WORKING PAPER 48

Pakistan Country Series No. 13

Conjunctive Water Management in the Rechna Doab: An Overview of Resources and Issues

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INTERNATIONAL WATER MANAGEMENT INSTITUTE

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The conjunctive water management project aimed to identify combinations of institutional and technical strategies to manage surface and groundwater at regional scale to promote environmental sustainability and maximize agricultural productivity of water ('crop per drop'). Two major semi-arid irrigated areas, the Rechna Doab in Pakistan and Murrumbidgee Region in Australia, were chosen for this study. This three year project was funded by ACIAR, and was executed with the technical collaboration of CSIRO, Australia. The local collaborators in Pakistan have been Pakistan Council for Research in Water Resources (PCRWR), Soil Salinity Research Institute (SSRI) and Ayub Agricultural Research Institute (AARI).

Cover photograph: Conjunctive water management by using tractor driven tubewell on an irrigated farm in the Rechna Doab.

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Jehangir, W. A.; Qureshi, A. S.; Ali, N. 2002. *Conjunctive water management in the Rechna Doab: An overview of resources and issues*. Working Paper: 48. Lahore, Pakistan: International Water Management Institute.

ISBN: 92-9090-489-5

Keywords: water management / conjunctive use / water resources /water quality / waterlogging / salinity / private sector / groundwater development / land resources /intensive cropping / productivity / returns / surface water / agriculture / environmental sustainability / crops / irrigated farming / population / climate / geology / sedimentation / clay soils / rivers / canals / tube wells / farms / cultivation / wastelands / crop yield / rice / wheat / cotton / sugarcane / Pakistan / Rechna Doab

The authors extend their special thanks to Ms. Ayesha Bhatti and Mr. Muhammad Iqbal Khan for providing the editorial and secretarial support, respectively.

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ACRONYMS

AARI	Ayub Agricultural Research Institute
ACE	Associated Consulting Engineers
ACIAR	Australian Council of International Agricultural Research
AWB	Area Water Board
BRBD	Bambanwala-Ravi-Bedian-Depalpur
BSLink	Ballolki Sulemanki Link Canal
CSIRO	Commonwealth Scientific and Industrial Research Organization
HLC	Haveli Link Canal
IWASRI	International Waterlogging and Soil Salinity Research Institute
IWMI	International Water Management Institute
LBDC	Lower Bari Doab Canal
LCC	Lower Chenab Canal
MRLink	Marala Ravi Link Canal
NDC	National Development Consultants
NESPAK	National Engineering Services of Pakistan
PCRWR	Pakistan Council for Research in Water Resources
PPSGDP	Punjab Private Sector Groundwater Development Project
QB Link	Qadirabad Balloki Link Canal
RSC	Residual Sodium Carbonate
SAR	Sodium Adsorption Ratio
SCARPs	Salinity Control and Reclamation Projects
SMO	SCARPs Monitoring Organization
SSRI	Soil Salinity Research Institute
SSTP	Second SCARP Transition Project
STW	SCARP Tubewells
TS/Haveli	Trimu-Sidhnai Haveli
TTSingh	Toba Tek Singh
UCC	Upper Chenab Canal
UJC	Upper Jhelum Canal
URR	Upper Rechna Remaining
WAPDA	Water And Power Development Authority
WASID	Water and Soil Investigation Directorate

CONJUNCTIVE WATER MANAGEMENT IN THE RECHNA DOAB: AN OVERVIEW OF RESOURCES AND ISSUES

1. INTRODUCTION

Conjunctive water management is the use of multiple water resources (surface water and groundwater) within a basin so that at the time of irrigation, adequate water of acceptable quality is available at the farm. The meaning of conjunctive water management and its scope, practices and standards vary depending on the scarcity and quality of water in a country and its importance for economic growth. The use of conjunctive water management means an assured crop, higher yields, more income and more employment.

This report is a review of the conjunctive water use of surface water and groundwater within the Rechna Doab. The Rechna Doab is located in the Punjab province and has an area of 2.98 million hectares (Figure 1). The cultivated area in the Rechna Doab is regarded as the granary of the Punjab province and comprises eight districts, namely, Sialkot, Gujranwala, Sheikhupura, Faisalabad, Toba Tek Singh, Jhang, Narowal and Hafizabad. The area consists of two distinct agro-climatic zones, i.e. the Punjab Rice-Wheat (PRW) zone and the Punjab Sugarcane-Wheat (PSW) zone (WAPDA, 1979). Irrigated agriculture started in the Rechna Doab in 1892 via Lower Chenab Canal. The irrigation system in the Rechna Doab consists of 504 km of branch canals, 240 km of main canals and 373 km of link canals, and about 0.2 million tubewells are installed in the freshwater areas. This report is prepared to provide an overview of land and water resources available in the Rechna Doab and the institutional issues that need to be addressed for effective conjunctive water management in the Rechna Doab.

1.1 Objective

The goal of this study is to document the resource base, technologies, institutions and management methods that have been used, or may play a vital role in the conjunctive water management of the multiple sources (groundwater and the surface water) in the Rechna Doab.

1.2 Organization of the Study

The report consists of eight chapters. Chapter 2 provides a brief description about the physiography, population, climate and soils, of the Rechna Doab. The next two chapters are devoted to highlight the surface and groundwater resources in the Rechna Doab. Chapter 3 provides information about the network of the main and link canals, while Chapter 4 contains information about available groundwater resource, its quality and quantity in the Rechna Doab. Chapter 5 provides information about waterlogging and salinity conditions in the Rechna Doab. It sheds light on the achievements of SCARPS project and discusses the post SCARP situation in the area. Chapter 6 highlights the land resources and productivity issues in the Rechna Doab. It also provides information about the land use intensity, cropping intensity and temporal changes experienced in the area since 1960. Chapter 7discusses the crop productivity by estimating Gross margins per hectare of the major crops in the Rechna Doab. It describes the existing potential for horizontal and vertical increase in the cropping areas in the Rechna Doab and also highlights the constraints faced by the farmers for conjunctive water management in the Rechna Doab. The summary and conclusions are given in Chapter8.

2. THE RECHNA DOAB

2.1 Study Area

The study area consisted of 2.98 million hectares (Mha) in the Rechna Doab. The word *Doab* means the land between two rivers. In this case, the Rechna Doab is the land between the rivers, Ravi and Chenab. The location of Rechna Doab is shown in Figure 1. It is a part of the alluvium-filled Indo-Gangetic plane. Out of 2.98 million hectares of gross area, about 2.3 million hectares is cultivated and classified as the irrigated croplands.

2.2 Physiography of the Rechna Doab

The area trends southwesternly to a topographic relief difference of 113 meters. The average slope is 0.37 m/km along the 390 km length of the Doab, which decreases by about 25 percent in the lower reaches. The Soil Survey of Pakistan has identified four distinct landforms on the basis of the degree of soil development, surface of configuration, and relative elevations. The first landforms are *bar uplands*, the oldest landforms comprising the flat-topped river terrace, locally known as Sandal Bar. The soil material for the bar uplands is predominantly medium-textured with a weak structure in the subsoil; moderately coarse material probably forms part of old lavee deposits. There are numerous patches of saline-alkali soils found with dense subsoil structure, low porosity and a strong kankar zone at a depth of one meter. The silt loam texture may be partly covered by sand deposits (IWASRI, 1988). The bar upland indicates elevated land beyond the reach of floodwater of the rivers.

The second landforms are *active flood plains*, which lie in the vicinity of the Ravi and Chenab rivers. The young and active flood plains stretch in a narrow belt along the rivers and comprise stratified silt loams to the very fine sandy loams to a depth of one meter that is underlain by sand. The third landforms are *abandoned flood* plains. The abandoned flood plains comprise the early holocene deposits of the rivers and occur in the Chenab Plain to the north and Kamalia Plain to the south. The soils in the Kamalia Plain are mostly silt loams with a weak subsoil structure and no kankar zone. The Chenab Plain has deeply developed loams and silt loams, with a sandy composition in undulating parts (suitable for dry-farming). The surface is generally leveled and lies above the present flood levels (Rehman *et al.*, 1997). The last landforms are the *Kirana Hills*, a minor feature when compared to the alluvial complex, but very prominent. The *piedmonts* exist in the northeast near the Jummu and Kashmir boundary (Khan 1978).

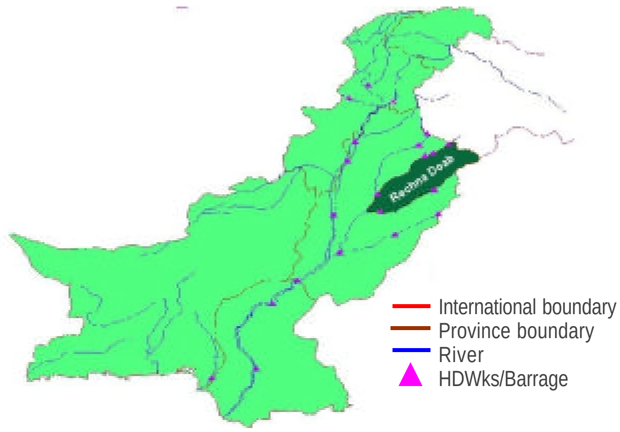

Figure 1. Hydrological layout of the Rechna Doab, Punjab, Pakistan

2.3 Area and Population

The total geographic area of the Rechna Doab (35,217 km^2) provides sustenance to 21.1 million population. About 25 percent of this area is situated in the Jhang District, and about 17, 16.6 and 10.28 percent falls in districts of Sheikhupura, Faisalabad and Gujranwala, respectively. The remaining area is distributed among districts of Sialkot, Toba Tek Singh, Narowal and Hafizabad, covering about 8.56, 9.23, 6.64 and 6.72 percent of the total area, respectively.

Table 1. Area and population of different districts in the Rechna Doab

Districts	Area (sq. km)	Distribution of area in the Rechna Doab (%)	Population (Million persons)	Distribution of population in the Rechna Doab (%)	Population density per sq. km
Faisalabad	5,856	16.63	5.341	25.31	912
Sheikhupura	5,959	16.92	3.232	15.32	542
Gujranwala	3,622	10.28	3.374	15.99	932
Jhang	8,809	25.01	2.804	13.29	318
Sialkot	3,016	8.56	2.689	12.74	892
Toba Tek Singh	3,252	9.23	1.59	7.54	489
Narowal	2,337	6.64	1.249	5.92	534
Hafizabad	2,366	6.72	0.822	3.90	347
Rechna Doab (Total)	35,217	100	21.101	100.00	599

Source: Government of Punjab (2000).

About 21.1 million people inhabit the Rechna Doab, with a population density of nearly 599 persons per square kilometer (Govt. of Punjab, 2000). Out of total population of the Rechna Doab, about 25 percent lives in Faisalabad, while 16 and 15 percent in Gujranwala and Sheikhupura, respectively. Other districts, such as Jhang, Sialkot, Toba Tek Singh, Narowal and Hafizabad have 13.29, 12.74, 7.6, 6 and 4 percent of the population, respectively. The population density of these districts is also presented in Table 1. The highest number of persons in one square kilometer of area resides in Faisalabad District; most of the population is concentrated in the Faisalabad City (center of agro-industrial activities), where 2.28 million persons lived in 1999 (Govt. of Punjab, 1999).

2.4 Climate

Temperature and rainfall are the most important climatic determinants and play a significant role in the conjunctive water management. The climate is characterized by large seasonal fluctuations of temperature and rainfall. The summer is hot, lasting from April through October with temperatures ranging between 21-50 ^{o}C.

During winter, usually considered as October-April period, daytime temperature ranges between 15-27 ^{o}C and it varies between 7-27 ^{o}C at night. The mean annual precipitation varies from 340 millimeters in the south to 1080 millimeters in the upper reaches of the Doab. Table 2 provides the quantum and temporal variability of rainfall at Faisalabad, Lahore, and Sialkot located within and close to the Rechna Doab, based on long-term average. Monsoonal rains (during July and August) contribute most, and constitute 53.4, 58.5 and 60 percent of total annual rainfall, respectively for Faisalabad, Lahore and Sialkot. Although, the amount and timing of rainfall is highly variable and inadequate, it has significant effects on the hydrology and agriculture of the area.

Table 2. Mean monthly rainfall in mm (1973-1997) at selected locations in and around the Rechna Doab

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Faisalabad	11.4	19.4	25.5	23.8	16.0	36.6	117.8	94.9	38.8	4.2	3.0	7.0	398.4
Lahore	25.1	33.5	42.9	23.6	22.2	53.3	218.4	212.9	69.7	15.9	7.2	12.7	737.4
Sialkot	41.3	48.1	56.8	33.9	28.4	71.2	318.2	347.8	106.6	18.4	10.7	27.5	1108.9

Source: Pakistan Meteorological Department, Regional Offices.

2.5 Soils

In the Rechna Doab, the soils are classified into five series based on vertical and horizontal textural variations, and are presented in Figure 2. The names and characteristics of the series are explained below:

Jhang: Coarse (sand and loamy sand)

The soils are very permeable, usually slightly calcareous, and seldom have a zone of lime accumulation. Owing to their coarseness, these soils are unlikely to build up higher levels of salinity or fertility.

Farida: Moderately Coarse (sandy loam and fine sandy loam)

These are the most extensive soils in the Rechna Doab. Derived from older alluvial deposits, they are generally found on smooth, nearly leveled topography. The surface is mildly calcareous, whereas the sub soils are moderately to highly calcareous. With a wide range of adoption, the fertility levels and organic matter can be readily built up.

Buchiana: Medium (loam, silt loam, and silt)

These soils have also been derived primarily from the older sediments. Being moderately permeable, they have well to high water holding Capacities that make them the most favorable soils for farming. Kankar zones are frequent in the upper substratum, particularly in areas where the watertable has fluctuated within the soils crust.

Nokhar: Fine (sandy clay, silty clay, and clay)

The substratum of these soils is commonly of moderate fine texture. The internal drainage is highly restricted and surface drainage features are unfavorable. Extent wise, they constitute only a small fraction of the Rechna Doab.

Chuharkana: Moderately fine (silty clay loam, sandy clay loam, clay loam)

This type of soil occurs across depressional or semi-depressional areas, and has compact substrata that support a rather narrow range of crop adoption. Because of limited drainability, the salinity hazard for these soils is much more pronounced, especially when accompanied by high watertables.

For the initial 15 centimeters of the soil strata representing the top root zone, surface soils show much more heterogeneity when compared to the series mentioned above.

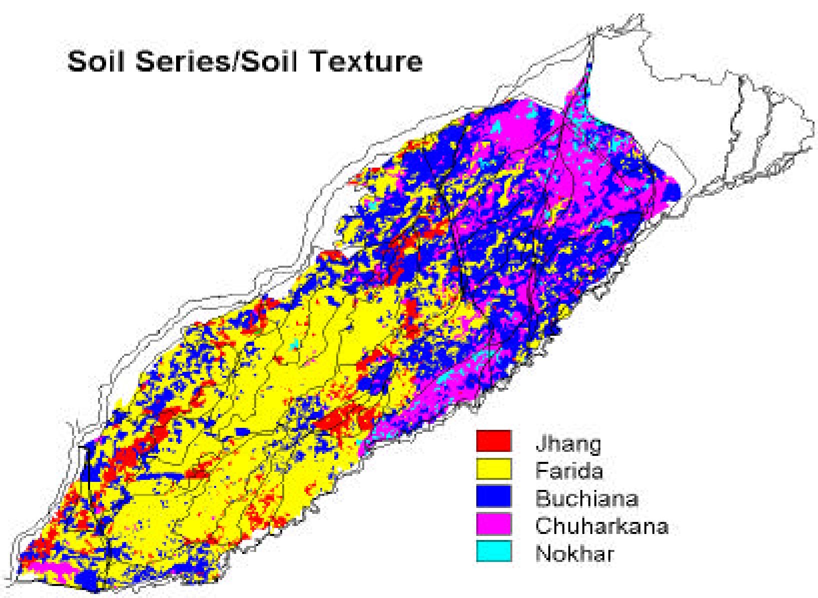

Figure 2. Spatial distribution of different soil series in the Rechna Doab

2.6 Geology

The consolidated exposed rocks near Chiniot, Sangla and Shahkot represent the remnants of the buried ridge of metamorphic or igneous origin forming the basement of the alluvial deposits in the Doab. The rocks are known as the Kirana Hills and are of the Pre-Cambrian age. These rocks cover the central part of the Rechna Doab, forming their longitudinal section across the width of the Doab. The alluvial fill was deposited in subsiding troughs by the ancestral and present tributaries to the Indus River (Khan, 1978). Overlying the Pre-Cambrian metamorphic or igneous rocks in the basement, the unconsolidated alluvial deposits are of the Pleistocene to recent age deposited through the continuing meandering flows of the river systems that developed in ancient times. The sediments in the upper part of the Doab consist of medium to fine sand, silt and clay. Gravel and coarse sand are uncommon. The origin of clays could not be identified specifically but these are presumed to be the repeatedly reworked loess deposits of the hills at the north and northwest. Though the alluvium complex is of a heterogeneous nature (thickness unknown), it forms a fairly transmissive unified aquifer. In some areas, the soils are fairly homogeneous containing high percentages of silt and fine to very fine sand; clay contents are higher only in depressional areas.

In the upper reaches of the Doab, the alluvial plain overlaps an older rock formation. The upper 200 meters, as described by Greenman *et al*, (1967), is composed of a thick sequence of alluvial sand, silt and clay that has been laid down since late tertiary time by the Indus River and its tributaries. Recurrent floods and frequent changes in the rate of flow caused the stream to meander back and forth across the land surface in a braided pattern of irregularly shifting channels.

The monotony of the alluvial plain is broken by scattered hills and bedrock outcrops near Chiniot, Sangla Hill and Shahkot in the Rechna Doab. The bedrock hills are projections of the northwest-trending Delhi-Shahpur (or Sargodha) ridge, which is largely buried by alluvium. The ancient crystalline rocks trend southeastward across the Rechna Doab, starting from near Sargodha and extending beneath Kirana, Chiniot, Sangla Hill, Shahkot and Mangtanwala. A number of isolated peaks on this ridge rise above the surface of the plain at Kirana, Chiniot, Sangla Hill and Shahkot. The bedrock surface declines sharply to the northeast of the ridge (Upper Rechna area) as indicated by a test hole near Sheikhupura, which gave a depth of about 460 meters without reaching bedrock. In the southwestward (Lower Rechna area), the surface of the ridge slopes more gradually, and test holes from 275 to 460 meters deep near the ends of the Rechna Doab failed to reach bedrock (Aslam, 1997).

Hence, the groundwater in the Rechna Doab occurs in two basins at larger depths separated by the buried ridge. The maximum thickness of the alluvium is not known. Logs of test wells show that everywhere the thickness of alluvium is nearly 185/190 meters or more. The basement rocks are impermeable and define the lower limit of the groundwater reservoir.

2.7 Aquifer Characterization

The underlying deposits in the Rechna Doab have little vertical or horizontal continuity. The bulk of the alluvium is composed of silt and fine sand, or a mixture with an absence of thick layers of pure clay. The material is highly porous and capable of storing and transmitting water readily. The horizontal permeability is greater than vertical (Bennett *et al.*, 1967). In upper reaches of the Doab, the alluvial complex consists principally of fine to medium sand, silt and clay. The porosity of the water-bearing material ranges from 35 to 45 percent with an average specific yield of about 14 percent. The uniformity coefficient varies between 2.5 and 5 (Rehman *et al*., 1997).

The alluvial sediments mainly consist of gray and grayish-brown fine to medium sand, silty sand, silt and clay. Gravel and very coarse sand are uncommon; Kankar, a calcium carbonate material of secondary origin, is found associated with fine-grained strata. Pure clay is generally found in lenses. The origin of clay has not been ascertained, but presumably, it is repeatedly reworked loess. Of the alluvial complex, sand forms the areas of fairly transmissive aquifer material in which groundwater occurs under watertable conditions (Khan 1978).

The inter-fluvial region of the Rechna Doab is flat with little natural drainage, and is underlain by a deep, unconfined, high-yielding aquifer that is relatively homogeneous and highly anisotropic. Benenett *et al.* (1967) provided a detailed hydrologic description of the aquifer. They give mean values of the hydraulic conductivities as 1.2E-3 m/s and 1.5E-5 m/s in the horizontal and vertical directions, respectively. The much lower vertical permeability is due to the presence of clay layers in an otherwise fairly coarse sandy aquifer. The specific yields with the watertable in the sand layer and the clay layer are 0.15 and 0.06, respectively. It is desirable, therefore, to install tubewells so that the screen length will not fall within the thick clay layers. Despite the anisotropic nature of the alluvium that prevents the regional movement of water across different depths of aquifer, tubewells can be operated anywhere with specific drawdowns with the average of 4.6 centimeters/lps.

Although the alluvium may locally contain large proportions of silt and silt clay, the occurrence of these deposits is generally in the form of thin lenticular beds. Generally, lenses of clay, silt and silty-sand compose about 25 to 35 percent of the entire bulk of alluvium. These finely grained deposits of low permeability are generally discontinuous so that beds of sand constituting the remaining 65 to 75 percent of the alluvium serve as a unified highly transmissive aquifer (Mundorff *et al.,* 1976). Groundwater in the alluvial aquifer is generally unconfined. However, because of the random distribution of clayey strata, the aquifer is anisotropic and lateral permeability is generally much greater than vertical permeability.

The water-bearing characteristics of the alluvial aquifer were evaluated by about 140 pumping tests in the Punjab province. These tests produced information on specific yield, lateral or radial hydraulic conductivity and vertical hydraulic conductivity. Based on pumping tests, the specific yield of the unconfined aquifer ranges from 1 to 42 percent with an average value of 14 percent. Specific yield determinations in these tests for material un-watered at the watertable were generally 3 to 8 meters below the land surface. Horizontal permeability of the material in the screened zones ranges from 3E-4 to 2E-3 m/s. In areas having less permeable alluvium, the range is from less than 3E-4 to 6E-4.

The results of 49 sites in the Rechna Doab gave an average value of lateral permeability of 1.16E-3 meters per second. In majority of the cases, the average permeability ranges from 3E-4 to 1.83E-3 m/s. About 69 percent of the sites gave a range of permeability from 7.62E-4 m/s to 1.92E-3 m/s. Vertical hydraulic conductivities determined at 14 sites range from 3E-6 m/s to 1.28E-4 m/s (Bennett *et al.*, 1967). The average value of vertical hydraulic conductivity for an aquifer site at Chuharkana was about 1.46E-5 m/s. Anisotropy ratios (lateral to vertical hydraulic conductivities) at all 15 sites range from 3:1 to 195:1. Excluding the three highest and two lowest values, the remaining two-thirds range from 15:1 to 90:1 with an average value of about 55:1 (Mundorff *et al.* 1976).

Khan (1978) has summarized the results of pumping tests and lithological, mechanical and water quality analyses of test holes and wells conducted for the Rechna Doab area based on the pumping test data of 47 test wells. The range and mean hydraulic conductivity and specific yield values in three irrigation circles are given in Table 3.

Table 3. The aquifer characteristics in the Rechna Doab area

Irrigation Canal Circles	Number of Test well	Hydraulic conductivity (m/s)		Specific Yield (%)	
		Range	Mean	Range	Mean
Upper Chenab Canal Circle	16	3.05E-04-1.52E-03	9.14E-04	0.01-0.22	0.082
Lower Chenab Canal East Circle	21	6.10E-04-3.05E-03	1.22E-03	0.06-0.33	0.175
Lower Chenab Canal West Circle	10	3.05E-04-2.13E-03	1.22E-03	0.06-0.29	0.129

3. SURFACE WATER RESOURCES

The gravity flow of surface water through canal supplies in the Rechna Doab area constitutes a major portion of the total water available for weir-controlled irrigated agriculture. The supplies are conveyed to almost every part of the Rechna Doab through a contiguous network of elevated main and branch canals, distributaries, minors and watercourses. Also, there are four major link canals, which supply and transmit surface water through the Rechna Doab area to the eastern rivers (Ravi and Sutlej) of the Punjab province. The length of the main, branch and link canals within the Rechna Doab is more than 1,100 kilometers. The schematic diagram of the irrigation network in the Rechna Doab is shown in Figure 3.

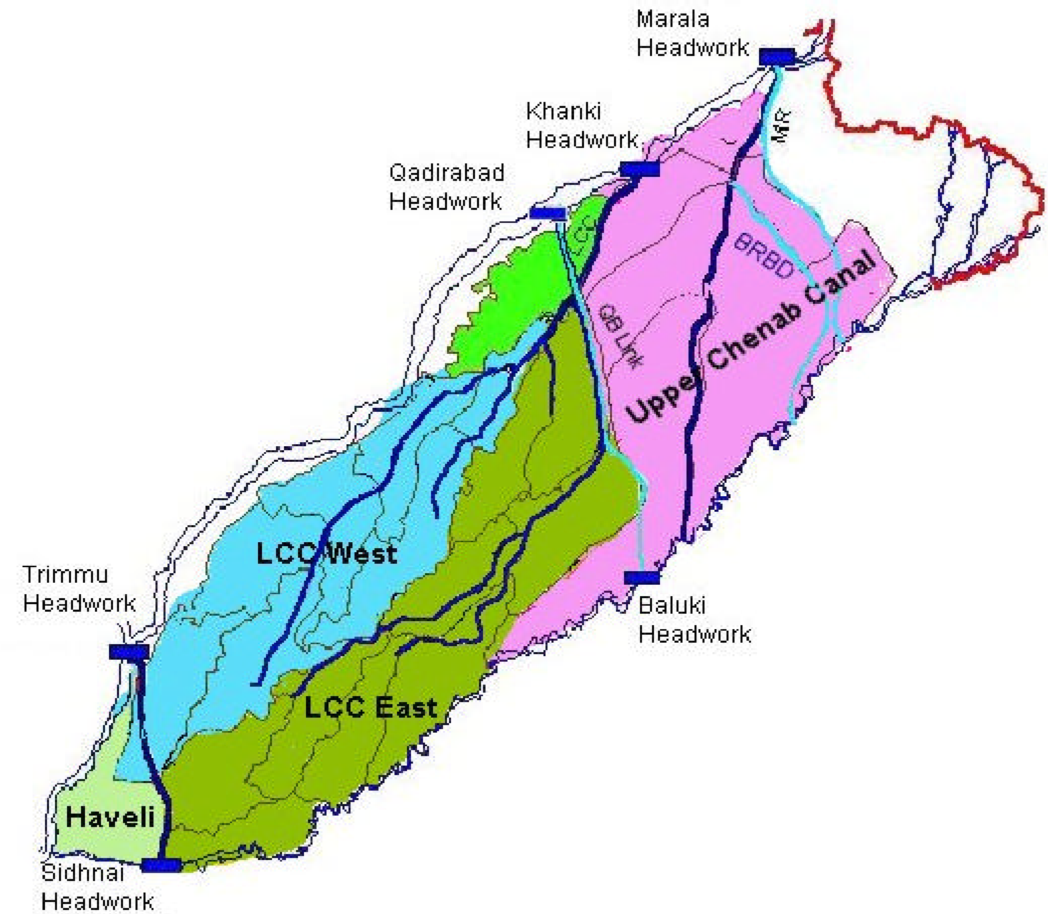

Figure 3. The schematic diagram of irrigation network in the Rechna Doab

3.1 Rivers along the Rechna Doab Boundary

The Chenab and Ravi rivers bound the wedge-shaped Rechna Doab area. The flows of the Chenab and Ravi rivers are regulated at six major headworks to ensure adequate irrigation supplies to the Rechna Doab area and other areas of the Indus Basin. A headworks is a collective term for all works (weir or diversion dams, head regulators and their appurtenant structures) required at intakes of main or principal canals to divert and control river flows and to regulate water supplies into the main canals.

Chenab River enters Pakistan in the Sialkot District, constitutes the northwestern boundary and supplies surface water to the main and link canals of the Rechna Doab area. Four headworks, Marala, Khanki, Qadirabad and Trimmu on the Chenab River are located along the course of the river in the same order to ensure diversions to the main and link canals of the Rechna Doab area. Also, along the course of the Chenab River, the Upper Jhelum Canal (UJC) outflows between the Marala and Khanki Headworks. The Rasul-Qadirabad Link Canal feeds water to it at Qadirabad Headworks, the Jhelum River joins above at the Trimmu Headworks, while Ravi River meets about 64.4 kilometers further downstream of the Trimmu Headworks at the lower tip of the Rechna Doab area.

The average monthly flows in the Chenab River at four headworks for the water year 1994-95 (April to March) are given in Table 4. Annually, the average minimum, maximum and mean flows (cumecs) in the Chenab River above the Marala Headworks are 225, 3465 and 1172, respectively, while below the Trimmu Headworks these are 0, 3916, and 936, respectively. Hence, surface water supplies of 236 cumecs from the Chenab River and outflows from the Jhelum River, and Rasul-Qadirabad Link Canal are utilized and transmitted through and along the northwestern boundary of the Rechna Doab.

Balloki and Sidhnai Headworks on the Ravi River receive and ensure surface water for the river flow and the other parts of the Indus Basin. The average monthly flows in the Ravi River at two headworks for the water year 1994-95 are given in Table 5. The annual average minimum, maximum and mean flows in the Ravi River above the Balloki Headworks are 471, 1942, and 803 cumecs, respectively, while below the Sidhnai Headworks these are 0, 1352 and 251 cumecs.

The Marala Headworks on the Chenab River and the Balloki Headworks on the Ravi River constitute the rim stations for the respective rivers. A rim station on a river is the first gauging station for estimating and ensuring the availability of flow in the river (Ahmed, 1988).

Table 4. The average monthly flows (cumecs) in the Chenab River

Headwork		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Marala	Above	466	947	1797	3465	3275	1459	424	225	357	369	638	636
	Below	216	541	1168	2922	2783	911	111	57	217	356	444	414
Khanki	Above	346	625	1274	3760	3608	1252	230	200	310	511	531	417
	Below	171	433	1045	3544	3373	1013	6	0	119	422	453	241
Qadirabad	Above	673	940	1407	3834	3599	1136	491	487	487	427	870	858
	Below	143	342	821	2435	3053	577	0	0	54	270	392	425
Trimmu	Above	414	943	1061	3736	4137	1535	369	195	306	828	537	602
	Below	174	537	585	3355	3916	1332	9	0	72	691	211	346

Source: (WAPDA (1996)

Table 5. The average monthly flows (cumecs) in the Ravi River

Headwork		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Balloki	Above	594	820	880	1493	1942	1080	548	483	471	195	610	524
	Below	17	99	57	696	1348	513	0	0	18	105	125	14
Sidhnai	Above	258	394	378	889	1755	957	337	199	245	245	371	283
	Below	19	43	0	584	1352	605	1	0	13	175	138	80

Source: WAPDA (1996)

3.2 Main and Link Canals

Two main canals and four link canals off-taking from the Chenab River irrigate a gross land area of 2.98 million hectares between the two rivers and transmit water to other parts of the Indus Basin. The Upper and Lower Chenab canals are the main canals, off-taking at the Marala and Khanki Head-works, respectively. The four link canals are Marala-Ravi (MR), Qadirabad-Balloki (QB), Trimmu-Sidhnai (TS) and Haveli. Also, Bambanwala-Ravi-Bedian-Depalpur (BRBD) Canal, a branch canal from the Upper Chenab Main Canal, transmits its larger volume of water to the eastern Punjab areas. The irrigated area commanded by a link canal within the Rechna Doab is designated as internal.

Within the Doab, a total of 2.39 million hectares are under perennial supplies (year-round water supplies, except for a one-month closure during the mid-*Rabi* season) and non-perennial supplies (during the *Kharif* season only). In the Rechna Doab, most of the non-perennial irrigation supplies are restricted to the commands of the Upper Chenab Canal (UCC), the Marala-Ravi Internal and the Haveli Internal. The Punjab Irrigation and Power Department have divided the irrigated areas of the Rechna Doab into three major administrative circles of Lahore and Faisalabad irrigation zones: Upper Chenab Canal Circle, Lower Chenab Canal East Circle and Lower Chenab Canal West Circle. The Rechna Doab area below TS/Haveli Link canals is designated as the Haveli Internal and it is within the jurisdiction of the Haveli Circle of the Multan Irrigation zone (Haq, 1998).

3.2.1 Upper Chenab Canal, BRBD and MR Link Canals

The two main canals fulfill most of the irrigation needs and sustain irrigated agriculture in the Rechna Doab area. The Upper Chenab Canal (UCC) commands the majority of the area between the Marala Ravi and Qadirabad-Balloki Link Canals and a small area below the Qadirabad-Balloki Link Canal along the Ravi River. The area is popularly termed as the Upper Rechna Doab and is administratively within the Upper Chenab Canal Circle of the Lahore Irrigation Zone in districts of Sheikhupura, Gujranwala, Narowal and Sialkot.

The UCC runs almost diagonal in this area before conveying some of its water to the Ravi River upstream of the fall of QB Link Canal at the Balloki headworks on the river. The UCC has been operating in the Upper Rechna Doab area since 1915. The UCC was constructed under the Triple Canal Project during 1905-15 (Upper Jhelum and Lower Bari Doab canals were the other two) by the then British-ruled Indian Government in this part of the subcontinent (Ahmed, 1988). The design discharge of the UCC is 467 cumecs and covers a canal command area of 0.59 million hectares (Ahmed, 1988). The UCC runs on perennial basis, but the extra the command area is not served on perennial basis because of the irrigation water requirements in other parts of the Indus Basin and relatively fresh groundwater availability in the area.

The UCC at 40.6 kilometer downstream of its head divides into the Nokhar Branch, the BRBD Link Canal (formerly the Raya Branch) and the Main line, Lower of UCC to fulfill irrigation needs of the Upper Rechna Doab area. The Raya Branch of the UCC was rehabilitated in 1948 to carry additional flows towards the eastern Punjab area in the wake of stoppage flows of rivers feeding water to the area through the Central Bari Doab and Sutlej Valley canals by India (Ahmed, 1988). The branch canal widened at Bambanwala, crossed the Ravi River through a siphon and carried water to Bedian and Depalpur canals. Hence, a new name Bambanwala-Ravi-Bedian-Depalpur (BRBD) Link Canal was given to the Raya Branch. The BRBD canal receives supplies through the UCC at RD 40.6 kilometers and is further fed through sub-link canal off the MR Link Canal, which meets BRBD at about RD 56 kilometers. The total length of BRBD canal is about 164 kilometers and it carries a flow of 118 cumecs at the head and gets additional 57 cumecs from the MR Link Canal. The BRBD Link Canal irrigates 0.194 million hectares of the Upper Rechna Doab area through a network of distributaries, minors and watercourses before conveying water to the eastern Punjab areas.

The MR Link also irrigates 0.071 million hectares of the Upper Rechna Doab area before conveying flows to the BRBD Link Canal and the Ravi River. The MR Link Canal is a 101 kilometers long unlined channel constructed during 1954-56 to convey water to the Ravi River, for onward transmission to the Sutlej River at Sulemanki through the Balloki-Sulemanki Link Canal. The MR Link Canal carries a flow of 637 cumecs to irrigate part of the Upper Rechna Doab area and transfer water to the BRBD Link Canal and the Ravi River. The historical monthly average discharge rates (cumecs) of the UCC, MR and BRBD Link canals for the water year 1994-95 are given in Table 6.

Table 6. The average monthly flows (cumecs) of the MR, UCC and BRBD Link canals

Link canals	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
MR	9.44	164.25	329.45	245.44	182.19	256.77	19.82	0.00	0.00	0.00	0.00	0.00
Sub-Link BRBD	0.00	0.00	56.64	66.08	56.64	26.43	13.22	0.00	0.00	0.00	0.00	0.00
UCC	240.72	242.61	300.19	298.30	310.57	291.69	292.64	168.03	139.71	13.22	193.52	221.84
BRBD	77.41	75.52	108.56	115.17	118.00	111.39	108.56	76.46	65.14	1.89	55.70	62.30

Source: WAPDA (1996)

a) Upper Chenab Canal (UCC) Circle

The areas irrigated by the UCC, BRBD and MR Link Canals are within the jurisdiction of the UCC Circle. Administratively, the UCC Circle is further divided into three divisions, each containing two to four subdivisions for the operation and maintenance of the irrigation network. The division and subdivision-wise salient features, in terms of culturable command area (CCA, in hectare), the number of distributaries and minors (channels), number of watercourses (outlets), discharges (Q, in cubic meters per second), and discharge per thousand hectares of CCA (Q_{1000}) in the UCC Circle are given in Table 7.

Table 7. The division and subdivision-wise salient features of the Upper Chenab Canal Circle

Division/Subdivision	CCA (ha)	Channels	Outlets	Q (cumecs)	Q_{1000} (cumecs)
Marala Division	114745	35	775	68.93	0.60
Malhi Subdivision	33905	21	325	23.02	0.68
Nokhar Subdivision	80840	14	450	45.91	0.57
Gujranwala Division	276195	83	2123	134.28	0.49
Sadhoke Subdivision	64940	24	648	31.53	0.49
Gujranwala Subdivision	94757	23	601	37.42	0.39
Shahdara Subdivision	42685	17	405	25.29	0.59
Muridke Subdivision	73813	19	469	40.04	0.54
Sheikhupura Division	220015	55	1176	113.58	0.52
Sikhanwala Subdivision	41738	13	139	21.04	0.50
Sheikhupura Subdivision	46512	14	321	31.53	0.68
Noushera Subdivision	71299	18	402	26.96	0.38
Mangtanwala Subdivision	60466	10	314	34.05	0.56
UCC Circle	610955	173	4074	316.78	0.52

Source: Upper Chenab Canal Circle, (Punjab Irrigation Department, 1997)

3.2.2 Lower Chenab Canal, QB, TS and Haveli Link Canals

The Lower Chenab Canal (LCC) is the second (older and larger) of the two main canals in the Rechna Doab area. The LCC off-takes from the Chenab River at the Khanki headworks. It covers the entire area between QB and TS Link canals and some of the area above the QB Link Canal along the Chenab River and below the TS Link canal. The LCC was planned, constructed and initiated as weir-controlled canal-irrigated agriculture in the late nineteenth century. It is the third oldest canal in the Punjab province; the Central Bari Doab and Sidhnai canals are the other two canals, which were constructed before the LCC. Over the course of time, the LCC was remodeled for enhanced capacity, coverage and scope from non-perennial to perennial. Presently, it commands a gross area of 1.42 million hectares and has the capacity to carry flows of 376 cumecs through the Khanki Headworks and additional 116 cumecs through the sub-link from the QB Link Canal. The LCC is divided into two commands. Administratively, these commands are known as the Lower Chenab Canal East Circle and Lower Chenab Canal West Circle.

The QB Link Canal off-taking from the Qadirabad Headworks on the Chenab River was constructed and opened in mid 1960s to transmit a supply of 527 cumecs to the Ravi River at Balloki Headworks and to the LCC through a sub-link canal. The canal is about 130 kilometers long, and was constructed under the second phase of the Indus Basin Resettlement Plan as a result of the Indus Water Treaty in 1960 (Ahmed, 1988). The TS and Haveli Link canals off-take from the Trimmu Headworks on the Chenab River below the confluence of the Jhelum River and are aligned parallel to supply flows to the Ravi River at Sidhnai for onward transmission to other parts of the Indus Basin. The TS Link Canal is about 70 kilometers in length and has a carrying flow capacity of 312 cumecs. It was constructed and opened in the early-1960s under the first phase of the Indus Basin Resettlement Plan (Ahmed, 1988). The Haveli Link Canal was constructed and opened in the late 1930s to supply the Sidhnai Canal off-taking from the Sidhnai Headworks. It has the capacity to carry 140 cumecs to supply flows to the Ravi River and command an internal area of about 80,000 hectares. The historical monthly average discharges (cumecs) of the LCC, QB, TS and Haveli Link canals for the water year 1994-95 are given in Table 8.

Table 8. The average monthly flows (cumecs) of the LCC, QB, TS and Haveli Link canals

Link Canals	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
LCC	175.58	192.57	228.45	216.17	235.05	238.83	224.67	200.13	191.63	89.68	78.35	175.58
QB	529.58	597.55	587.16	550.35	546.57	558.84	491.82	487.10	433.29	157.65	477.66	433.29
Sub-Link LCC	108.56	105.73	102.90	97.23	99.12	105.73	115.17	111.39	91.57	0.94	86.85	115.17
TS	118.00	244.49	291.69	212.40	91.57	67.02	203.90	67.97	99.12	51.92	204.85	138.77
Haveli	122.72	135.93	145.37	130.27	84.02	94.40	133.10	127.44	127.44	36.82	103.84	117.06

Source: WAPDA (1996)

a) Lower Chenab Canal (LCC) East Circle

The LCC East Circle area borders Ravi River in the eastern portion. It is located between the QB and TS Link canals. The LCC East Circle comprises the Mian Ali Branch Canal, Upper Gugera Branch Canal, its off-taking branches, Lower Gugera and Burala Branch canals, and a huge network of distributaries, minors and watercourses. The circle has a gross and culturable command area of 0.803 and 0.622 million hectares, respectively, in the Hafizabad, Sheikhupura, Faisalabad and Toba Tek Singh districts. The circle has been selected for constitution of the Area Water Board (AWB) on a pilot basis, under the newly launched institutional reform implementation of the National Drainage Program. The circle is divided into three divisions, each containing three subdivisions, for the management of the irrigation network. The salient features of the LCC East Circle are given in Table 9.

Table 9. The division and subdivision-wise salient features of the Lower Chenab Canal East Circle

Division/Subdivision	GCA (ha)	CCA (ha)	Channels	Outlets	Q (cumec)	Q_{1000} (cumec)
Upper Gugera Division	288219	230631	60	1127	45.64	0.20
Chuharkana Subdivision	97417	70064	16	329	12.45	0.18
Mohlan Subdivision	112694	89538	25	437	17.59	0.20
Paccadala Subdivision	78108	71029	19	361	15.60	0.22
Lower Gugera Division	265786	206413	58	1046	46.93	0.23
Bhagat Subdivision	96394	75167	19	389	17.33	0.23
Buchiana Subdivision	81151	64178	21	302	13.10	0.20
Tarkhani Subdivision	88240	67068	18	355	16.50	0.25
Burala Division	248981	185390	64	960	47.07	0.25
Kanya Subdivision	77473	56114	15	302	13.05	0.23
Sultanpur Subdivision	60629	44524	14	219	11.27	0.25
Tandlianwala Subdivision	110879	84752	35	439	22.75	0.27
LCC East Circle	802986	622434	182	3133	139.64	0.22

b) Lower Chenab Canal (LCC) West Circle

The LCC West Circle borders the Chenab River on its western side. It covers a large area between QB and TS Link canals and a small area below TS/Haveli Link canals. The circle comprises Rakh Branch Canal, Jhang branch along with its Bhowana branch, and a large network of distributaries, minors and watercourses. The circle has a gross and culturable command area of 0.759 and 0.586 million hectares, respectively, in the Hafizabad, Faisalabad, and Jhang districts**.** The LCC West Circle is also divided into three divisions, each containing two to three subdivisions, for the irrigation network management. The division and subdivision-wise salient features of the circle are given in Table 10.

Table 10. The division and subdivision-wise salient features of the Lower Chenab Canal West Circle

Division/Subdivision	GCA (ha)	CCA (ha)	Channels	Outlets	Q (cumec)	Q_{1000} (cumec)
Faisalabad Division	173731	129393	54	870	27.19	0.20
Kot Khudayar Subdivision	81252	51289	27	405	13.81	0.27
Aminpur Subdivision	92479	78104	27	465	13.38	0.17
Hafizabad Division	170663	138547	40	766	29.34	0.21
Sangla Subdivision	51610	40225	20	246	7.07	0.18
Uqbana Subdivision	119053	98322	20	520	22.27	0.17
Jhang Division	299890	224620	75	1074	51.99	0.23
Dhaular Subdivision	98000	66012	25	379	10.73	0.16
Veryam Subdivision	108122	94924	26	382	24.39	0.26
Wer Subdivision	93768	63684	24	313	16.87	0.27
Khanki Division	115014	93565	31	485	27.1	0.29
Sagar Subdivision	115014	93565	31	485	27.1	0.29
LCC West Circle	759298	586125	200	3195	135.62	0.23

Sources: Rehman *et al*. (1997) and Ashraf and Khan (1984)

c) Haveli Internal

The triangular area between the TS/Haveli Link canals and the confluence of the Ravi and Chenab rivers is designated as the Haveli Internal. The area is under the administrative control of the Haveli Circle of Multan Irrigation Zone in districts of Khanewal and Jhang. A network of distributaries, minors and watercourses from the Haveli Link Canal commands both perennial and non-perennial areas.

The gross and culturable command areas are 81,384 and 73,250 hectares, respectively, with an allocation of 24 cumecs, i.e. 0.34 cumecs per thousand hectares of CCA (Ashraf and Khan, 1984). Also, the commands along the Ravi River are siphon-irrigated by the Koranga Channel of the Lower Bari Doab Canal. A looped spillway channel also exists to divert the high flood flows in the Ravi River at Sidhnai.

4. GROUNDWATER RESOURCES

Surface water supplies are available through irrigation canals but these supplies are usually insufficient, and therefore, farmers have to pump groundwater to supplement the canal water in the fresh groundwater areas. Farmers suffer irrigation water scarcity in the saline groundwater areas. Sometimes, they lose their crops due to prolonged dry spells. Rainfall in the lower parts of the Rechna Doab is infrequent and also inadequate. Therefore, farmers never rely on rainfall in these areas. Similarly, drain water availability is also unreliable and needs extra energy arrangements for uplifting the irrigation supplies and have quality limitations also.

The groundwater storage underlying the Rechna Doab represents a tremendous resource. The total storage capacity is equivalent to more than twenty Tarbela reservoirs. The upper 100 feet of saturated soil represents 3-4 times the combined storage of the Tarbela and Mangla reservoirs. The alluvial material in the Rechna Doab forms part of the extensive heterogeneous and anisotropic unconfined groundwater reservoir underlying the Indus Plain with the depth of more than 300 meters. The underlying deposits have little vertical or horizontal continuity. The bulk of alluvium is composed of silt and fine sand, or mixtures with an absence of thick layers of pure clay. The material is highly porous and is capable of storing and transmitting water readily.

The replenishment of the Rechna Doab Groundwater reservoir takes place by infiltration of river water, by leakage from canals and by percolation of rain, especially in the upper parts of the Doab where rainfall is relatively high. The groundwater is being developed on a large scale by means of tubewells due to highly permeable unconfined groundwater aquifer of the Indus Plain.

The use of groundwater for irrigated agriculture in Pakistan has a long history. In early days, the groundwater abstraction was made by means of open wells with rope and bucket, Persian wheels, karezes, reciprocation pumps and hand pumps. Large-scale pumpage and use of groundwater for irrigated agriculture in the Indus Basin started during 1960s with the launching of Salinity Control and Reclamation Projects (SCARPs). Thousands of large capacity tubewells were installed to control groundwater table and supplement irrigation supplies. This demonstration also led to a proliferation of private tubewells with a capacity of about one cusec (0.028 m^3/s) and lesser by farmers in the 1970s and 1980s. Subsidized supply and introduction of country-made diesel engines provide an impetus for dramatic increase in the number of private tubewells from 10,000 in 1960 to half a million, approximately, in 2000 (PPSGDP, 2000).

About 70 percent of the private tubewells are located in the canal command areas while the rest provides groundwater-based irrigation. Presently, the density of private tubewells is one tubewell for 22 hectares. Growth of private tubewells in the past has not been uniform and there have been jumps in mid 80s and mid 90s. The present growth rate of private tubewells is about 5 percent per year and annual increase in groundwater withdrawal is 1.2: BCM. Operating factor of these tubewells ranges from around 2 percent to 25 percent depending upon the availability of canal water and cropping intensity of individual farmers. Generally, the small farmers have higher rate of cropping intensity (PPSGDP, 2000).

Salinity of these groundwater supplies varies widely with tubewells being too saline for irrigation. For good quality groundwater, tubewells serve the dual purpose of alleviating waterlogging and supplementing the canal water supply. The rapid development of private tubewells indicates farmers' heavy dependence on pumped groundwater for their crop production. Most of the tubewells pump marginal to poor quality groundwater (Aslam, 1997).

The development of private tubewells in the Rechna Doab started in mid 60s. In the beginning, private tubewell development was slow but an explosive increase took place during 1980s. Pumping from the private tubewells lowered the watertable and increased water supply significantly. The rapidly growing exploitation of groundwater for irrigation by private tubewells greatly enhanced the vertical drainage of the public tubewells. Majority of tubewells in the LCC command system pumped marginal to hazardous quality groundwater, causing a gradual build-up of salinity/sodicity in the soil profile and rendering the agricultural lands unproductive. Though, there has been tremendous growth in private tubewell development, data on the operation and water quality of pumped water is not being collected by any government agency. There is no institutional arrangement for the management of groundwater development in the private sector.

4.1 Groundwater Quality

The variation in lithology imparts a wide range of hydraulic properties and different chemical characteristics to groundwater. The wells, screened opposite the most permeable sand lenses, may pump water of different chemical qualities from different horizons. Groundwater discharge from each well is a mixture from several water-bearing zones and represents the average water quality imposed by local geological conditions, rate of pumping and hydraulic characteristics. The sampling from wells distributed over the aquifer do not necessarily indicate the upper or lower limits of TDS concentrations, but in general, show the distribution pattern of water quality in the upper few hundred meters of the groundwater reservoir affected by pumping. The aerial and vertical distribution of fresh and saline groundwater in the Rechna Doab is principally the result of circulation in the reservoir. The flow of the groundwater from areas of recharge to areas of discharge is three-dimensional along curvilinear flow paths controlled by vertical differences in the hydraulic head. The dissolution of the chemical constituents in groundwater is dependent upon: the composition of the material through which it moves; the residence time that the water is in the aquifer; the length of the flow path; water temperature; and the chemical composition of the recharge. The dissolution is also dependent upon the base exchange and the adsorption of dissolved ions amongst themselves.

Studies by Swarzenski (1968) pointed out that the boundaries between saline and fresh water are not sharp; rather mineralization gradually increases with depth and distance from sources of recharge. Neither fresh nor saline groundwater can be defined as separate and distinct bodies in terms of their stratigraphic positions. Recharge from canal seepage and infiltration of irrigation water has superficially modified the vertical and aerial distribution of fresh and saline groundwater bodies that existed in the pre-irrigation period. Canal seepage locally diluted brackish groundwater and increased circulation, which created lenses underneath. However, the impact of this change has not been uniform along the canals due to stratification and anisotropic conditions

Other modifications in the distribution patterns of saline and fresh water are due to the disproportionately large evaporation losses by irrigation practices and waterlogging problems. In areas where the watertable rises to or is near the land surface, evaporation has increased the mineralization of groundwater at shallow depths, whereby it is common to find water of relatively poor quality overlying water of better quality. Flow net changes due to increased pumpage have locally induced the inflow of brackish water towards pumping centers. The increased circulation, particularly in the vicinity of canals, gradually decreased the mineralization of groundwater that resulted in a more homogeneous composition. While hydrologic equilibrium gets re-established, it is less likely to happen for chemical equilibrium.

Water quality samples were collected from the test holes up to the depth of 300 to 350 feet (92-107 meters) and tubewells of already implemented SCARPs I and IV. The data on groundwater quality indicated generally good quality in the upper part of the Doab and along the rivers but deteriorating down the Doab and with the distance from the rivers in the lower part of the Doab. In saline areas, the total dissolved solids exceeds 10,000 parts per million (ppm) in areas generally covered under the bar upland forming quite a sizeable portion of the Rechna Doab (Khan, 1978).

Groundwater of good quality is found in the upper parts of the Doab and in a 24 to 48 kilometers wide belt along the flood plains of the Chenab and Ravi rivers. Highly saline groundwater is found in the lower and central parts of the Doab. The Upper Rechna contains fresh water of 500 ppm but in the central and lower portions, groundwater salinity concentration varies from 3,000 to 18,000 ppm. In the central and lower parts of the Doab, most of the tubewells are pumping marginal to poor quality groundwater, especially at the tail ends of the canal irrigation system where the farmers are heavily dependent upon tubewell irrigation. Past research on tubewell operation and the quality of pumped water in the LCC system of the Rechna Doab shows that all tubewells in the watercourse commands of the Lagar Distributary pump poor quality groundwater, which is unfit for irrigation. The prevailing rate of installation and use of tubewell water may cause problems relating to the over-exploitation of the fresh groundwater reservoir, salt imbalance-buildup of salinity/sodicity. The result is an increase in unproductive lands, extra costs for groundwater quality improvement and salinized soils reclamation, and permanent up-coning of saline groundwater.

Based on the chemical analysis of groundwater samples taken from various depths within the groundwater reservoir, the salinity concentrations of groundwater increase with the depth in most cases. This implies that a vertical salinity gradient exists in the aquifer of the Rechna Doab. The salinity of groundwater samples taken from the useable groundwater zone (TDS < 3,000 ppm) ranges from 400 to 600 ppm up to the depth of 155 meters in most cases. In the saline groundwater zone (TDS ≥ 3,000 ppm), the high salinity starts at a shallow depth of 30 meters. Within the top 30 meters, only two sites show groundwater up to 500 ppm, but deeper water up to 110 meters is generally highly saline. In 1960, about 1500 shallow (6 to 18 meters below the ground surface) groundwater samples were collected and analyzed to evaluate the salinity in the Rechna Doab. This analysis showed that about 49 percent of samples contained salinity of 750 ppm, 39 percent varied in salinity from 751 to 1,500 ppm, 10 percent varied from 1,501 to 3,000 ppm and 3 percent was above 3,000 ppm.

Monitoring the groundwater quality of completed SCARPs tubewells and private tubewells in the Rechna Doab area has been a continued activity. The reported groundwater qualities of both shallow and deep horizons under various monitoring programs, surveys and inventories are summarized in tables 11 to 15. The groundwater quality is analyzed at the subdivision level in these tables wherever possible. Table 14 provides shallow and deep groundwater quality data for various schemes of SCARP-I, which are mostly located in the upper reaches of the Lower Chenab Canal Command covering the complete or a portion of the subdivisions of the east and west circles. Some subdivisions of the Upper Chenab Canal Circle are also partly covered by the SCARP-I.

Table 11. SCARPs Monitoring Organization data/IWMI's distributary-wise survey on tubewell water quality

Scheme	Year	Number of TW	EC in MicroS/cm	Distributary Command	Year	Number of TW	EC in MicrosS/cm	
SCARP-I	1960-89	2074					Range	Mean
	1960-89	500	1000-4000	Lagar	1988	202	480-3000	-
	1960-89	53	1500-4000		1988	72	1500-3000	-
SCARP-IV	1975-89	952	650-1600		1988	11	800-1500	1156
SCARP-V SKPP	1975	101			1995	13	690-1910	1108
SCARP-V SKPP	1975	11	350-1100	Mananwala	1990	168	350-3000	-
SCARP-V SPP	1981-86	40	1600-6200		1990	75	1500-3000	-
				Pir Mahal	1992	37	270-1500	-
				Junejwala Minor	1992	68	760-3000	-
					1992	21	1500-3000	-

Table 12. IWMI's subdivision-wise groundwater quality sample survey in 1995 of the Lower Chenab Canal (LCC) command

Division/ Subdivision	Number of TW		EC in microS/cm		Division/ Subdivision	Number of TW		EC in microS/cm	
	Private	Public	Range	Mean		Private	Public	Range	Mean
Upper Gugera Division	24	1	540-4050	1644	**Faisalabad Division**	14	-	380-2590	1161
Chauharkana	11	1	540-2200	1284	Aminpur	3	-	380-2590	1523
Mohlan	10	-	970-4050	2179	Kot Khuda Yar	11	-	440-2190	1063
Paccadala	3	-	1000-1500	1303	**Hafizabad Division**	4	1	1800-4000	2360
Lower Gugera Division	2	-	521-1420	970	Sangla Hill	3	1	1800-2100	1950
Buchiana	2	-	521-1420	970	Uqbana	1	-	4000	4000
Burala Division	9	-	1300-3000	1978	**Jhang Division**	29	-	480-4030	1525
Kanya	1	-	1700	1700	Dhaular	16	-	480-4030	1594
Tandlianwala	8	-	1300-3000	2013	Veryam	13	-	480-2200	1440
LCC East Circle	35	1	521-4050	1690	**Khanki Division**	5	-	920-1300	1090
Haveli	11	1	320-6600	1280	Sagar	5	-	920-1300	1090
					LCC West Circle	52	1	380-4030	1495

Table 13. Shallow groundwater quality in selected watercourse commands of SCARP-IV&V areas in the Upper Chenab Canal (UCC) and Lower Chenab Canal (LCC) circles, respectively

SCARP-IV Division/ Subdivision	Number of Private TW	EC in microS/cm		SCARP-V Division/ Subdivision	Number of Private TW	EC in microS/cm	
		Range	Mean			Range	Mean
Gujranwala Division	63	521-2230	1204	**Lower Gugera Division**	9	554-2475	1455
Shahdara Subdivision	38	521-2020	1158	Bhagat	9	554-2475	1455
Muridke Subdivision	25	778-2230	1275	**Burala Division**	38	419-1358	762
Sheikhupura Division	160	282-1808	933	Sultanpur	38	419-1358	762
Sikhanwala Subdivision	45	282-1327	771	**LCC East Circle**	47	419-2475	858
Mangtanwala Subdivision	115	430-1808	997				
UCC Circle	223	282-2230	1010				

Source: PPSGDP (1998)

Table 14. Second SCARP Transition Project scheme-wise survey of tubewells

SCARP-I/Scheme	Shallow			Deep		
	EC in microS/cm			EC in microS/cm		
	No. of TW	Range	Mean	No. of TW	Range	Mean
Beranwala	58	340-3350	1678	49	375-3250	1883
Chuharkana	7	900-1980	1626	3	1110-1610	1373
Hafizabad	77	340-2800	1448	67	800-2250	1474
Harse Sheikh	8	680-3500	1340	2	1300	1300
Jaranwala	30	280-3900	1766	24	600-5200	2338
Pindi Bhatian	5	800-1560	1256	5	1220-1810	1670
Sangla Hill	55	520-2830	1491	52	940-2420	1467
Shahkot	96	480-6300	1690	86	880-5000	1987
Shadman	8	270-1400	994	6	1180-1450	1288
Zafarwal	96	750-6600	2372	70	1090-5200	2698
SCARP Project-I	440	270-6600	1601	364	375-5200	1756

Source : ACE-NESPAK-NDC (1997)
Note: For shallow groundwater quality, privately installed tubewells are compared with the SCARP tubewells in SCARP areas.

The groundwater qualities at deep and shallow horizons in the SCARP I area are also evaluated during the implementation of the Second SCARP Transition Project and compared over a period of time (ACE-NESPAK-NDC, 1997). Based on water quality data of 1988-89 for 1870 SCARP tubewells (STW) of deep horizon, 63 percent of the project area was reported in the fresh water zone (EC in μS/cm ≤ 1500; SAR ≤ 10; RSC ≤ 2.5), 34 percent in the marginal water zone (EC~1500-2700; SAR~10-18; and RSC~2.5-5), and 3 percent in the hazardous water zone (EC ≥ 2700; SAR ≥ 18; and RSC ≥ 5). The comparison of chemical qualities of deep groundwater in terms of number and percentage of STW in the year 1962-63 and 1988-89 indicated a trend of deterioration of the overall SCARP-I area (ACE-NESPAK-NDC, 1997). The shallow groundwater quality survey of 1139 private tubewells (PTW) and installed piezometers indicated 80 percent area in the fresh water zone, 14 percent in the marginal water zone, and 6 percent in the hazardous water zone. The periodic monitoring of 165 observation locations from the period of 1993 to 1997 in the project area indicated deteriorating water quality at 85 locations and improvement at 80 locations for the four-year period (ACE-NESPAK-NDC, 1997).

4.2 Groundwater Availability

In Rechna Doab, the farmers exploit groundwater to supplement canal water supplies. The quality of the groundwater differs spatially. Table 15 presents the occurrence of the fresh and saline water zones in the Rechna Doab. Out of the total surveyed 1.947 million hectares of canal command area, about 1.626 million hectares has fresh and useable groundwater supplies, but 0.321 million hectares contains saline groundwater. Farmers with saline groundwater have meager opportunity to exploit groundwater and supplement their canal water supply.

Table 15. Reported areas in million hectares by groundwater quality in the Rechna Doab, Punjab, Pakistan

Canal Circles	Fresh	Saline	Total
Upper Chenab Canal Circle	0.648	-	0.648
Lower Chenab Canal West Circle	0.383	0.090	0.473
Lower Chenab Canal East Circle	0.597	0.159	0.755
Haveli	-	0.072	0.072
Rechna Doab	1.626	0.321	1.947

About 193,000 public and private tubewells pump groundwater in the Rechna Doab. The pumpage from the private and public tubewells is presented in Table 16. The total annual pumpage of groundwater in the Rechna Doab is estimated to be 1.476 million hectare-meters (Mhm) in 1995, of which 0.303 Mhm is the pumpage from public tubewells and the remainder of 1.173 Mhm is pumped through private tubewells. Punjab Private Sector Groundwater Development Project (PPSGDP) Consultants estimated the number of public and private tubewells in 1997-98 in administrative districts covering the Rechna Doab as well (PPSGDP, 1998). The reported number of public and private tubewells is shown in Table 17. Total number of tubewells in these districts is 195,017 up to 1997-98.

Table 16. Reported annual pumpages in million hectare-meters from public and private tubewells in the Rechna Doab

Canal Circles	Public Tubewell	Private Tubewell	Total
Upper Chenab Canal Circle	0.109	0.648	0.757
Lower Chenab Canal West Circle	0.075	0.216	0.292
Lower Chenab Canal East Circle	0.120	0.308	0.428
Rechna Doab	0.304	1.173	1.476

Source: PPSGDP (1998)

The number of reported private tubewells has increased from 66,549 in 1985 to 195,017 in 1997-98. The average compound growth rate of private tubewells over a period of nine years is estimated to be 10.5 percent.

Table 17. District-wise public and private tubewells in the Rechna Doab

District	Public	Private	Total
Gujranwala	40	38515	38555
Hafizabad	38	16939	16967
Sialkot	86	36075	36161
Narowal	32	21129	21161
Sheikhupura	473	27323	27796
Faisalabad	114	13925	14039
Toba Tek Singh	163	8691	8854
Jhang	926	30548	31474
Total	1872	193145	195017

Source: PPSGDP (1998)

Private tubewell (PTW) inventory, PTW density (number of tubewells per unit area) and utilization/operation factor (ratio of daily tubewell working hours to number of hours in a day) surveys were also conducted in the Rechna Doab under various research and development schemes. Under the Second SCARP Transition Project (SSTP), the consultants carried out hydro-geological studies and developed a mathematical model to simulate the groundwater conditions in eleven schemes of the First SCARP, comprising the project area. As part of the studies, scheme-wise increase in number of private and community tubewells (including installed/replaced) under the project are reported (ACE-NESPAK-NDC, 1997). Historical trend of increase in number of PTW and density is shown in Table 18. The average compound growth rate for increase in PTW over a period of eight years is estimated to be 16 percent. A higher growth rate may be attributed to project interventions of installing 4232 tubewells in the area during 1992 to 1997. Based on the experience gained in the surveys, the consultants adopted for their studies average discharge of 24 lps and operation factor of 15 percent for PTW before project implementation while discharge rates and operation factors of 21 lps and 12 percent, respectively, for PTWs and 28 lps and 20 percents, respectively, for CTWs installed during project implementation were adopted.

Table 18. Scheme-wise increase in private tubewells and density in the SSTP area in the Rechna Doab

First SCARP Scheme	CCA (Ha)	PTW			PTW (per 100 Ha CCA)		
		1989	1992	1997	1989	1992	1997
Pindi Bhattian/Harse Sheikh	13310	324	495	1096	2	4	8
Chichuki Mallian/Shadman	32777	739	1608	3248	2	5	10
Chuharkana/Shahkot	97386	1762	3081	5904	2	3	6
Jaranwala	33685	489	1241	3051	1	4	9
Zafarwal	89410	1374	1965	5632	2	2	6
Hafizabad	66389	2842	3707	5601	4	6	8
Sangla Hill	52053	939	1732	2801	2	3	5
Beranwala	30446	467	845	2031	2	3	7
Total	415456	8936	14674	29364	Average=2	4	7

Source: ACE-NESPAK-NDC (1997)

Reportedly, all the SCARP tubewells (STW) in the fresh groundwater (FGW) areas are transitioned to PTW in the SSTP area. In 1997, PTWs in FGW areas comprised 72 percent of the total PTW in the SSTP withdrawing 74 percent of the total groundwater extracted (252,610 hectare-meter) through PTWs. Also, 128 STWs in saline groundwater areas remained working and were withdrawing 6,784 hectare-meter of groundwater (ACE-NESPAK-NDC, 1997).

Inventories of private tubewells in selected watercourses along different reaches of irrigation channels in the Fourth and Fifth SCARPs within the Rechna Doab were also compiled under the Punjab Private Sector Groundwater Development Project (PPSGDP) as part of development of groundwater regulatory framework task (PPSGDP, 1998). The data was processed on subdivision level by locating the irrigation channels selected for survey in the list of channels for a particular subdivision. The subdivisions covering Fourth SCARPs are part of the Upper Chenab Canal Circle, while those of Fifth SCARPs are controlled by Lower Chenab Canal East Circle of the Punjab Irrigation Department. Table 19 summarizes the number of watercourses (W/C) surveyed and their cultureable command area (CCA), number and density of tubewells, and average discharge at subdivision level within parts of the PPSGDP area. Based on this inventory, 8 tubewells per 100 hectare having average discharge of 18 lps are estimated for Fourth SCARP area. For the Fifth SCARP area, 18 tubewells per 100 hectare with discharge rate of 29.7 lps are estimated. Based on crop-year-operating-hour data, the operation factors of 7 percent for 91 tubewells in Bhagat subdivision and 11 percent for 246 tubewells in Sultanpur subdivision are estimated.

The yearly percent increase in private tubewells in the selected watercourse commands of Fourth and Fifth SCARPs were also estimated by PPSGDP (1998). The average growth rates were 19 and 11 percent per year, respectively, for Fourth SCARP and Fifth SCARP during the period 1987 to 1997.

Table 19. Subdivision-wise private tubewells and density in the selected watercourses commands of Fourth and Fifth SCARPs in the Rechna Doab

Subdivision	Number of W/C Surveyed	CCA (Ha)	Number of PTW	PTW (per 100 Ha CCA)	Average Discharge (lps)
Fourth SCARP (Muridke-Mangtanwala)					
Muridke	11	1811	124	7	18
Shahdara	12	1581	151	10	15
Sikhanwala	9	1189	121	10	18
Mangtanwala	26	5282	398	8	20
Fifth SCARP (Shorkot-Kamalia)					
Bhagat	6	1045	146	14	31
Sultanpur	19	4026	502	12	29

Source: PPSGDP (1998)

5. WATERLOGGING AND SALINITY CONDITIONS IN THE RECHNA DOAB

5.1 Background

Recharge to the aquifer was principally seepage from the rivers and, to a lesser degree, precipitation. It was equal to the natural discharge of groundwater by evapotranspiration and subsurface flow. Under the conditions that prevailed, a dynamic equilibrium was established among all the various components of recharge, discharge and groundwater storage. Seepage from the Chenab and Ravi rivers generally moved towards the center of the Doab, where a portion unutilized against evapotranspiration losses progressed in a southwesterly direction of subterranean slopes. Prior to the canal construction, the watertable occurred at a depth of more than ten meters and in the center of the Doab, at more than 30 meters. Because of the relatively flat topography, low hydraulic gradient and generally poor drainage conditions, the watertable began to rise due to increased recharge through the unlined irrigation channel and deep percolation from croplands. Simultaneously, with the rise of the watertable, the hydraulic gradient and consequent movement of groundwater towards the center of the Doab decreased annually. By 1930, the watertable in the center of the Doab had risen above the altitude of the adjacent rivers, thereby reversing the hydraulic gradient and direction of the groundwater flow. By 1960, the watertable rose as much as 30 meters in the area southeast of Faisalabad, and in many other areas it reached the land surface. With the rise in watertable, the secondary salinisation of culturable lands started rendering precious land into waste. The government intervened from time to time to reclaim the land resources for irrigated agriculture in the area. Some of the major remedial measures to rectify situation are discussed here one by one:

5.1.1 Provision of Surface Drains

Waterlogging was first noticed in the upper region of the Rechna Doab a few years after the opening of the Lower Chenab Canal (LCC) in 1892. By 1903, large areas under its command turned into marshes. The Ahmadpur and Kot Nikka open drains were the first in a series of open drains constructed for the Rechna Doab to complement the surface irrigation network under the Upper Chenab (UC) and Lower Chenab (LC) canals. These proved to be very effective, and later on, other drains were constructed. In 1933, a comprehensive plan was prepared to construct large number of drains, and by 1947, UCC had 611,500 hectares of land drained by 1,217 kilometers of drains and LCC had 1,500,000 hectares drained by 1,329 kilometers of drains. At present, a complete network of natural and constructed surface drains exists in the Rechna Doab (Figure 4). Similarly, Upper Rechna Remaining and Fourth Drainage Projects also aimed at providing surface and subsurface drainage developments to respective area and consisted of open drains and tile drain/sump arrangements for collection and disposal of drainage effluent.

5.1.2 Lining of Canals

As the lack of maintenance placed a damper on drain construction, lining of canals was initiated to reduce the seepage. In 1943, lining a portion of the Jhang Branch Canal was undertaken. This presented many difficulties and did not prove very successful. Further lining of canals was not undertaken. However, many new canals were lined such as the BRBD and Haveli Link canals.

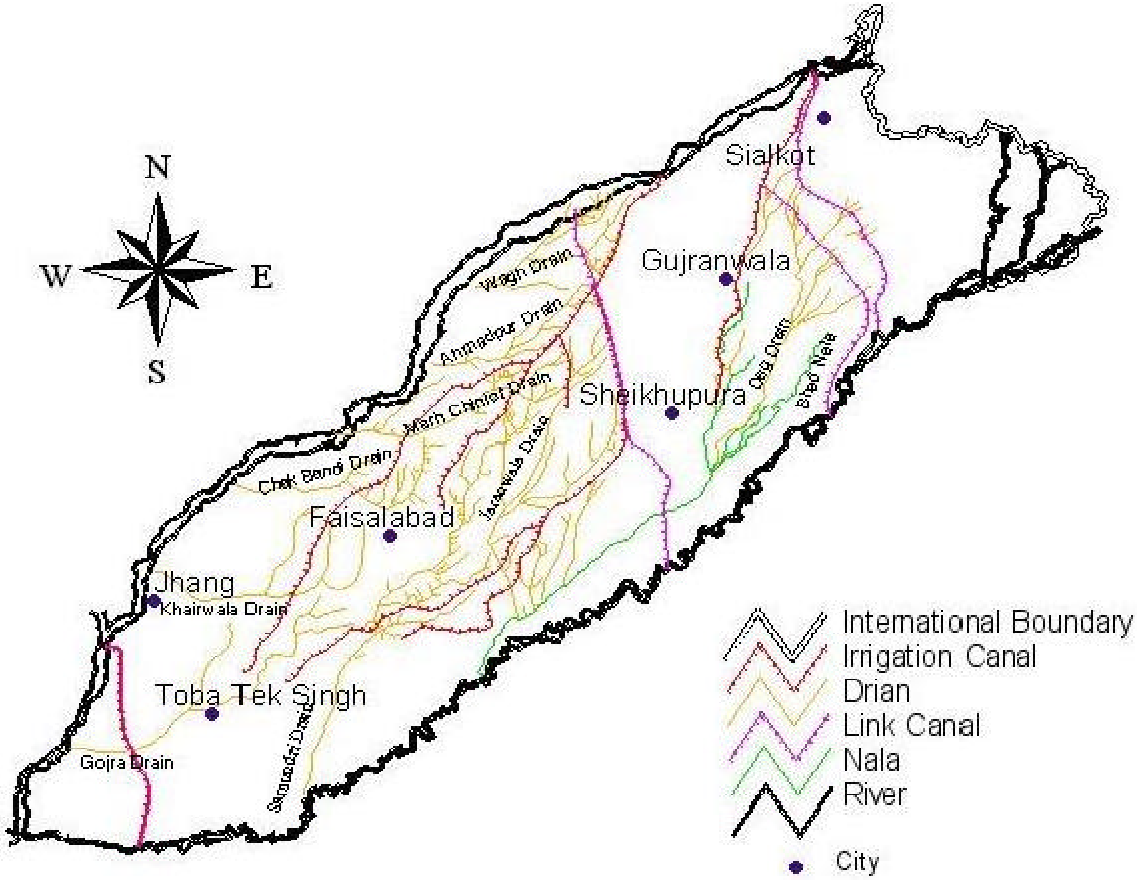

Figure 4. Drainage network in the Rechna Doab

5.1.3 Pumping of Groundwater

Attempts were also made to control the watertable by intercepting seepage from canals through tubewells and drains parallel to canals but rising watertables could not be controlled. The tubewell pumping schemes, implemented by the Punjab Irrigation Department during 1945-51 to eradicate waterlogging and supplement irrigation water, were mostly based on inadequate data and could not meet the magnitude of the problem. Resultantly, they had no significant effect. The first such project was Rasul Tubewell Scheme with 1,526 units installed in the Chaj Doab. The Soil Reclamation Board also implemented reclamation schemes from 1954 to 1960 and installed 190 tubewells in Chuharkana, Jaranwala, Chichoki Mallian and Pindi Bhattian for a total area of 48,000 hectares in the Rechna Doab.

After its establishment in 1958, the Water And Power Development Authority (WAPDA) assumed the land reclamation mandate and initiated a systematic approach of data collection and monitoring inherited from the defunct WASID. For the Rechna Doab, three major reclamation schemes were planned which are following:

(i) Areas in the center of the Doab were included in the very first initiative under SCARPs. It was primarily a vertical drainage scheme on 0.492 million hectares of gross area. The objective was to lower the watertable and utilize fresh groundwater as an additional source of irrigation supplies. In total, 2,069 tubewells of varying capacity were installed between 1960-63 for a cumulative discharge volume of 0.2 million-hectare-meters.

(ii) Areas in the present Upper Rechna Doab completed SCARP-IV and the Upper Rechna. The remaining projects consisted of both surface and vertical drainage. Additionally, flood protection measures were initiated for the MR and BRBD Link canals.

(iii) Areas in the present day Lower Rechna Doab completed SCARP-V (Shorkot-Kamalia), Satiana, Khairwala, Gojra-Khewra, and the Fourth Drainage Schemes. Due to several revisions since the original planning in late 1960s, pilot projects were implemented to provide relief against the rising watertable.

(A) SCARPS Achievements

To get rid of waterlogging and salinity problems, the Government of Pakistan started the vertical drainage scheme as SCARP projects during the 1960s. As stated earlier, the basic aim of the salinity control and reclamation program was to reduce the culturable waste areas under waterlogging and salinity. The scheme was thought to be beneficial in two aspects i.e. providing vertical drainage to waterlogged areas and augmenting the water supplies through deep tubewells available for use along with surface supplies. Different SCARPS schemes were introduced and implemented in the Rechna Doab (Figure 5).

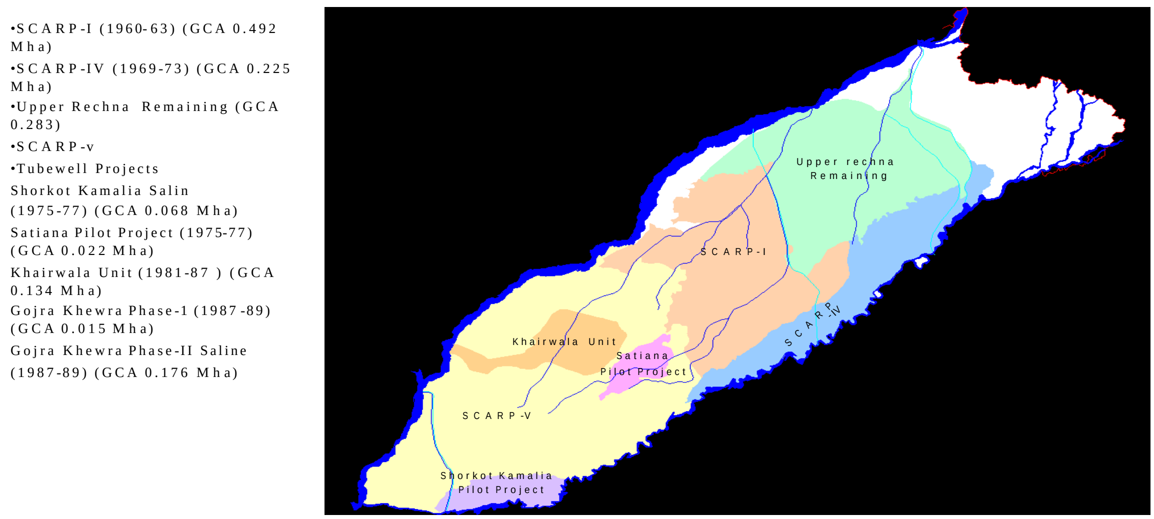

Figure 5. Salinity Control and Reclamation Projects (SCARPs) in the Rechna Doab

(a) SCARP 1: The SCARP-1 project was primarily a vertical subsurface drainage scheme anticipated for about 0.492 million hectares of gross area in the Rechna Doab. The project encompassed twelve schemes; Beranwala, Chichoki Mallian, Chuharkana, Hafizabad, Harse Sheikh, Jaranwala, Khanqah Dogran, Pindi Bhatian, Sangla Hill, Shahkot, Shadman and Zafarwal.

Investigations undertaken by the USGS (Malmberg, 1968) in SCARP 1 indicated that pumping had more than doubled the irrigation supply and lowered the watertable to a depth of more than 3 meters across the most of the project area. As a result, more than 66 percent of the 162,000 hectares of land, damaged by waterlogging and salinity, was wholly or partially reclaimed. The cropping intensity increased from about 77 percent in 1962 to 101 percent in 1968.

(b) SCARP IV (Mangtanwala and Muridke): To alleviate waterlogging, control salinity and augment additional irrigation supplies in Mangtanwala and Muridke areas, SCARP IV constructed 935 fiberglass tubewells in the fresh groundwater areas of the Rechna Doab along the Ravi River (Figure 5). These tubewells had a total discharge capacity of nearly 62 cumecs. The total area of the Mangtanwala / Muridke units was 225,652 hectares. About 37 percent of the tubewells in the Muridke unit were of lower capacity (57 & 85 lps) as compared to the earlier installations of less than 22 percent in the Mangtanwala unit, where the emphasis was more on high capacity wells. Interestingly, there was no tubewell discharging at 0.5 cusec (14 lps) incremental intervals in either of the two schemes, which covered one-third area under SCARP 1.

Based on the data collected in SCARP I and SCARP II, the fiberglass tubewells of SCARP IV were reported to outlast the mild steel versions under SCARP I tubewells, especially during the early years of operation. SCARP I had over 47 percent of the tubewells operating under 3 cusecs (85 lps) capacity as compared to nearly 32 percent for SCARP IV. Higher capacity wells suffering from greater loss in specific capacity over time (Memon, 1993).

(c) SCARP V (Lower Rechna Area): The original reclamation program planned by the WAPDA consultants M/s. Tipton and Kalambach during 1966 for the SCARP V (LRR) project comprised 1.1 million hectares of culturable area. The Jhang, Rakh, Lower Gugera and Brula Branches of the LCC command provide irrigation to this area. The Haveli Canal and the Koranga Feeder of the Central Bari Doab Canal irrigate the remaining areas. This project could not be materialized.

Subsequently, on the recommendations of the World Bank, the project as a whole was deferred and its lower parts under the commands of Haveli, Koranga Feeder, and the tail reaches of the LCC system were renamed and planned as Shorkot-Kamalia Unit of SCARP V comprising 0.172million hectares. As an early action plan during 1974, the consultants proposed a project, covering a gross area of 68,400 hectares termed as the "pilot project". About 101 tubewells were installed in this SCARP V area to alleviate the problem of waterlogging and salinity. The overall cropping intensity in SCARP V area has increased from 114 percent to 135 percent.

The remaining part of the SCARP V was assigned to the Project Planning Organization (PPO) North zone (NZ) during 1974 for the preparation of the revised plan. In view of the severity of the drainage problem, the PPO developed a scheme for the construction of 71 drainage tubewells under "Satiana Pilot Project" as part of the overall plan to provide relief to the waterlogged areas of about 73,650 hectares in Satiana.

The PPO (NZ) also proposed the Gojra Khewra and the Khairwala Surface Drainage System and Fourth Drainage projects. The Fourth Drainage Project was launched in 1983 to reclaim water from about 119,000 hectares of land. During 1993 after the completion of these projects, the watertable depths across the most of the project areas decreased considerably.

(d) Upper Rechna Remaining (URR): The gross area of the Upper Rechna Remaining Project is about 0.47 million hectares. This area is served by three canal systems (LCC, UCC and MR Link Canal, all of which derive their supplies from the Chenab River). Historic data (1966-75 average) on canal diversions indicate that due to non-perennial irrigation supplies in the commands of the LCC and MR Link Canal, these areas experience an acute deficit of irrigation supplies during most part of the year, except for the months of May and June. These shortages are more acute from November to March. The area located in the fresh groundwater zone has exploitation opportunities to offer. The cropping intensity is reported to be more than 140 percent.

The project area has three main drainage basins, Deg Nala, QB Link and Ahmedpur Vagh. The first two basins drain in Ravi River while, Ahmedpur Vagh drains in Chenab River. The QB Link and Ahmedpur Vagh Basins have drains that are mostly artificial and do not efficiently drain the area during the monsoon season. In the Deg Nala Basin, about 60 drains equivalent to 393 kilometers were constructed to bring the drainage effluent to the Deg Nala in the Upper Rechna, which ultimately disposes the drainage, water to the Deg Diversion Channel, and finally, discharges into the Ravi River upstream of Balloki Headwork.

Drainage channels in the Deg Nala Basin are primarily to transmit surface runoff received from across the MR and BRBD Link canals. For the protection of the MR Link and BRBD, cross drainage works are provided and an additional 183 kilometers of artificial drains cover sheet-runoff from damaging the UCC; collectively; these discharge into the Nikki Deg Natural Drainage Channel. However, at many places, the embankments of roads and canals block the path of drainage. For overflows resulting from storms of higher intensity than designed for the cross drainage structures, the damage to rice crop is substantial.

(e) Post-SCARP: SCARP was very useful in eliminating waterlogging, controlling salinity and providing additional irrigation water to increase cropping intensities and yields. However, in mid1980s, the following problems were identified which were resolved through the SCARP transition and improvement projects (ACE 1985):

- With the deterioration of the operational efficiency of SCARP tubewells over time and consequent reduction in pumpage, the watertable started showing a rising trend in most parts of the area.
- With increasingly high power tariffs, rapid depreciation of tubewells and low water rate for tubewell supply, the O & M costs of SCARP tubewells were increasing and there was unsustainable financial burden on the irrigation sector O&B budget.
- Replacement of a large number of aging tubewells was needed.
- Farmers were generally dissatisfied with the performance of the SCARPs, but accepted the services because of highly subsidized rates of SCARP tubewell water supply.
- With frequent repairs and fault removals needed by aging tubewells, the Irrigation Department had a limited capacity to manage and operate SCARP tubewells.

(f) SCARP Transition Pilot Project: In the late 80s, a pilot project for the transition of SCARP tubewells in the Khanqah Dogran scheme of the First SCARP was launched. The basic concept was the involvement of private sector pumping for irrigation from shallow groundwater generally falling within fresh water limits. This was aimed to balance the drainage requirement of the pilot project area where public sector operation of SCARP tubewells was terminated.

The objective of transferring fresh groundwater pumpage was to meet more effectively the irrigation and drainage requirements and increase agricultural production and farm incomes through conjunctive use of water. This could be achieved by electrification and installation of private tubewells, irrigation/drainage improvement works (e.g. lining of minors and watercourses), and institutional developments. Under the pilot project, 213 SCARP tubewells were transferred and replaced by 2,100 private tubewells. This was done by providing necessary financial incentive and technical guidance to the farmers (ACE-NESPAK-NDC, 1997).

(g) Second SCARP Transition Project: The successful implementation and enthusiastic response from the farmers of the SCARP Transition Pilot Project led to the development and execution of Second SCARP Transition Project. The transition activities were expanded to the remaining schemes of the first SCARP by closing 1,353 SCARP tubewells and replacing them through the installation of 4,700 comparatively, shallow private/community tubewells operated by farmers/groups of farmers (ACE-NESPAK-NDC 1997). Included in the project was a hydrogeological study to collect and update the data, forming a basis for analysis of long-term sustainability of groundwater withdrawals and its use in the project area without causing any undesirable effects on hydrogeologic regime and environment. The study concluded that distribution and pattern of pumping did not indicate significant vertical or lateral movement of groundwater of undesirable quality in future at large scale and recommended to regulate the number and distribution of tubewells in the project area by public agency.

5.2 Punjab Private Sector Groundwater Development Project (PPSGDP)

On the successful culmination and enthusiastic reception by farmers of SCARP transition projects, the Government of Punjab has been executing and co-financing with the World Bank the PPSGD project in the province for a five-year period (1997-2002). The project lies in the fresh groundwater areas of Second SCARP (including Shahpur), Third SCARP (Rangpur Unit) and remaining SCARPs within Rechna Doab (Fourth-Muridke Mangtanwala and Fifth-Shorkot Kamalia). The PPSGD Project also covers saline groundwater areas of the Second SCARP and saline groundwater pockets within and at the boundaries of fresh groundwater areas (PPSGDP, 1999). The project envisages disinvestments of 4,230 SCARP tubewells and establishment of 6,360 private tubewells owned by individuals/groups of farmers. The other objectives are (a) to do lining of distributaries, minors and watercourse; installation of drainage tubewells in saline areas; (b) Prevention of intruding saline groundwater; (c) Establishment of groundwater management areas using groundwater models; and (d) Preparation of a regulatory framework for groundwater use and institutional development.

5.3 Illustration of Waterlogging

The SCARPs Monitoring Organization (SMO), a sub-unit of WAPDA, is responsible for monitoring the changes in the groundwater. It monitors the results of the vertical drainage strategy adopted by WAPDA. The depth to watertable data collected through a network of 950 observation wells/locations in the Rechna Doab for the period spanning April/June 1959-64 served as benchmark observations for the SCARP schemes. Reportedly, 10.9 percent of the area had watertable within 1.5 meters, 39.3 percent had watertable between 1.5 and 3 meters, and the remaining 49.8 percent had watertable at more than 3 meters. By 1980, major SCARP tubewells within the Rechna Doab completed several years of operational life in pumpage-assisted watertable reduction.

The evaluation of monitored data through a network of 981 piezometers for the period 1980-96 revealed that the recorded instances of high water levels are insignificant. Most of the areas had watertables below 1.5 meters and predominantly more than 3 meters deep, thereby, indicating no perceivable threats to the drainage of the root zone. The SMOs' depth to watertable data for the year 1990, 1993, and 1996 have been analyzed at the Punjab Irrigation Department's division/circle level. Analyzed aerial distributions in different depths to watertable (DTW) categories in the Rechna Doab for the pre-monsoon (June) and post-monsoon (October) are given in tables 20 to 22 and presented in Figure 6.

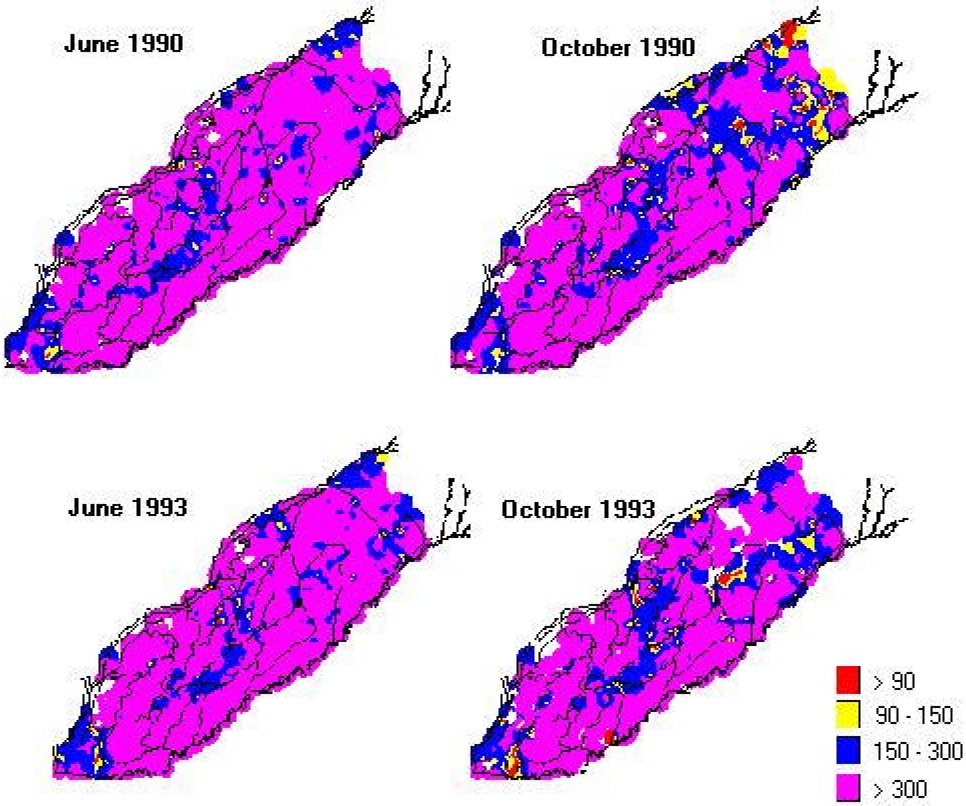

Figure 6. Spatial and temporal distribution of watertable in the Rechna Doab

Table 20. The pre-monsoon depth to watertable situation in the Rechna Doab (1990-93)

Division/Circle	Areal Distribution in different DTW Categories (Jun-90)							Areal Distribution in different DTW Categories (Jun-93)						
	Total Area*	DTW<1.5 m		DTW~1.5-3 m		DTW>3 m		Total Area*	DTW<1.5 m		DTW~1.5-3 m		DTW>3 m	
	Ha	Ha	%	Ha	%	Ha	%	Ha	Ha	%	Ha	%	Ha	%
UCC Circle	742694	6954	0.9	97159	13.1	638581	86.0	749061	6674	0.9	98465	13.1	643922	86.0
LCC East Circle	800384	4797	0.6	134295	16.8	661292	82.6	802648	4365	0.5	126678	15.8	671605	83.7
Upper Gugera	288083	2387	0.8	43553	15.1	242143	84.1	288265	2020	0.7	42047	14.6	244198	84.7
Lower Gugera	263899	2410	0.9	71194	27.0	190295	72.1	265618	1679	0.6	63820 In 1990s,	24.0	200119	75.3
Burala	248402	0	0.0	19548	7.9	228854	92.1	248765	666	0.3	20811	8.4	227288	91.4
LCC West Circle	628565	11339	1.8	104805	16.7	512421	81.5	621845	17643	2.8	81887	13.2	522315	84.0
Faisalabad	164851	3667	2.1	19856	11.4	141328	81.3	166564	2917	1.8	15688	9.4	147959	88.8
Hafizabad	170714	2233	1.5	41328	27.6	127153	84.8	170714	8673	5.1	46071	27.0	115970	67.9
Jhang	293000	5439	1.8	43621	14.5	243940	81.3	284567	6053	2.1	20128	7.1	258386	90.8
Haveli Internal	94907	8337	8.8	59146	62.3	27424	28.9	94155	10797	11.5	65734	69.8	17624	18.7
Rechna Doab	2266550	31427	1.4	395405	17.4	1839718	81.2	2267709	39479	1.7	372764	16.4	1855466	81.8

Table 21. Post-monsoon depth to watertable situation in the Rechna Doab (1990-93)

Division/Circle	Arial Distribution in different DTW Categories (Oct-90)							Arial Distribution in different DTW Categories (Oct-93)						
	Total Area*	DTW<1.5 m		DTW~1.5-3 m		DTW>3 m		Total Area*	DTW<1.5 m		DTW~1.5-3 m		DTW>3 m	
	Ha	Ha	%	Ha	%	Ha	%	Ha	Ha	%	Ha	%	Ha	%
UCC Circle	745507	61989	8.3	251672	33.8	431846	57.9	698609	37665	5.4	192646	27.6	468298	67.0
LCC East Circle	769163	16026	2.1	158202	20.6	594935	77.3	787920	32513	4.1	158523	20.1	596884	75.8
Upper Gugera	286863	8087	2.8	57190	19.9	221586	77.2	281184	10300	3.7	55891	19.9	214993	76.5
Lower Gugera	265618	5500	2.1	82426	31.0	177692	66.9	263762	9660	3.7	78688	29.8	175414	66.5
Burala	216682	2439	1.1	18586	8.6	195657	90.3	242974	12553	5.2	23944	9.9	206477	85.0
LCC West Circle	620159	13694	2.2	133267	21.5	473198	76.3	617565	19261	3.1	128097	20.7	470207	76.1
Faisalabad	161082	2867	1.8	25303	15.7	132912	82.5	170224	10474	6.2	22343	13.1	137407	80.7
Hafizabad	170714	5196	3.0	65398	38.3	100120	58.6	170056	5812	3.4	83223	48.9	81021	47.6
Jhang	288363	5631	2.0	42566	14.8	240166	83.3	277285	2975	1.1	22531	8.1	251779	90.8
Haveli Internal	94192	6788	7.2	58732	62.4	28672	30.4	94332	26365	27.9	52436	55.6	15531	16.5
Rechna Doab (Total)	2229021	98497	4.4	601873	27.0	1528651	68.6	2198426	115804	5.3	531702	24.2	1550920	70.5

Table 22. Post-monsoon depth to watertable situation in the Rechna Doab (1996)

Division/Circle	Arial Distribution in different DTW Categories (Oct-96)				
	Total Area*	DTW<1.5 m		DTW>1.5 m	
	Ha	Ha	%	Ha	%
UCC Circle	724000	111521	15	612479	84.6
LCC East Circle	747000	28386	3.8	718614	96.2
LCC West Circle	860000	43860	5.1	815280	94.8
Haveli Internal	95000	5005	5.3	89995	94.7
Rechna Doab (Total)	2426000	188772	7.8	2236368	92.2

Note: Total area is the area analyzed for the particular year in a division/circle.

In the 1990s, the areas with watertables within 1.5 meter depths were aggregated as 1.4 percent of the total Rechna Doab for the pre-monsoon period. For post-monsoon, it is 4.4 percent. For depth to watertable between 1.5 and 3 meters, the areas are, respectively, 17.4 and 27.0 percent for the two periods and for depth to watertable greater than 3 meters, these are 81.2 and 68.6 percent, respectively. The increases in the first two DTW categories during the post-monsoon period show the contribution of rainfall to the groundwater reservoir.

The monitoring and analysis of depth to watertable data was also carried out under the Second SCARP Transition Project (1993-97) for the selected eleven schemes of the SCARP-I area. The May/June and October monitoring data from 97 SMOs observation-points and 75 shallow and deep piezometers installed were used to ascertain the groundwater level fluctuations. In June 1989, at the feasibility stage, 0.2 percent of the project area had watertable within 1.5 meters, 15.4 percent between 1.5 and 3 meters and remaining 84.4 percent below 3 meters. In June 1992, before the start of the project, the respective percentages of areas were 0, 10 and 90, and after the project in June 1997, 2, 24 and 74 percent. The rise in watertable in June 1997 was attributed to heavy monsoon rains. After the wet period (October) for the years 1989 and 1992, the watertable situations (aerial percentages) for respective depth to watertable categories (within 1.5 meters, between 1.5 and 3 meters, and below 3 meters) were: 5, 25 and 70 percent; and 2, 22 and 77 percent, respectively. (ACE-NESPAK-NDC, 1997).

The depth to watertable (DTW) data for Fourth and Fifth SCARPs located within the Rechna Doab was analyzed under the PPSGD project. The average DTW ranges and trends are reported for various units within the above-mentioned SCARPs for the year 1997. For Muridke and Mangtanwala units of Fourth SCARP the average DTW are 4.5 and 4 meters, respectively; DTW ranges are 1.8-7.3 and 1.2-9.6 meters, respectively; while trend of watertable is rising in Muridke and has been stable with the rise since 1997 for Mangtanwala. Similarly, for Kamalia and Pir Mahal units of Fifth SCARP: the average DTW are 7.3 and 10.1 meters, respectively; DTW ranges are 5.2-10 and 1.5-11.2 meters, respectively; while trend of watertable is falling for Kamalia but stable for Pir Mahal since 1994 (PPSGDP 1998a).

5.4 Illustration of Salinity

The soils in the Rechna Doab are divided into two broad groups to describe the soil salinity as the salinity level in the soil also affects the conjunctive water management: normal soils and saline-sodic soils (Figure 7). The normal soils are non-saline and non-sodic, relatively porous and well structured with lime accumulation generally below the depth of 120 centimeters. The saline-sodic soils are divided into two categories: dense saline-sodic and porous saline sodic. The dense saline-sodic soils with a 60-130 centimeters thick B-horizon are non-calcareous to strongly calcareous. The hydraulic conductivity of these soils is very slow, having median values of 0.18 centimeters/day for silty clay loam and 0.3 centimeters/day for silt loam. In comparison, the normal hydraulic conductivity ranges between 11-14.5 centimeters/day for non-saline and non-sodic soils of sandy clay to sandy clay loam texture. The porous saline-sodic soils are moderately calcareous and comprise silty clay, silty clay loam, silt loam and loam.

The literature shows that the problem of soil salinity in the upper regions of the Rechna Doab came under the notice of the Punjab Government as early as 1927, when the groundwater table was either at the surface or quite near it. The Waterlogging Inquiry Committee started a salinity survey (Thur Girdawari) to estimate the extent of the damaged area during 1927. It was initially confined only to those areas where the watertable was within 1.5 meters from the ground surface. Following investigations in 1937, the presence of salinity in deep watertable areas was also established. As a result of these findings, the Thur Girdawari work was taken up by the Irrigation Department and extended to the entire irrigated area with varying watertable depths in the Punjab region in 1943, and subsequently to all of the four provinces of Pakistan in 1960. Salinity was attributed to high watertable conditions and groundwater as the source of salts. The earliest salinity surveys in 1927 were, therefore, confined only to those areas where the watertable was within 5 feet of the ground surface. Later, investigations conducted in 1937 revealed that salts were originally present in the soil crust and their movement was accelerated to the surface by high watertables and inadequate irrigation applications. In 1943, the survey was extended to the entire irrigated area with varying watertable depths in the Punjab region.

Land Reclamation Board, established in 1940, began to carry out the reclamation activities regularly from 1942. In 1952, a Soil Reclamation Board was set up and given wide statuary powers to implement reclamation schemes. These schemes included Chuharkana, Jaranwala, Chichoki Mallian and Pindi Bhattian for a total of 48,000 hectares in the Rechna Doab. Within these schemes, 190 project wells were constructed and began to operate during 1954-60. These schemes were later incorporated into SCARP-I, which was the first planned watertable control project in the country. A tubewell scheme between Sheikhupura and UCC was also completed. Adaptive research at Chukanwali and Jaranwala field experimental stations was subsequently replicated at the farmers' fields for leaching of the root zone and growing of suitable crops.

To reclaim the farmlands, which were partially affected by salinity, the government initially confined its efforts to the state lands and estates of large farmers, where it was possible for the Irrigation Department to provide separate outlets for reclamation supplies. Afterwards, the government decided to extend this reclamation activity to small farms also. These reclamation supplies were only possible during the excessive summer flows. This program in the Punjab province reclaimed about 504,471 hectares of land during 1990-91.

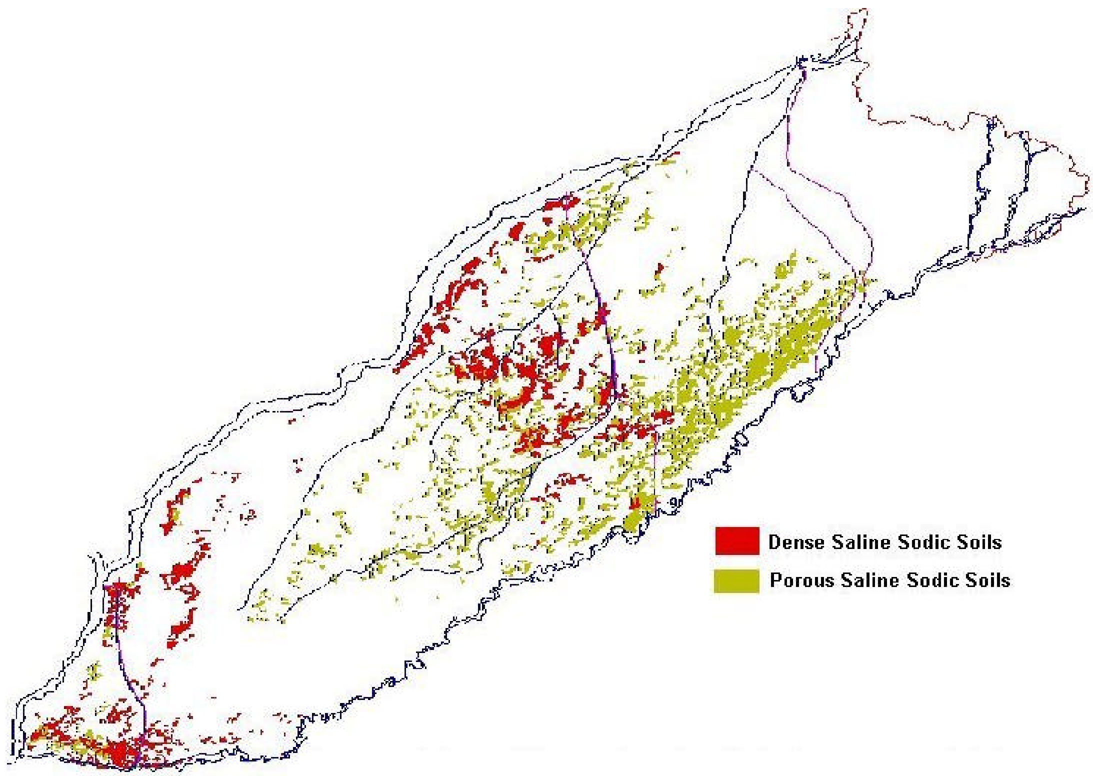

Figure 7. Distribution of saline and saline-sodic soils within the Rechna Doab

6. LAND RESOURCES

6.1 Land Resources in the Rechna Doab

This section highlights the operational distribution of landholdings in the Rechna Doab across different farm-size groups and their relationship with unused cultivable lands. An understanding of these relationships will help in understanding the technical and institutional constraints, which inhibit better water management options on farms including conjunctive water use.

6.2 Farm Number and Area

Approximately, 0.935 million farms in the Rechna Doab contribute in the agricultural production. Of these farms, 12.76 percent are located in the district Sialkot, 15.93 percent in Sheikhupura, 19.7 percent in Faisalabad, 8.93 percent in Toba Tek Singh and the remaining 9.25 percent in Gujranwala. The distribution of these farms in different farm categories shows that large (>10 ha) farms constitute only about 3.71 percent of the total farms, while the small (<2 ha) and medium (up to 10 ha) farms are in majority. Table 23 shows that 74.07 percent of farms in Sialkot are small, 24.67 percent medium and only 1.27 percent are large farms. Sheikhupura has 50.95 percent small farms, 44.88 percent medium farms and 4.17 percent large farms. The trend for the remaining districts of the Rechna Doab is almost the same. However, small farms in Hafizabad are the least among all the districts and large farms are highest in Jhang. These 0.935 million farms occupy 2.463 million hectares of farm area. As for the farm number, the farm area is also concentrated on medium farms. Although small farms are greater in number, they do not have a proportionate share in the area. In Sialkot, a large proportion (74.07 percent) of the small farms constitute only 34.3 percent of farm area. Similarly, 50.95 percent of small farms in Sheikhupura occupy 16.4 percent of the farm area.

Table 24 shows that medium farms are more than proportionate to their population strengths. About 27 percent of the farm area in the Rechna Doab is in the administrative boundaries of district Jhang, about 8 percent in Sialkot and 17.6 percent in Sheikhupura. The districts of Gujranwala and Faisalabad contribute 11.2 and 15.09 percent of the area, respectively. Toba Tek Singh contributes only 8.63 percent of the total farm area in the Rechna Doab.

Table 23. The spatial distribution of farm in districts and among farm categories in the Rechna Doab

District	Percent Distribution of Farms			Total (No.)	Distribution across the RD
	Small	Medium	Large		
Sialkot	74.07	24.67	1.27	119369	12.76
Sheikhupura	50.95	44.88	4.17	149070	15.93
Faisalabad	63.15	35.57	1.28	184377	19.70
T. T. Singh	55.95	41.21	2.84	83556	8.93
Jhang	50.29	42.52	7.19	185671	19.84
Gujranwala	48.16	46.11	5.72	86530	9.25
Hafizabad	39.91	53.34	6.75	39874	4.26
Narowal	68.48	30.11	1.41	87401	9.34
Rechna Doab	57.53	38.77	3.71	935848	100

Source: Government of Pakistan (2001)

Table 24. The spatial distribution of Farm Area Total (FAT) across different farm categories in the Rechna Doab

District	Percent Distribution of Farm Area			Total (Ha)	Distribution across the RD
	Small	Medium	Large		
Sialkot	34.3	52.6	13.0	196378	7.97
Sheikhupura	16.4	59.3	24.3	433388	17.60
Faisalabad	29.1	61.7	9.1	371637	15.09
T. T. Singh	20.7	61.1	18.3	212558	8.63
Jhang	13.3	46.7	40.0	665845	27.03
Gujranwala	14.2	57.7	28.1	275807	11.20
Hafizabad	10.6	58.1	31.3	147468	5.99
Narowal	30.0	57.9	12.2	159980	6.50
Rechna Doab	19.6	55.5	24.9	2463060	100

Source: Government of Pakistan (2001)

6.3 Cultivated Area

The demand for irrigation is directly related to the cultivated area. The cultivated area is defined as the area cropped at least once a year. This area is the sum of the net sown area and current fallow area. Table 25 represents the cultivated area in different districts of the Rechna Doab. A cultivated area has almost the same trends and distribution as the farm area. Tables 24 and 25 show that the farm area in the Rechna Doab is not utilized to its full potential, and that farmers could only cultivate 2.35 million hectares out of 2.46 million hectares of the farm area.

Table 25. The spatial distribution of cultivated area among farm categories in the Rechna Doab

District	Percent Distribution of Farms			Total (Ha.)	Distribution across the RD
	Small	Medium	Large		
Sialkot	34.82	52.69	12.50	192083	8.16
Sheikhupura	16.90	59.73	23.36	415692	17.66
Faisalabad	29.69	61.39	8.92	358155	15.22
T. T. Singh	20.95	61.21	17.84	205137	8.72
Jhang	13.78	47.07	39.15	623136	26.47
Gujranwala	14.52	57.85	27.62	268182	11.39
Hafizabad	10.92	58.94	30.14	140482	5.97
Narowal	30.95	57.88	11.17	150821	6.41
Rechna Doab	20.11	55.81	24.08	2353687	100

Source: Government of Pakistan (2001)

6.4 Culturable Waste Area

The scarcities of irrigation water induce farmers to use tubewell water of inferior quality, which leads to the problem of salinity. Resultantly, this increases the culturable waste area on the farms. The distribution of the culturable waste area (CWA) in the Rechna Doab is somewhat different from the cultivated area. The occurrence of CWA on small farms is less as compared to the medium and large farms. Table 26 shows that the percentage of CWA on the farm augments as the farm size increases. From Table 26 it is evident that the small farmers try to utilize all of their land intensively. In the case of Sialkot District, small farms endow only 11.66 percent of the total CWA, as compared to 54 percent approximately of the CWA, belonging to the medium farms. This trend prevails in the entire Rechna Doab, except in

Narowal and Faisalabad districts where the CWA is about 17 percent and 13 percent, respectively, on small farms. The inter-district comparison suggests that the highest percentage of CWA area (3.78 percent) exists on farms in Hafizabad as compared to other districts in the Rechna Doab. Among other districts of the Rechna Doab, Sialkot (1.02%) has the minimum CWA, which is variable in the remaining districts, from 3.17 percent in Sheikhupura to 2.08 percent in Gujranwala districts. Faisalabad District is situated in the saline groundwater zone and contains higher proportions of CWA as compared to other districts. A part of Sheikhupura District also falls under the saline zone besides Faisalabad District with respect to CWA.

Table 26. Distribution of Culturable Waste Area (CWA) among farm categories in the Rechna Doab

District	Percent Distribution of CWA in			Total (Ha)	CWA as a Percentage of Farm Area Total
	Small	Medium	Large		
Sialkot	11.66	34.24	54.16	2000	1.02
Sheikhupura	4.38	49.10	46.52	13740	3.17
Faisalabad	12.99	72.68	14.34	11569	3.11
T. T. Singh	8.97	55.49	35.52	5701	2.68
Jhang	3.47	45.17	51.35	19102	2.87
Gujranwala	3.82	51.82	44.35	5736	2.08
Hafizabad	2.66	43.23	54.09	5577	3.78
Narowal	16.93	49.56	33.52	4984	3.12
Rechna Doab	6.91	51.87	41.22	68408	2.78

Source: Government of Pakistan (2001)

Main reason for the presence of CWA in the Rechna Doab is the existence of salinity and waterlogging. Reportedly, other reasons like water scarcity or lack of resources to cultivate the land area are also responsible for CWA. Table 27 shows that in the case of Toba Tek Singh District, 86.70 percent of CWA, on average, are only due to waterlogging and salinity. As described earlier, waterlogging and salinity have affected vast areas in Toba Tek Singh District due to T.S. Link Canal. Similarly, districts of Sheikhupura and Faisalabad have also higher percentages of saline area, which are responsible for the higher incidence of CWA on the farmlands located in these districts. The incidence of salinity is quite low in the upper parts of the Rechna Doab. Therefore, the Sialkot District registers small area (11.68 %) for CWA, mainly due to salinity and waterlogging.

Table 27. Percentage share of saline and waterlogged area in the CWA in the Rechna Doab

District	Percent Distribution			Overall %age	Total CWA (Ha)
	Small	Medium	Large		
Sialkot	30.73	10.40	8.41	11.68	1999.60
Sheikhupura	43.71	47.65	55.78	51.26	13740.19
Faisalabad	71.24	65.43	62.52	65.77	11569.00
T. T. Singh	84.89	83.31	92.46	86.70	5700.93
Jhang	17.88	26.97	26.18	26.25	19101.58
Gujranwala	1.66	14.72	70.27	38.86	5735.73
Hafizabad	73.02	68.12	64.94	66.52	5576.69
Narowal	7.63	19.61	15.48	16.19	4984.22
Rechna Doab	45.18	45.97	46.59	46.17	68407.93

Sources: Government of Pakistan (2001)

6.5 Land Use Intensity

Land use intensity (LUI) represents the proportionate share of the total cultivated area to the total farm area. It indicates the extent to which the culturable land is used for production of crops on farms. Table 28 shows the LUI across districts in the Rechna Doab and its variations across different farm categories. It also shows that LUI has an inverse relationship with the farm size. LUI for small farms in the Rechna Doab is greater than both the medium and large farms. The reason might be that owners of small farms are dependent on their limited land resources, and they cultivate their lands much more intensively when compared to medium and large farmers. It was found that as the farm size increases, the LUI decreases due to higher incidence of culturable waste area on the medium and large farms. This is partly due to waterlogging and salinity and partly because of scarce irrigation supplies.

The spatial variations in LUI across districts (Table 28) show that Hafizabad District has the lowest LUI and Sialkot District contains the higher land use intensity (99 percent). The highest rainfall in the district of Sialkot and the presence of the fresh groundwater may be responsible for the lowest percentage of culturable waste area. The land use intensity was found less in the Jhang and TT Singh districts. One reason for the lower LUI might be that both the districts are located along the tail end of the Lower Chenab Canal (LCC) system and also have the saline groundwater of poor quality, which may not be used for irrigation to the crops.

Table 28. Land use intensity of different farm categories in different districts of the Rechna Doab

Districts	Small	Medium	Large	Overall
Sialkot	100.0	99.3	93.8	99.0
Sheikhupura	99.0	97.7	91.0	97.0
Faisalabad	99.0	96.0	95.5	97.0
TT Singh Distt	98.3	97.3	91.3	97.0
Jhang	99.0	97.3	95.8	97.0
Gujranwala	99.7	98.3	95.5	98.0
Hafizabad	99.3	97.7	94.0	96.0
Narowal	98.3	97.3	93.8	97.0
Rechna Doab	99.1	97.6	93.8	97.3

Sources: Government of Pakistan (2001)

Overall, LUI in the Rechna Doab is reported to be 97.3 percent and across small, medium and large farm categories, 99.1, 97.6 and 93.8 percent, respectively. The emphasis here is that when compared, the difference between small and medium farms becomes less. The reason is that the small farms have less than two hectares of area, medium farms have up to 10 hectares and large farms are those having more than 10 hectares of land.

6.5.1 Temporal Change in Land Use Intensity

Historically, the development of the irrigation system in the Rechna Doab has enabled more area to be brought under plough, and cultivated area has amplified with the increase in irrigation facilities. Land use intensity (LUI), which describes the extent of farm area being used, is presented in Table 29. It shows that LUI has been the maximum on small farms for the last forty-two years. But, after 1972, the LUI on small farms remained almost constant, which means that small farms cultivate 99 percent of their farm area. Further improvement in land use intensity may be impossible due to area that is not available for cultivation (i.e. area under watercourses, farmhouses, etc) and similarly, for medium farms. However, LUI first increased on large farms during 1970s and then decreased in 1980, but improved again in 1990 and 2000. The lower LUI on the large farms may be due to the presence of proportionately more culturable waste area on these farms.

The overall land use intensity in the Rechna Doab increased after 1960. As already mentioned, this increase may be attributed to increased and reliable irrigation supplies from the irrigation system after the Indus Basin Treaty was signed, but changes have not been registered from 1972 to 1980. This static growth in LUI may be due to an increase in land degradation. With the advent of link canals and new water diversion structures the incidence of seepage led to an increase in waterlogging and salinity. During the 1990s, LUI increased again due to reclamation programs in the Rechna Doab area.

Table 29. Temporal changes in land use intensity of different farm categories in different districts of the Rechna Doab

Farm Size	1960	1972	1980	1990	2000
Small	92	98	98	98	99
Medium	92	96	96	96	98
Large	77	87	86	89	94
Overall	88	93	93	94	97

Sources: Government of Pakistan (1963, 1976, 1983,1994,2001)

6.6 Cropping Intensity

The cropping intensity (CI) represents the total cropped area on the farm. It indicates not only the extent to which the cultivated area is used for cropping (Government of Pakistan, 2002), but also shows how intensively it is used. Table 30 shows that the CI in the Rechna Doab is 169 percent per annum. The average cropping intensity for small, medium and large farms in the Rechna Doab is 178, 169 and 163 percent, respectively. This trend prevails across all the districts of the Rechna Doab. Small farmers usually function on a subsistence level without maintaining any fallow land. They tend to maximize the amount of crops grown on their farms. As farm size increases LUI decreases, and hence, CI decreases.

Table 30 shows that the overall CI is the highest in Gujranwala District (193), followed by districts of Sialkot (186) and Hafizabad (185). The reason for the highest cropping intensity in Gujranwala District is the presence of fresh groundwater and its use in conjunction with the canal water, which increases land use in the district. Although, the fresh groundwater is in abundance in Sialkot District, only 93 percent of the cultivated area in the district is irrigated. In Gujranwala District, 99 percent of the area have irrigation facilities. In the case of Sheikhupura District, about 98.5 percent of the total cultivated area is irrigated with surface and groundwater irrigation facilities.

Table 30. Cropping intensity of different farm categories in the Rechna Doab

Districts	Small	Medium	Large	Overall
Gujranwala	192	194	188	193
Sialkot	188	186	174	186
Sheikhupura	186	183	183	182
Faisalabad	160	144	158	148
T. T. Singh	168	152	147	154
Jhang	167	148	120	139
Hafizabad	192	187	173	185
Narowal	176	158	161	163
Rechna Doab	179	169	163	169

Source. Government of Pakistan (2001)

6.6.1 Temporal Changes in Cropping Intensity

The cropping intensity (CI) shows how intensively farmers use the cultivated area. During the 1960s the CI on small and medium farms in the Rechna Doab was 105 percent, while the corresponding figure for large farms was 61 percent (Table 31). The overall CI during the 1960s was registered at 91 percent in the Rechna Doab. The availability of the extra water supplies from the SCARP tubewell schemes and the development of private tubewells along with the availability of inputs such as improved seeds and fertilizers enabled the cultivation of the farm area more than once. This led to a rise in the cropping intensity from 91 percent in the 1960s to 131 percent during 1980s and 169 percent in 2000. Temporal changes in the cropping intensity have not disturbed the inverse relationship between the farm size and CI, i.e. the smaller the farm size the higher the cropping intensity, and vice versa.

Table 31. Temporal changes in cropping intensity of different farm categories in different districts of the Rechna Doab

Farm Size	1960	1972	1980	1990	2000
Small	105	142	153	168	179
Medium	105	123	133	147	169
Large	61	98	109	124	163
Overall	91	121	131	146	169

Source. Government of Pakistan (2001)

6.6.2 Kharif Cropping Intensity

The annual cropping intensity can be segregated into Rabi and Kharif. The Kharif cropping intensity shows the percentage of the cultivated area under Kharif crops. Major Kharif crops grown in the Rechna Doab are rice, cotton, sugarcane and fodder. The intensity of the Kharif crops in the Rechna Doab remains lower than the Rabi crops because farmers face water scarcity when sowing Kharif crops. Also, timely rainfall availability may not occur to supplement the canal water supply when these crops are sown. Table 32 shows that the Kharif cropping intensity is still high on small farms (79 %) as compared to medium (77.0 %) and large farms (61.4 %). Overall, about 73.5 percent of the area has been classified for Kharif crops.

Table 32. Kharif cropping intensity among different farm categories across districts of the Rechna Doab

Districts	Small	Medium	Large	Overall
Gujranwala	95	96	96	96
Sialkot	91	90	87	90
Sheikhupura	87	88	88	88
Faisalabad	67	65	70	66
T. T. Singh	75	70	67	70
Jhang	70	62	30	50
Hafizabad	93	91	90	91
Narowal	79	72	68	74
Rechna Doab	79	77	61	73

Source: Government of Pakistan (2001)

6.6.3 Rabi Cropping Intensity

The Rabi cropping intensity represents the percentage of cultivated area covered by the Rabi crops. The overall Rabi cropping intensity in the

Rechna Doab is reported to be 89 percent. The major Rabi crop in Rechna Doab is wheat, which is sown in both irrigated and un-irrigated areas. Table 33 shows that the inter-farm comparison of the Rabi cropping intensity, again, is higher on small farms than on the medium and large farms. It shows inter-district differences in the Rabi cropping intensity. In Gujranwala, the Rabi cropping intensity is the highest (97.2 %), followed by Sialkot and Hafizabad that show 96 and 93.8 percent of Rabi cropping intensities. In the case of Sheikhupura, Jhang and TT Singh districts, the Rabi cropping intensity is reported to be 92.1, 87.5 and 79.4 percent, respectively.

Table 33. Rabi cropping intensity of different farm categories across districts of the Rechna Doab

Districts	Small	Medium	Large	Overall
Gujranwala	99	98	96	97
Sialkot	98	96	91	96
Sheikhupura	93	93	90	92
Faisalabad	88	78	76	80
TT Singh	88	79	72	79
Jhang	92	85	89	88
Hafizabad	98	95	90	94
Narowal	95	86	86	89
Rechna Doab	93	88	88	89

Source: Government of Pakistan (2001)

6.7 Cropping Patterns

Mostly, rice, wheat, cotton and sugarcane occupy the farm area in the Rechna Doab. In the upper Rechna Doab, rice is major Kharif crop and wheat a major Rabi crop, while mixed cropping is practiced in the lower Rechna Doab. Table 34 shows that wheat occupies most of the area in Rabi crops, which varies from 59 percent in Jhang, 75 percent in Toba Tek Singh, 83 percent in Gujranwala and 86 percent in Sialkot, respectively. The cotton crop is cultivated only in districts of the lower Rechna Doab (Faisalabad, T. T. Singh and Jhang). In Sialkot, Gujranwala, Sheikhupura, Hafizabad and Narowal, paddy is grown during the Kharif season on 98, 87, 79, 78 and 70 percent of the area, respectively. These districts have fine soil, which is suitable for the rice crop. As we move towards the lower end of the Rechna Doab, the soil texture becomes medium, and then, coarse.

The central regions of the Rechna Doab contain medium-textured soil, which is suitable for the sugarcane crop. Therefore, Faisalabad's cultivated area has the highest percentage of sugarcane cultivation, though it is not the most dominant crop. The higher percentage of sugarcane renders Faisalabad as a wheat-sugarcane zone. All of the three crops are present in small percentages in Toba Tek Singh and Jhang, and represent a mixed cropping system. The presence of coarse-textured soils in Toba Tek Singh endures cotton growing suitably as compared to other districts of the Rechna Doab.

Table 34. Area under major crops across districts in the Rechna Doab (Percentage)

Districts	Wheat	Paddy	Cotton	Sugarcane
Gujranwala	83	87	0.1	0.1
Sialkot	86	98	0.1	1
Sheikhupura	78	79	0.1	3
Faisalabad	74	10	13	38
TT Singh	75	13	31	27
Jhang	59	33	17	19
Hafizabad	81	78	0.1	3
Narowal	83	70	0.1	2
Rechna Doab	77	59	8	12

Source: Government of Pakistan (2001)

7 PRODUCTIVITY IN THE RECHNA DOAB

Productivity differences have been observed in many parts of the Rechna Doab. These differences in productivity by farm size were first mentioned in a number of farm management studies carried out in India, Pakistan and other developing countries during the 1960s, 1980s, 1990s and 2000. The most frequently stated proposition was that an inverse relationship exists between output-per-acre and farm size. These studies attempted to explain the apparent low land productivity on large farms by testing the hypothesis that large farms make lesser use of variable inputs per acre. Scarcity of irrigation water, lack of proper management and inefficient use of land resources were said to be the major reasons for low productivity on farms [Bhattacharya and Saini (1972), Khusro (1974), Salam (1976), Afzal (1989), Bagi (1981), Berry and Cline (1979), Doelalikar (1981), Hallam (1991), Khan and Akbari (1986), and Taslim (1990), Jehangir *et al*..(2002), Hussain *et al* .(2002)].

This section highlights the current productivity level in the Rechna Doab and the potential for bringing out more area under cultivation if the production constraints including the irrigation are relaxed through conjunctive use of surface water with groundwater. The crops in the Rechna Doab are grown in accordance with the family's requirement, soil texture, availability of irrigation supplies and climatic conditions; therefore, diversity of crops is found on farms. These include food crops, oil seed crops, fiber crops and fodder crops. However, only four major crops (wheat, rice, cotton and sugarcane) have been considered for detailed study. The area, production and yield of the major crops in the Rechna Doab are presented in tables 35-38.

7.1 Area, Production and Yield of the Wheat Crop in the Rechna Doab

Table 35 presents the area, production and yield of the wheat crop in the Rechna Doab. During 2000-01, about 1.736 million hectares of land was cultivated under wheat crop, producing 4.58 million ton of wheat at the rate of 2.6 ton per hectare. The average wholesale price of wheat during 2000-01 was Rs. 7.5 per kilogram. In monetary terms, the total value of the wheat product was 34395 million rupees in the Rechna Doab.

Table 35. District-wise area, production and yield of the wheat crop

District	Area (000 ha)	Prod (000 tons)	Yield (ton/ha)	Avg. prices for 2000-01 (Rs/kg)	Total Value of Product (Rs. Million)
Faisalabad	262	767	2.9	7.5	5752.5
Sheikhupura	299	882	2.9	7.5	6615.0
Gujranwala	215	612	2.8	7.5	4590.0
Jhang	361	920	2.5	7.5	6900.0
Sialkot	193	445	2.3	7.5	3337.5
TT Singh	145	413	2.8	7.5	3097.5
Narowal	131	201	1.5	7.5	1507.5
Hafizabad	130	346	2.7	7.5	2595.0
Rechna Doab	1736	4586	2.6	7.5	34395.0

The highest area under the wheat crop was cultivated in Jhang, where 361 thousand hectares of area were sown with wheat crop. Although this area is the highest in the Rechna Doab, it is not proportionate, as the wheat crop was only covered by 10.26 percent of the geographic area. For Gujranwala and Sialkot, respectively, this proportion is 6.11 and 5.48 percent. It shows that there is still a potential for cropped area to be increased in Jhang. Unlike the rice crop, wheat is sown in all the districts of the Rechna Doab. In case of rice crop, its cultivation depends upon water availability, soil texture and climatic conditions. The suitable conditions for rice cultivation are found only in the Upper Rechna Doab (comprises Sheikhupura, Sialkot and Gujranwala districts). Therefore, in these districts rice is grown extensively during the Kharif season.

7.2 Area, Production and Yield of the Rice Crop in the Rechna Doab

Table 36 reveals that the area under rice cultivation in the districts of Gujranwala, Sheikhupura and Sialkot is the highest in the Rechna Doab. The contribution by these districts was significant towards the total production. The total value product from the rice crop is estimated to be Rs. 18066.5 million during 2000-01 in the Rechna Doab (Table 36).

Table 36. District-wise area, production and yield of the rice crop

District	Area(000 ha)	Prod (000 tons)	Yield (ton/ha)	Price (Rs/kg)	Total Value of Product (Rs. Million)
Faisalabad	29	41	1.4	11.5	471.5
Sheikhupura	260	412	1.6	11.5	4738.0
Gujranwala	228	419	1.8	11.5	4818.5
Jhang	86	127	1.5	11.5	1460.5
Sialkot	175	263	1.5	11.5	3024.5
TT Singh	25	34	1.4	11.5	391.0
Narowal	85	88	1.0	11.5	1012.0
Hafizabad	111	187	1.7	11.5	2150.5
Rechna Doab	999	1571	1.6	11.5	18066.5

7.3 Area, Production and Yield of the Cotton Crop

Cotton is a major kharif crop on farms located in central and lower parts of the Rechna Doab. Table 37 provides estimates of the area, production and total value product of the cotton crop in the Rechna Doab. From Table 37, it is evident that in the districts of Gujranwala, Hafizabad, Sialkot and Narowal (since the soils are clayey and not fit for cotton production), the farmers do not grow any cotton on their farms, while in Sheikhupura cotton is grown only on small areas. The farmers in these areas grow cotton to fulfill their domestic requirements and not for commercial purpose. In Jhang,Toba Tek Singh and Faisalabad, cotton is the major Kharif crop covering an area of 61, 45 and 44 thousand hectares, respectively. Total value of cotton produced in the Rechna Doab during 2000-01 was estimated to be Rs. 43211.9 million.

Table 37. District-wise area, production and yield of the cotton crop

District	Area(000 ha)	Prod (000 tons)	Yield (ton/ha)	Price (Rs/kg)	Total Value of Product (Rs. Million)
Faisalabad	44	100	2.3	18.1	41193.2
Sheikhupura	1	1	1.0	18.1	18125.0
Gujranwala	-	-	-	-	-
Jhang	61	142	2.3	18.1	42192.6
Sialkot	-	-	-	-	-
TT Singh	45	117	2.6	18.1	47125.0
Narowal	-	-	-	-	-
Hafizabad	-	-	-	-	-
Rechna Doab	151	360	2.4	18.1	43211.9

7.4 Area, Production and Yield of the Sugarcane Crop

Estimates in Table 38 show high intensity of sugarcane crop on the farms in the districts of Faisalabad, Jhang and Toba Tek Singh, where medium-textured soils dominate. Sugarcane is a high-delta crop and needs both proper soils and ample water for its growth. In the district of Faisalabad, the area under sugarcane crop is maximum, since the soil is medium-textured, suitable for sugarcane production, and the farmers make use of groundwater in conjunction with the surface water to augment their irrigation supplies. As we move towards the tail end of the irrigation system, the area under sugarcane decreases. Table 38 provides estimates for the area production and yield of sugarcane in the Rechna Doab. The sugarcane is grown on 103 thousand hectares in Faisalabad, and in districts of Jhang and TT Singh, it is grown on 72 and 37 thousand hectare, respectively. The total value product of sugarcane in the Rechna Doab is estimated to be Rs. 9916.2 million from 11018 thousand tons of sugarcane produced in the Rechna Doab during 2000-01.

Besides other factors, the crop production also depends upon soil texture, groundwater quality and quantity of canal water. Farmers in the Rechna Doab face the shortage of surface water supplies. About 57 percent of the farmers keep part of their land fallow due to shortage of irrigation water. To meet the crop water requirement, farmers use groundwater with canal water supplies. Farmers with groundwater of good quality have tubewells installed on their farm, and resultantly, have sufficient and more reliable water supplies. Therefore, in the areas where soils are suitable for specific crops, the presence of good quality groundwater can help to enhance the productivity of the crops.

Table 38. Area, production and yield of the sugarcane crop

District	Area (000 ha)	Prod (000 tons)	Yield (ton/ha)	Price (Rs/kg)	Total Value of Product (Rs. Million)
Faisalabad	103	4813	46.7	0.9	4331.7
Sheikhupura	18	679	37.7	0.9	611.1
Gujranwala	3	106	35.3	0.9	95.4
Jhang	72	3130	43.5	0.9	2817.0
Sialkot	2	79	39.5	0.9	71.1
TT Singh	37	1804	48.8	0.9	1623.6
Narowal	4	143	35.8	0.9	128.7
Hafizabad	6	264	44.0	0.9	237.6
Rechna Doab	245	11018	45.0	0.9	9916.2

7.5 Gross Margin Per Hectare from Crop Production

7.5.1 Returns from Wheat Crop

Table 39 shows per hectare cost and benefits from the wheat crop. Wheat is grown throughout the Rechna Doab. It is grown on a variety of soil types, from sandy loam to clay soils. According to Table 39, the highest yield (4.25 T/Ha) is reported inToba tek Singh followed by Jhang producing 3.95 T/Ha. The soil conditions for crop production are favorable in both the districts, i.e. medium-textured soils and good investments on groundwater inputs involved in crop production. The lowest yield was reported in Narowal. Gross margins from the wheat crop in the Rechna Doab varies from Rs. 6750 on the farms located in the Narowal District to Rs. 20794 on the farms located in Toba Tek Singh District.

Table 39. Per hectare production, total cost and gross margins of wheat crop across districts in the Rechna Doab, (Rs/ha)

Districts	Faisalabad	Hafizabad	Jhang	TTSingh	Sheikhupura	Gujranwala	Narowal	Sialkot
Cost of land prep.	2404	2335	2204	2607	2216	2202	1992	1737
Cost of labour	558	541	474	741	467	516	193	487
Cost of seed	914	850	1038	991	867	882	983	890
Inputs	3322	3015	3865	3841	3233	3380	3347	2852
Cost of Irrigation	681	1157	1031	1200	1086	967	532	1030
Harvesting + Thresh	4216	3339	3373	3840	3311	3433	3217	3699
Total Cost	12096	11238	11984	13222	11180	11377	10264	10696
Average Yield (kg/ha)	3657	2768	3954	4250	2669	2866	2372	2965
Gross Income	29334	19895	32143	34015	18433	19761	17014	20210
Gross Margin	17238	8658	20159	20794	7254	8383	6750	9514

7.5.2 Returns from Rice Crop

The rice crop is also a major *Kharif* crop, which is grown throughout the upper Rechna Doab, and some parts of central and lower Rechna Doab. Total cost for rice production was highest in Toba Tek Singh i.e. Rs. 18590. Also, the yield was highest (3.89 T/Ha) in the same district. The high cost of production in Toba Tek Singh is due to the use of tubewell water and high rates for fertilizer application, which has increased the cost of irrigation to Rs. 5411 and the input cost to Rs. 5017/Ha approximately. Rice is a high delta crop and uses maximum quantity of water. Farmers in Gujranwala also use more tubewell water in rice production; therefore, the cost of irrigation is in the range of Rs. 2402/Ha to Rs. 5745/Ha in the districts of Narowal and Gujranwala, respectively. Gross margins from the rice production are in the range of Rs. 7917/Ha in Sheikhupura District to Rs. 14041/Ha in district of Toba Tek Singh (Table 40).

Table 40. Per hectare production, total cost and gross margins of rice crop across districts in the Rechna Doab (Rs/ha)

Districts	Faisalabad	Hafizabad	Jhang	TTSingh	Sheikhupura	Gujranwala	Narowal	Sialkot
Cost of land prep.	2313	2869	2254	2885	2408	2643	2391	2275
Cost of labour	1766	1495	1537	1811	1351	1657	1490	2007
Cost of seed	225	164	292	244	162	160	148	184
Inputs	3700	5712	4424	5017	3769	4300	3181	3058
Cost of Irrigation	3754	5135	4282	5411	4915	5745	2402	5082
Cost of harvesting	2356	2277	3075	3222	2619	2612	2638	3054
Total Cost	14114	17652	15865	18590	15224	17117	12249	15660
Average Yield (kg/ha)	2238	3174	3311	3894	2441	3020	2780	2751
Gross Income	21543	28250	27696	32630	23141	27858	25910	26812
Gross Margin	7429	10599	11831	14041	7917	10740	13661	11153

7.5.3 Returns from Sugarcane Crop

Sugarcane requires fertile, well-drained soils and abundant moisture for successful growth. It can be grown on a wide variety of soils but gives a good yield on clay loam. In the Rechna Doab, it is grown more intensively in the central and lower parts. The sugarcane yield is at the maximum in central regions of the Rechna Doab i.e. 62.1, 58.1, 56.9 and 56.8 T/Ha in the districts of Toba Tek Singh, Gujranwala, Faisalabad and Sialkot, respectively, while the yield is minimum 49.4 in district of Jhang (Table 41). Gross margins from sugarcane crop are the highest with Rs. 28385 and Rs. 25266/Ha on the farms located in the districts of Faisalabad and Sialkot, respectively. Table 41 shows that the lowest returns per hectare are estimated on the farms located in the district of Gujranwala where the gross margin was Rs. 17553/Ha.

7.5.4 Returns from Cotton Crop

The cotton crop is not extensively sown in the Rechna Doab. In the upper parts of the Doab, (districts of Gujranwala, Sialkot and Hafizabad), the intensity of cotton crop is very low. The intensity of the cotton crop increases towards the lower parts of the Rechna Doab. Table 42 shows that the highest yield of cotton was found in Jhang, which is 1.57 tons per hectare. Although investment on the cotton crop is highest in the district of Jhang and Faisalabad, the yield is lowest in Faisalabad.

Table 41. Per hectare production, total cost and gross margins of sugarcane crop across districts in the Rechna Doab (Rs/ha)

Districts	Faisalabad	Hafizabad	Jhang	TTSingh	Sheikhupura	Gujranwala	Sialkot
Cost of land prep.	3437	3988	3378	3257	2994	4882	3719
Cost of labour	2150	2965	1297	2200	1779	3830	2471
Cost of seed	6183	4324	5477	7342	4423	6388	5714
Inputs	5418	4578	5142	7161	3573	6483	5251
Cost of Irrigation	2319	6588	2986	4609	2931	6825	8605
Cost of harvesting	5947	6178	4885	7025	4216	6981	2965
Total Cost	25455	28620	23166	31594	19916	35388	28725
Average Yield (tons/ha)	56.9	54.4	49.4	62.1	47.6	58.1	56.8
Gross Income	53840	47196	46331	56692	43144	52941	53991
Gross Margin	28385	18576	23165	25098	23228	17553	25266

Table 42. Per hectare production, total cost and gross margins of cotton crop across districts in the Rechna Doab (Rs/ha)

Districts	Faisalabad	Jhang	TTSingh
Cost of land prep.	2397	2347	2120
Cost of labour	1820	1069	1280
Cost of seed	955	826	844
Inputs	9049	9892	8703
Cost of Irrigation	1042	1624	1011
Cost of harvesting	1531	1526	1523
Total Cost	16795	17285	15482
Average Yield (kg/ha)	1384	1570	1494
Gross Income	20942	24030	23662
Gross Margin	4146	6746	8180

The cotton yield in Faisalabad District was found lesser than the other districts as farmers did not invest much on necessary inputs on cotton crop as compared to the Jhang and Toba Tek Singh districts (Table 42). The gross margin from cotton crop ranged from Rs. 4146/Ha in Faisalabad District to Rs.8180/Ha in Toba Tek Singh District.

7.6 Potential for Horizontal and Vertical Increase in the Cropped Area

By using the 1990s census data and methodology deployed by Jehangir (1993), the indices to measure the inefficiency on farms across different districts in Rechna Doab were computed to measure the total productivity loss at the Rechna Doab level and at the district levels also (Table 43).

Total increase in cropped area at the Rechna Doab level, by making improvements in cropping intensity and by including the additional area from culturable waste lands, amounts to 2.319 million acres, which is about 40.69 percent of the total cropped area.

Out of this total additional cropped land, 21.01 percent is from improvements in cropping intensity and the remainder from bringing non-culturable wastelands into cultivation. By looking at Table 43, in the Faisalabad, Toba Tek Singh and Jhang districts, the cropped areas can be developed significantly, simply through improvements in cropping intensity. The trend is similar for the Gujranwala, Sheikhupura and Sialkot districts. Assuming that the farmers' cropping pattern does not change, and that the additional cropped area of 0.94 million hectares is distributed among the four major crops. Table 44 shows that on an average, about 0.37 million hectares will be allocated for wheat cultivation and 0 12 million hectares for the rice crop. Also, that the average area for cotton and sugarcane crops will be 0.09 and 0.098 million hectares, respectively. Main contribution in terms of the area under all four major crops comes from the Jhang District, followed by the Faisalabad, Sheikhupura and Gujranwala districts, which are the major contributors in area for all four crops.

Table 43. District-wise increase in cropped area through improvement in cropping intensity and use of presently culturable uncultivated area in the Rechna Doab (hectare)

Districts	Increase in cropped area by reclaiming and bringing under cultivation currently unused land	Increase in cropped area by improving cropping intensity of currently cultivated land	Total increase in cropped area (Col. 2) / (Col. 3).	Increase in CA by improving CI of CCA as % of TICA (Col. 3) / (Col. 4)*100	Col.4 as % of total cropped area**
(1)	(2)	(3)	(4)	(5)	(6)
Faisalabad	14662	195928	210590	93.04	29.37
T.T.Singh	12168	98896	111064	89.04	26.96
Jhang	21362	303099	324461	93.42	29.66
Gujranwala	15297	90617	105915	85.56	13.31
Sialkot	6447	41457	47904	86.54	7.07
Sheikhupura	15759	122817	138576	88.63	17.98
Rechna Doab	85695	852814	938509	90.87	21.01

Note: * A cropping intensity of 100% is assumed

** $\frac{(NSA + CAI + CWA - GCA)}{NSA + CAI + CWA} * 100$

Where:

CI = Cropping Intensity CCA = Currently Cultivated Area TICA = Total Increase in Cropped Area
NSA= Net Sown Area CAI = Cropped Area Irrigated CWA= Culturable Waste Area
GCA= Gross Cropped Area

Table 44. Potential increment in area under major crops in districts of the Rechna Doab, (hectare)

Districts	Wheat	Rice	Cotton	Sugarcane
Sialkot	19321	16287	0	798
Gujranwala	40953	38482	0	1059
Sheikhupura	51403	31293	2017	7597
Faisalabad	80983	6448	12084	35956
Toba Tek Singh	41615	8183	13552	14789
Jhang	135327	18115	62641	38489
Rechna Doab	369603	118809	90296	98688

Considering the existing average yields of the four major crops (wheat, rice, cotton and sugarcane) on the farms in the Rechna Doab, Table 45 estimates their potential productivity in the Rechna Doab. Table 45 shows that by increasing the cropping intensity of the cultivated areas and by bringing the culturable uncultivated area under cultivation, the Rechna Doab has the potential to produce 0.947 million metric tons of wheat, 0.281 million metric tons of rice, 0.103 million metric tons of cotton and 4.671 million metric tons of sugarcane. Once again, the major share of production comes from the Jhang and Faisalabad districts.

Table 45. Potential increment in the additional production of major crops in the Rechna Doab (metric tons)

Districts	Wheat	Rice	Cotton	Sugarcane
Sialkot	39200	16700	0	36000
Gujranwala	93800	49900	0	43900
Sheikhupura	151000	84000	2300	439200
Faisalabad	228400	12800	12400	1772900
T.T.Singh	111400	14500	13700	701900
Jhang	344100	54400	93200	2073100
Rechna Doab	947200	281800	103100	4671900

The results of study by Jehangir and Ali (2000) are given in Table 46, which also highlights that the non-availability of irrigation water at the proper time forces farmers to keep parts of their farm area fallow. It also hampers the productivity level on the farms in the Rechna Doab.

Table 46. Reasons for keeping area fallow in the Rechna Doab

Districts	Not Fallowing (%)	Scarcity of Irrigation Water (%)	Salinity (%)	Others (%)	Total (%)	No. of Farmers
Faisalabad	10	66	18	10	100	199
T. T. Singh	13	56	27	4	100	52
Jhang	18	46	15	21	100	67
Kabirwala	6	35	53	6	100	17
Sheikhupura	18	51	16	15	100	91
Hafizabad	12	65	18	6	100	91
Rechna Doab	13	57	20	10	100	443

The results contained in Table 46 reveal that in the Rechna Doab only, 13 percent of the farms were able to avoid the fallowing. About 57 percent of farmers reported keeping agricultural farms fallow due to scarcity of irrigation water as a major constraint. About 30 percent of the farms had either salinity problem or some other constraints, and had lesser cultivation intensity than the potential in the Rechna Doab.

The effective conjunctive water use may help the farmers to increase the area under crops in the Rechna Doab. It is recommended that the technical conjunctive water use strategies may be identified that would help farmers to increase their income whilst promoting sustainable conjunctive use and management of surface and groundwater.

8. SUMMARY AND CONCLUSIONS

There is a room to exploit the potential of land through horizontal and vertical expansion in the area and productivity of crops in the Rechna Doab by making institutional arrangements for practicing conjunctive water management at the public level. The development and rehabilitation of irrigation and drainage infrastructure and various water conservation schemes in the Doab have increased the annual cropping intensities in good proportion over the period of time. Currently, the farmers are practicing the conjunctive water management individually in the Rechna Doab, subject to the constraints of high cost of groundwater exploitation. Another constraint, which is threatening the farm economies, is the presence of salinity and waterlogging in the Rechna Doab. This study reveals that about 57 percent of farmers are reported to be keeping agricultural farms fallow due to scarcity of irrigation water. About 30 percent of the farms have either salinity problem or some other constraint, and are bound to have lesser cultivation intensity than the potential, which exists in the Rechna Doab. Cropping pattern and intensity demand water up to 24 billion cubic meters annually for meeting the requirements of major crops (wheat, rice, sugarcane and cotton). The farmers in the Rechna Doab are facing technical constraints of surface water availability. Capacity of surface water distribution, water rights, pumping capacity, groundwater levels, water quality and water demands need to be addressed for effective conjunctive water management. The review study highlights the following points:

- Groundwater management has always been accorded a low priority in the past. All previous efforts of improving groundwater management were project-oriented and fragmented. The only regular management task that pertains to groundwater so far is monitoring the levels and quality of groundwater.
- The financial, managerial and productivity reasons have caused institutional reforms in the irrigation management, which are being piloted in the Rechna Doab. As in the past, these reforms so far keep a strict compartmentalization in management and dichotomy in management functions of surface and groundwater.
- The reformed legal instruments are not fully compatible with the reform objectives.
- Appropriate changes are required in the policy and legal framework for preparation and implementation of a comprehensive regulatory framework, which is needed for effective conjunctive water management.

PROPOSED RESEARCH

The effective conjunctive water use may help the farmers to increase the cultivated area under crops in the Rechna Doab. It is recommended that the technical conjunctive water use strategies must be identified and implemented on the farmers' fields in order to help them in increasing their income whilst promoting sustainable conjunctive use and management of surface and groundwater. Careful monitoring of institutional reforms is required to assess the adequacy of reform, the impacts of new arrangements on water resource infrastructure, productivity and the environment.

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