.2.3 Depalpur Canal

The results are based on the depth to watertable data of total 13 selected observation wells (5 located in head, 5 in middle and 3 in tail reach of the canal). Watertable depth (mean of pre and post-monsoon observations) in the first observation during 1987 was 535, 501 and 492 cm, respectively in head, middle and tail reach of Depalpur Canal (Table 9). In the last observation (2009), the watertable dropped to 797 and 856 cm, respectively in head and tail reach. Rise in watertable in middle reach of Depalpur Canal as shown in Table 9 is due to the seepage from B.S. Link Canal. The pertinent results reveal maximum drop of 364 cm of watertable over a period of 15 years in tail reach of the canal command. The rate of depletion per year works out as 17 cm in head and 24 cm in tail reach which falls under the category "Medium to High Depletion". The groundwater hydrographs show the declining trend of watertable which is more prominent for tail reach (Figures 14 & 16).

Table 9 Watertable Fluctuations in Head, Middle and Tail Reaches of Depalpur Canal (1987-2001)

S. No.	Reach	Reading at Start	Final Reading (cm)	Difference (cm)	Period (year)	Dep/Rising (cm/year)
1	Head	535.31	797.05	261.74	15	17.45
2	Middle	501.4	482.09	-19.31	15	-1.29
3	Tail	492.25	855.88	363.63	15	24.24

Note: Negative Sign Shows Rise in Watertable.

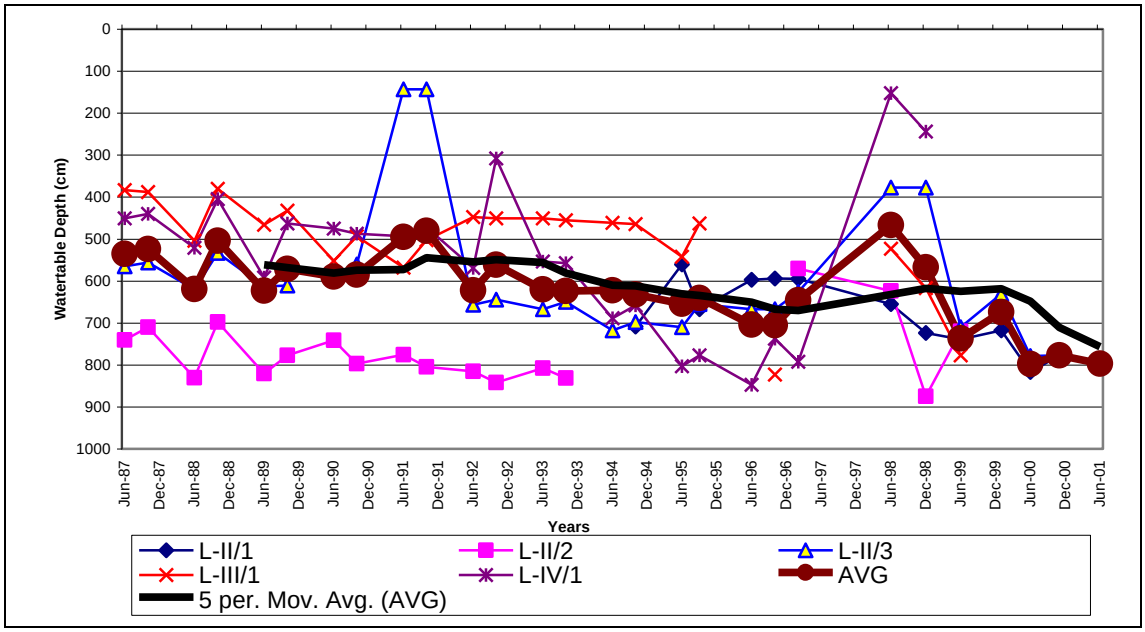

Figure 14 Watertable Fluctuations along Depalpur Canal –Head Reach

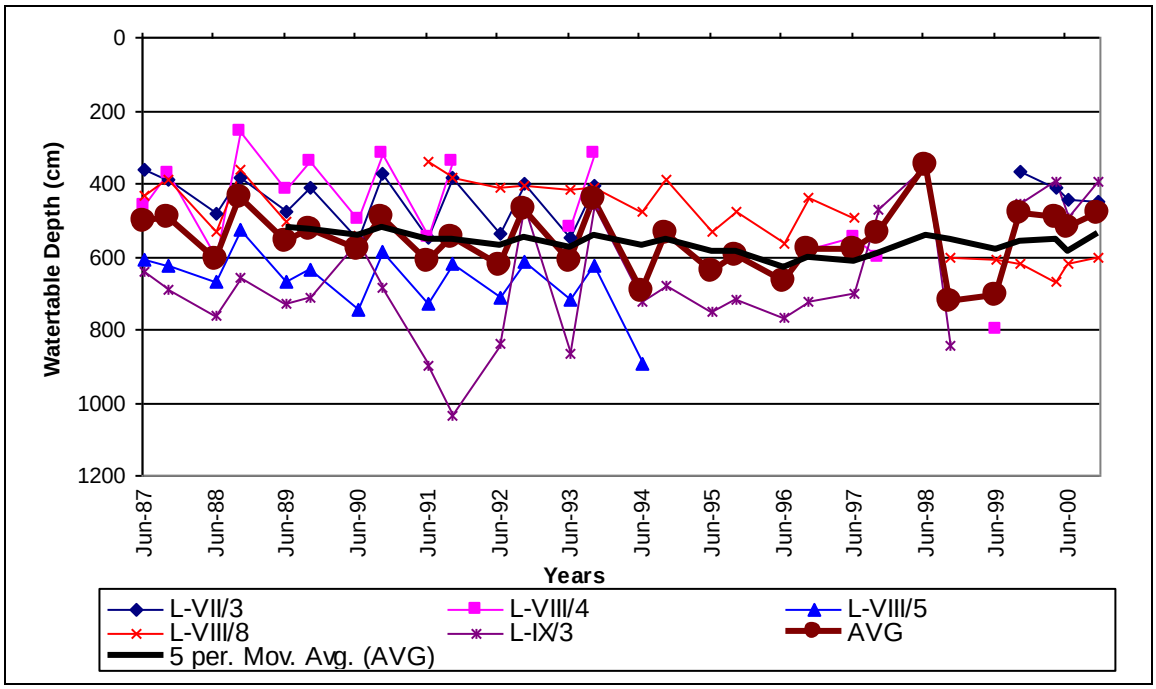

Figure 15 Watertable Fluctuations along Depalpur Canal –Middle Reach

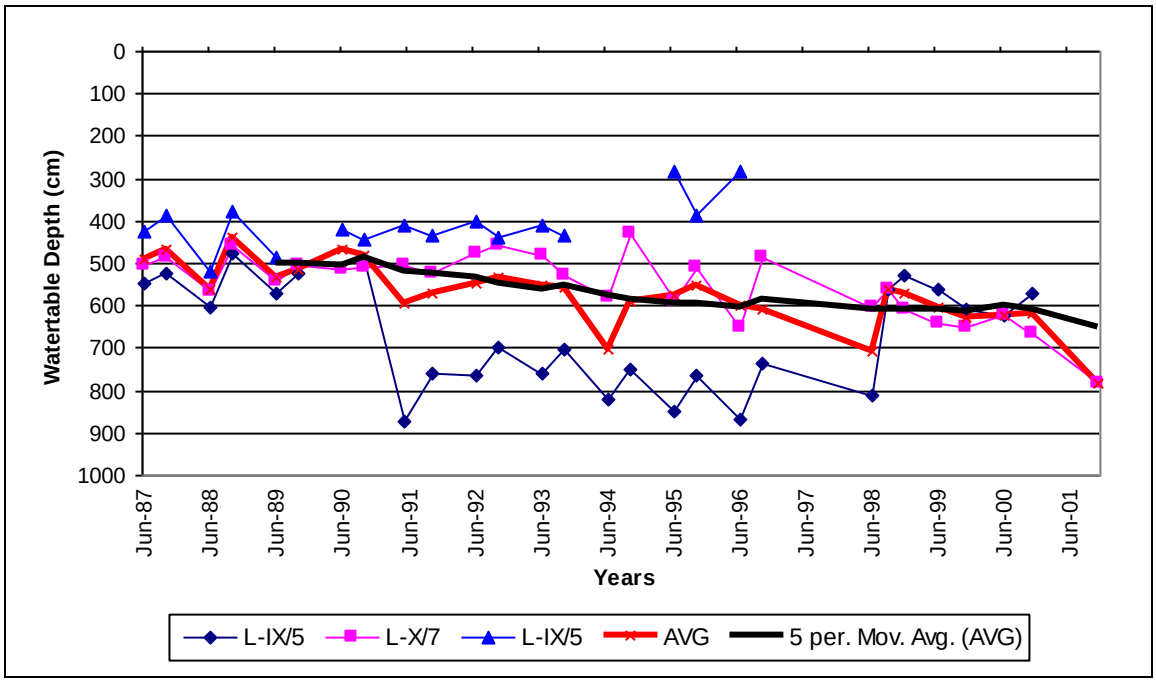

Figure 16 Watertable Fluctuations along Depalpur Canal –Tail Reach

3.3.2.4 Pakpattan Canal

The results are based on the depth to watertable data of total 10 selected observation wells (2 located in head, 5 in middle and 3 in tail reach of the canal). Watertable depth (mean of pre and post-monsoon observations) in the first observation during 1987 was 678, 624 and 879 cm, respectively in head, middle and tail reach of Pakpattan Canal (Table 10). In the last observation (2009), the watertable dropped to 729, 1087 and 1293 cm in the respective reaches. The pertinent results reveal maximum drop of 463 cm of watertable over a period of 23 years in middle reach of the canal command. The rate of depletion per year works out as 20 cm in middle and 18 cm in tail reach which falls under the category "Medium Depletion". The groundwater hydrographs show the declining trend of watertable which is more prominent for middle and tail reach (Figures 17 to 19).

Table 10 Watertable Fluctuations in Head, Middle and Tail Reaches of Pakpattan Canal (1987 to 2009)

S. No.	Reach	Reading at Start (cm)	Final Reading (cm)	Difference (cm)	Period (year)	Dep/Rising (cm/year)
1	Head	678.18	729.39	51.21	17	3.01
2	Middle	624.17	1087.22	463.05	23	20.13
3	Tail	879.35	1293.42	414.07	23	18.00

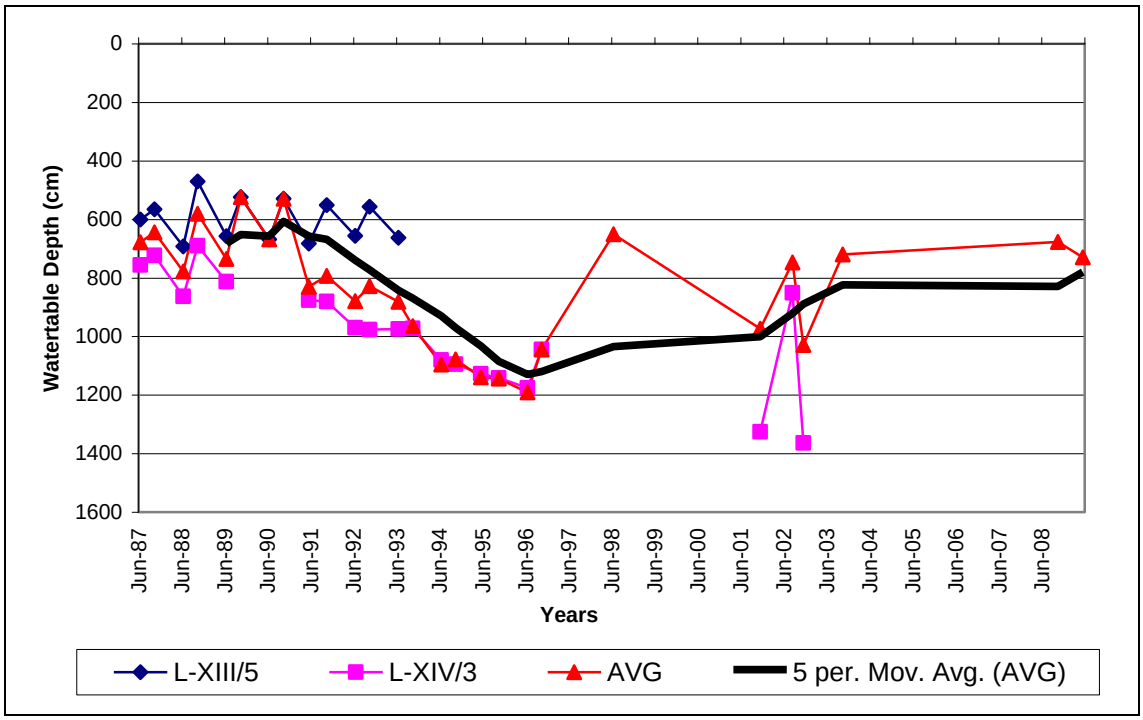

Figure 17 Watertable Fluctuations along Pakpattan Canal-Head Reach

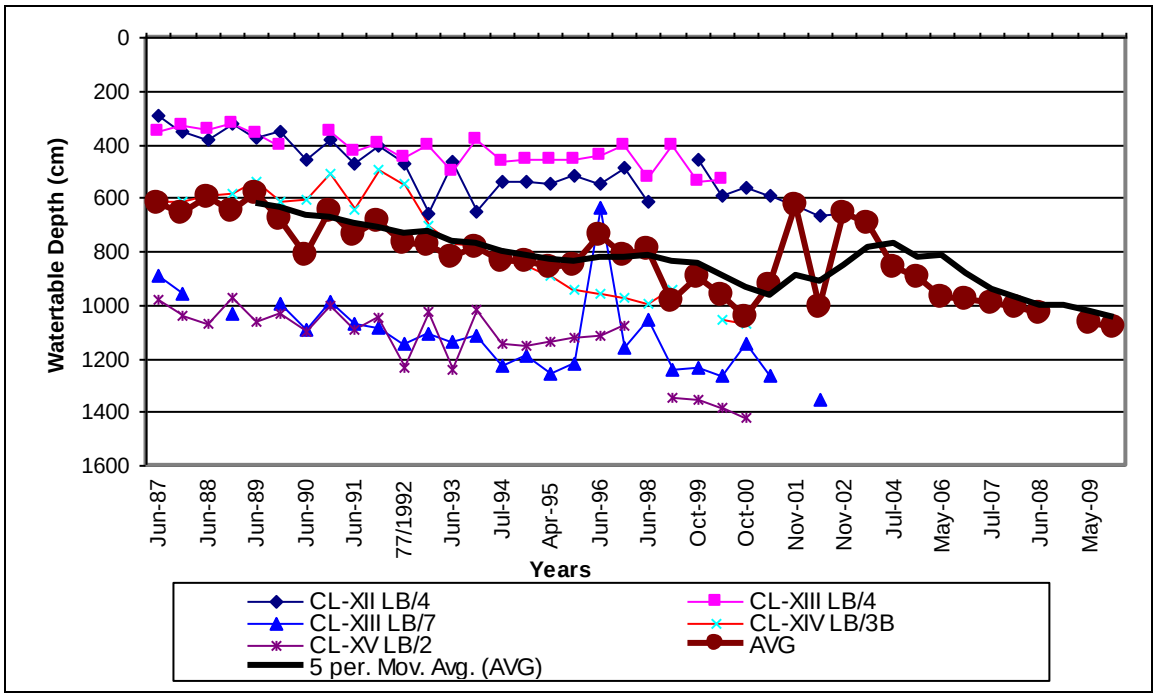

Figure 18 Watertable Fluctuations Along Pakpattan Canal-Middle Reach

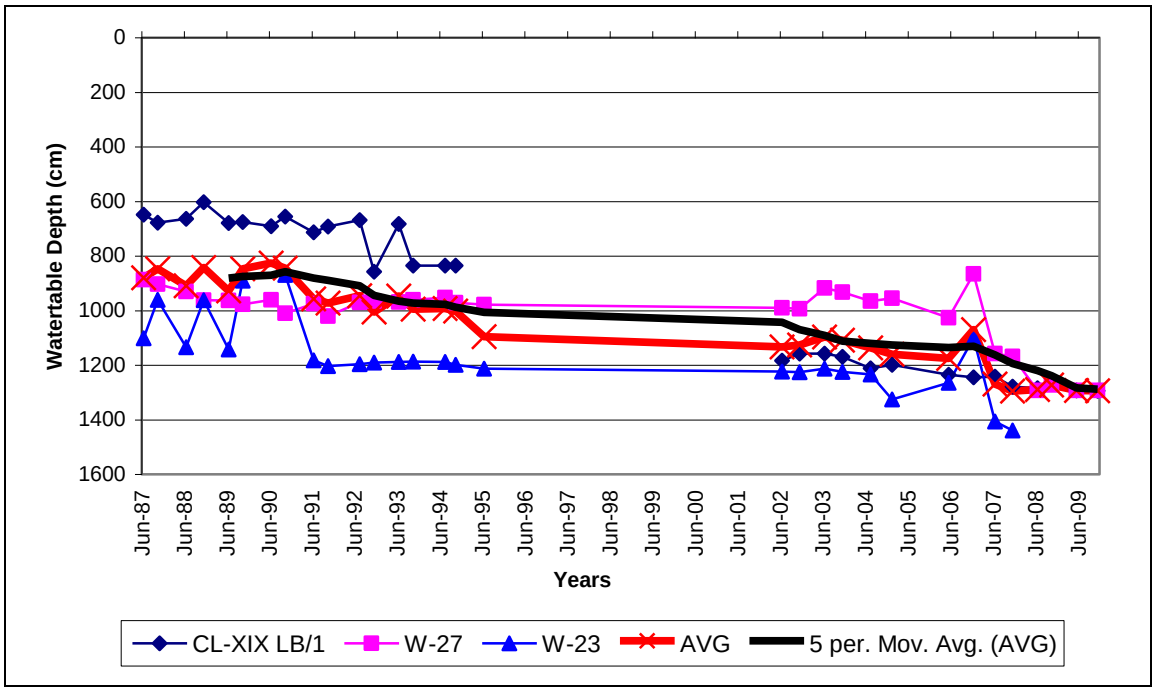

Figure 19 Watertable Fluctuations Along Pakpattan Canal-Tail Reach

3.3.2.5 Sidhnai Canal

The results are based on the depth to watertable data of total 9 selected observation wells (4 located in head, 4 in middle and one in tail reach of the canal). Watertable depth (mean of pre and post-monsoon observations) in the first observation during 2002 was 878, 860 and 1250 cm, respectively in head, middle and tail reach of Sidhnai Canal (Table 11). In the latest observation (2009), the watertable dropped to 900 & 887 for head and middle reach, while in case of tail reach, the watertable depth during the last observation was recorded in 2005 as 1445 cm. The pertinent results reveal maximum drop of 196 cm of watertable over a period of 4 years in tail reach of the canal command. The rate of depletion per year works out as 49 cm in tail reach which falls under the category "Very High Depletion". The groundwater hydrographs show the declining trend of watertable which is more prominent for tail reach (Figures 20 to 22).

Table 11 Watertable Fluctuations in Head, Middle and Tail Reaches of Sidhnai Canal (2002-09)

S. No.	Reach	Reading at Start (cm)	Final Reading (cm)	Difference (cm)	Period (year)	Dep/Rising (cm/year)
1	Head	878.21	900.15	21.94	9	2.44
2	Middle	860.37	887.17	26.8	8	3.35
3	Tail	1249.68	1445.36	195.68	4	48.92

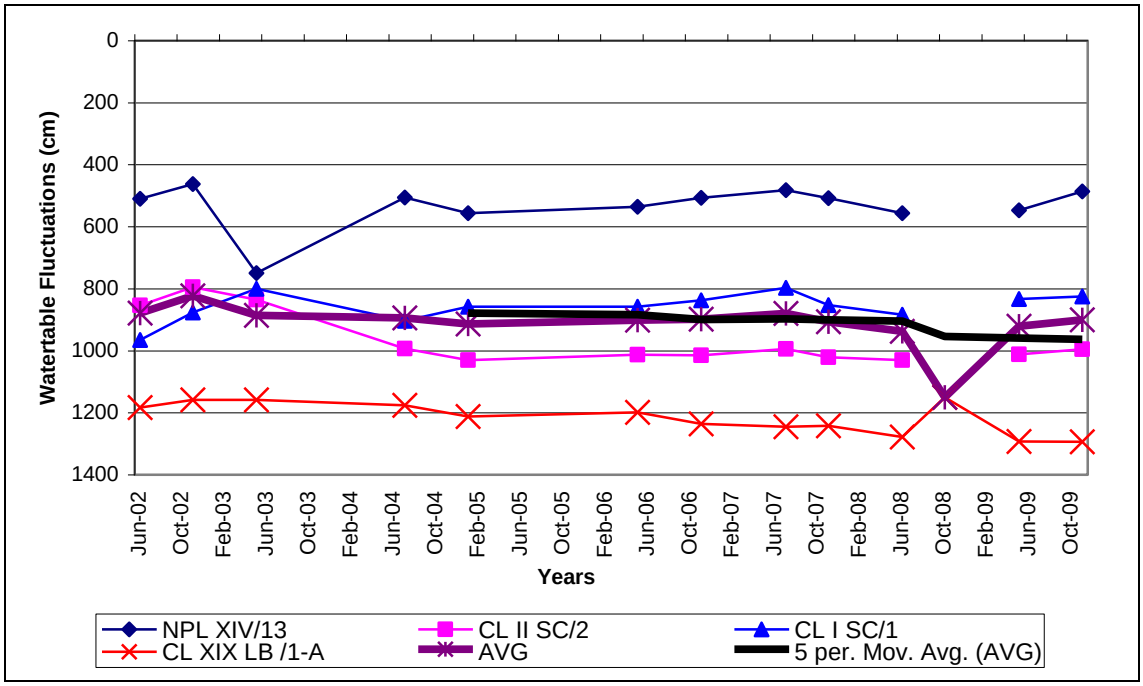

Figure 20 Watertable Fluctuations along Sidnai Canal-Head Reach

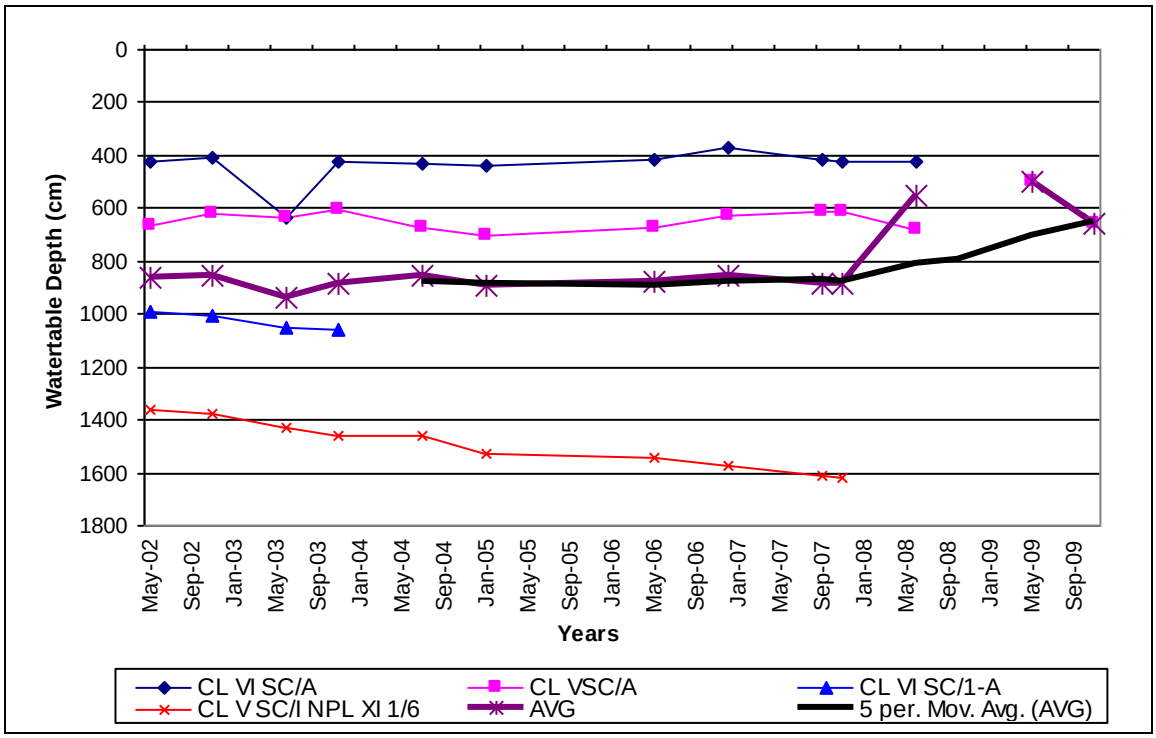

Figure 21 Watertable Fluctuations along Sidnai Canal-Middle Reach

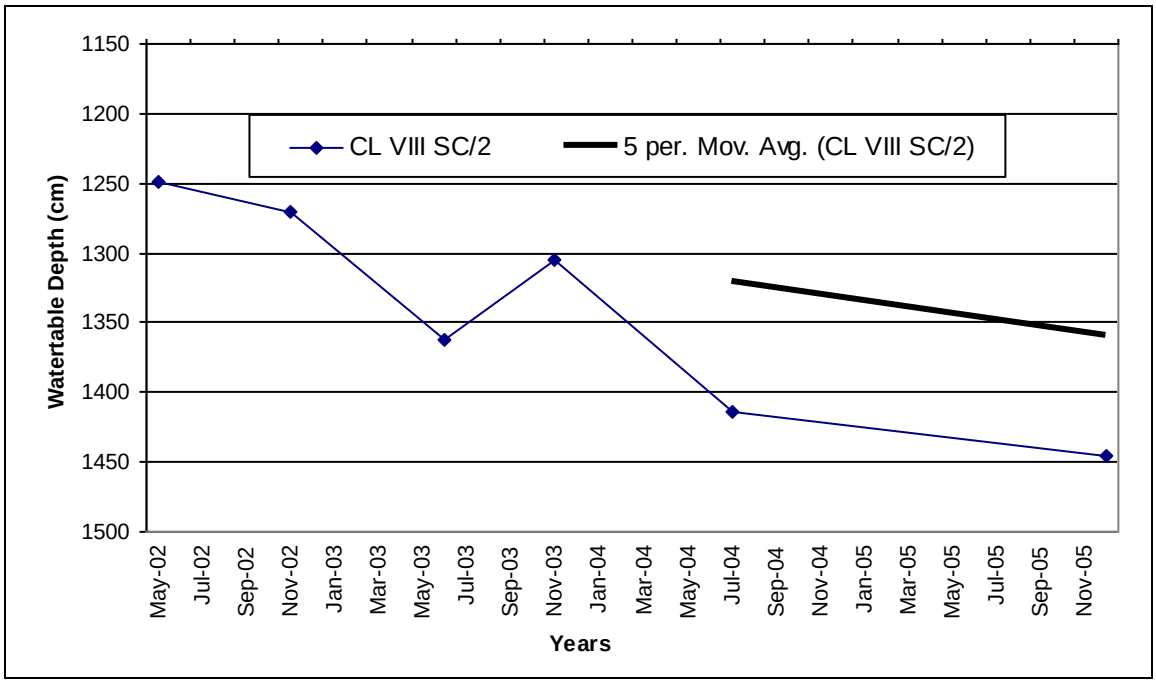

Figure 22 Watertable Fluctuations along Sidnai Canal-Tail Reach

3.3.2.6 Mailsi Canal

The results are based on the depth to watertable data of total 11 selected observation wells (4 located in head, 3 in middle and 4 in tail reach of the canal). Watertable depth (mean of pre and post-monsoon observations) in the first observation was 680 & 559 cm in head and middle reach (during 1987) and 1076 cm in tail reach (during 2002) of Mailsi Canal (Table 12). In the last observation (2009), the watertable dropped to 1163, 1373 and 1520 cm in the respective reaches. The pertinent results reveal maximum drop of 813 cm of watertable over a period of 23 years in middle reach of the canal command. The rate of depletion per year works out as 21 cm, 35 cm and 26 cm in head, middle and tail reach which falls under the category "High to Very High Depletion". The groundwater hydrographs clearly show the declining trend of watertable for head, middle and tail reaches (Figures 23 to 25).

Table12 Watertable Fluctuations in Head, Middle and Tail Reaches of Mailsi Canal (1987-2009)

S. No.	Reach	Reading at Start (cm)	Final Reading (cm)	Difference (cm)	Period (year)	Dep/Rising (cm/year)
1	Head	680.47	1162.81	482.34	23	20.97
2	Middle	559.31	1372.51	813.2	23	35.36
3	Tail	1076.25	1520.04	443.79	17	26.11

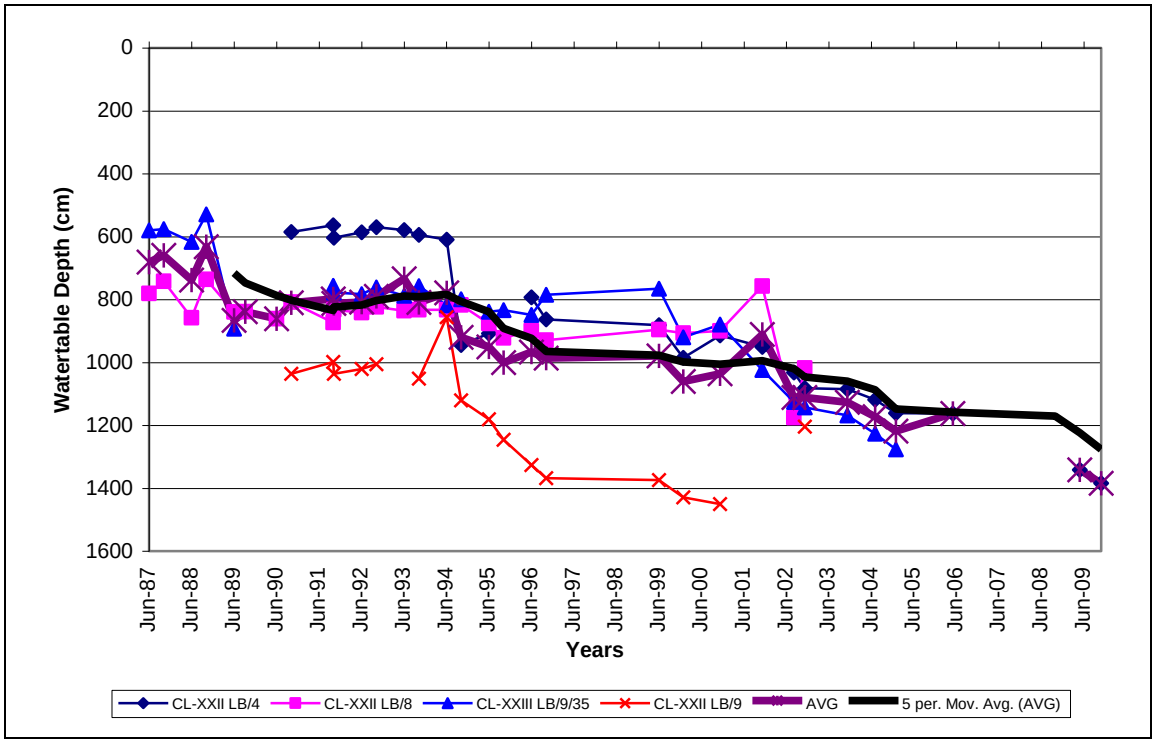

Figure 23 Watertable Fluctuations along Mailsi Canal-Head Reach

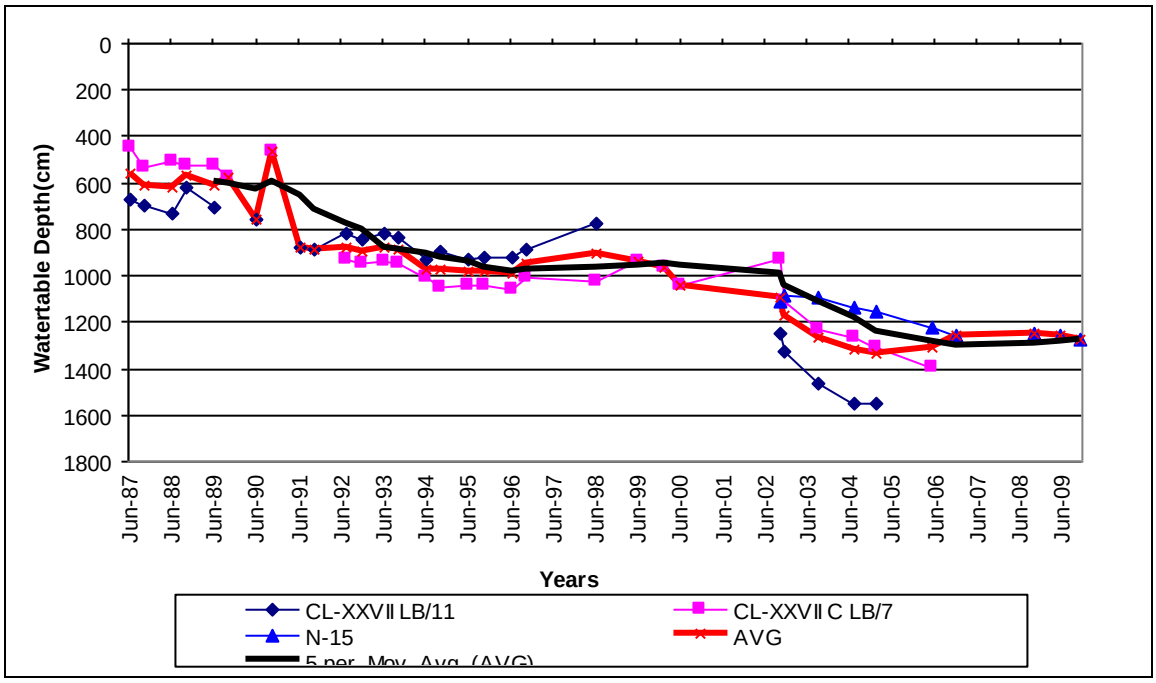

Figure 24 Watertable Fluctuations along Mailsi Canal-Middle Reach

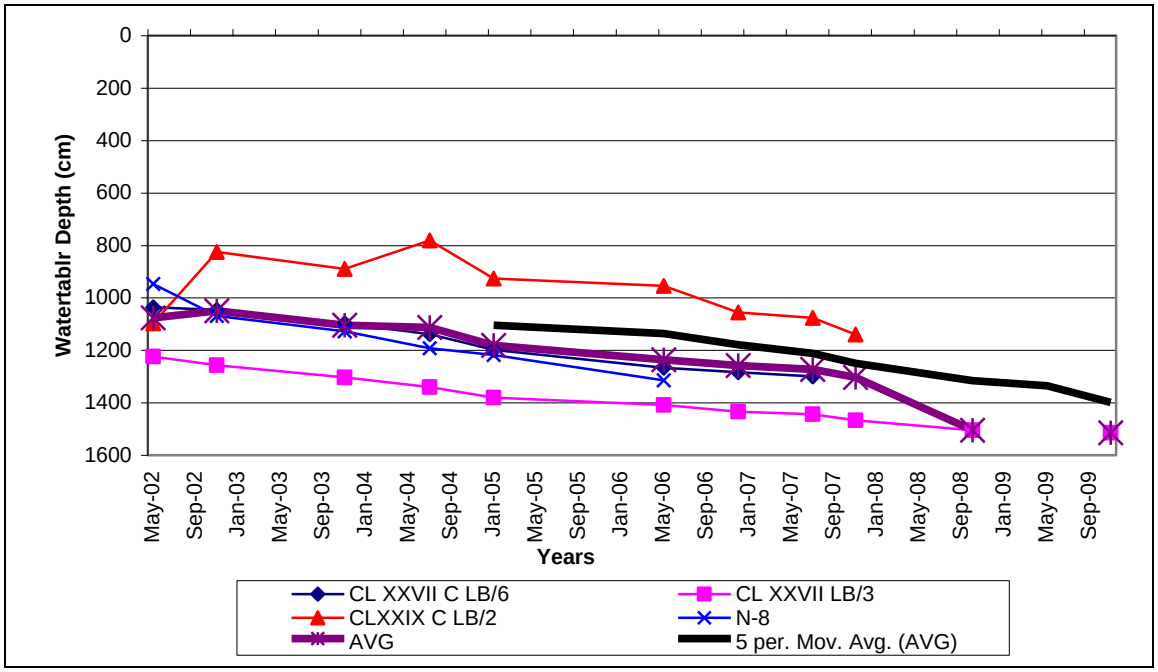

Figure 25 Watertable Fluctuations along Mailsi Canal-Tail Reach

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

(i) Compared with the period 1967-76, Kharif supplies to Bari Doab from the Indus Basin Irrigation System increased by 5 percent during 1977-00 and further increased by 6 percent during 2001-09, while Rabi supplies increased by 20 percent during 1977-00 and decreased by 18 percent during 2001-09.

(ii) High depletion rate (20-30 cm per year) of groundwater table was worked out for CBDC (head reach), LBDC (middle reach), Depalpur Canal (tail reach), Pakpattan Canal (middle reach), and Mailsi Canal (head and tail reach). The depletion remained very high (>30 cm per year) in case of Sidhnai Canal (tail reach) and Mailsi Canal (middle reach).

(iii) Area under watertable depth 0-150 cm, 150-300 cm and 300-450 cm during 2006-10 has reduced as compared to previous periods, while area under deeper watertable (> 600 cm depth) has increased significantly during this period. It can be due to reduced canal supplies, specifically during the drought period (1999-02) during which farmers had to rely on groudwater to meet their crop water requirements.

4.2 RECOMMENDATIONS

(i) Proper management of surface and groundwater is required in the study area to meet with the challenges of depletion of groundwater, due to shortage of surface water supplies and abstraction of groundwater water in the area to fulfill the crop water requirement.

(ii) Suitable artificial groundwater recharge techniques should be adopted in the groundwater depleted zones, to maintain the groundwater at required level.

REFERENCES

Ashraf M. and A. Majeed. 2006. Water Requirement of Major Crops for Different Agro-Climatic Zones of Balochistan. IUCN–The World Conservation. 139 pp.

Ahmad, N. 1982. An Estimate of Water Loss by Evaporation in Pakistan. Planning and Co-ordination Cell, Lahore. Irrigation, Drainage and Flood Control Research Council. 71 pp.

DMP. 2005. Drainage Master Plan of Pakistan, Volume-III, WRPO (P&D Division) and IWASRI, WAPDA. 251 pp.

SMO, 2010. Depth to Watertable Data collected from SCARP Monitoring Organization (SMO), WAPDA, Lahore.