Research Report No. R-58

Water Balance
in
Dhoro Naro Minor Command Area
Sindh, Pakistan

Technical Report

In Collaboration with
Swiss Federal Institute of Technology - Zurich
And IIMI International Irrigation Management Institute - Pakistan

JULY 1998

Pakistan National Program
International Irrigation
Management Institute, Lahore

Eidgenössische
Technische Hochschule
Zürich

Dissertation in Rural Engineering

Research, in Collaboration with
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Supervision

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Zurich, January 1998

Foreword

This report is the combined Dissertation in Rural Engineering for Ms. Beatrice Keller and Mr. Gabor Jaimes for their Master of Science degrees. They were students in the Institute for Land Improvement and Water Management of the Swiss Federal Institute of Technology (ETH) located in Zurich, Switzerland. They were located at the IIMI Nawabshah Field Station during August to December 1997 to complete all of the necessary field work.

We have a number of national and international students participating in the research program of the Pakistan National Program of the International Irrigation Management Institute. Their theses and dissertations are retained in our library for ready reference. Only a few of theses documents are selected for publication in our research report series. The principle criteria for publishing is good quality research and a topic that would be of interest to many of our national partners.

This report is an output of a collaborative research program with the Institute for Land Improvement and Water Management of ETH. This research is a part of our program under the "Pilot Project for Farmer-Managed Irrigated Agriculture under the Left Bank Outfall Drain Stage I project, Pakistan", which was funded by World Bank IDA and the Swiss Agency for Development and Cooperation (SDC).

Dhoro Naro Minor is one of the three pilot distributaries where the farmers have organized at each watercourse as a Water Users Association (WUA) and then organized as a Water Users Federation (WUF) for managing the combined irrigation and drainage facilities for the Dhoro Naro Minor command area.

Besides this report, there is a bound copy of the appendix located in the library of IIMI Pakistan in Lahore. For those interested in more details, this document of 242 pages can be reviewed.

Gaylord V. Skogerboe, Director
Pakistan National Program
International Irrigation Management Institute

Preface

The authors of this dissertation, Gabor Jaimes and Bea Keller, are students in rural engineering at the Swiss Federal Institute of Technology (ETH) in Zurich, Switzerland. The work is being carried out in the Section for Rural Development, Soil and Water Management of the Institute for Land Improvement and Water Management. This is a combined report of two different studies.

Gabor Jaimes had to finish his part within 14 weeks, from 06-10-97 to 23-01-98. Therefore, he stayed in Pakistan for 11 weeks, from October 5 until December 19, spending most of the time at the IIMI-Nawabshah field station.

Bea Keller already started on 03-08-97 and stayed in Pakistan for 16 weeks, also mainly in Nawabshah. Due to Jaundice she had to return to Switzerland on 23-11-97. So the authors put their parts together in Switzerland in January 1998.

Dr. Lashari, O&M Specialist at IIMI-Hyderabad, will combine this dissertation with his own study to write a report on salt and water balance of the selected study area.

Gabor Jaimes had previous field training in 1997 from February 16 to March 28, for WAPDA (LBOD) on remedial work of disposal channels in Nawabshah, supported by the Swiss Agency for Development and Co-operation (SDC).

For the purpose of this dissertation, Prof. Martin Fritsch and Sam J. Gelzer visited IIMI-Pakistan from 21-09-97 to 03-10-97 to get an overview of the circumstances and to determine the responsibilities of the students.

On December 15, Gabor Jaimes held a seminar at the IIMI-Hyderabad office to present his research work and some parts of Bea Keller's work to an audience composed mainly of IIMI staff and LBOD consultants *(see Appendix A1)*.

A first draft of the report was handed over to IIMI-Hyderabad by Gabor Jaimes before leaving Pakistan. The final draft, finished in Switzerland has been sent to IIMI-Lahore. Copies of this should be distributed to other IIMI stations (especially to IIMI-Hyderabad and IIMI-Nawabshah) as well as to WAPDA-LBOD (SMO, O&M).

This dissertation will be evaluated by Prof. Gaylord V. Skogerboe (Director IIMI-Pakistan) and Prof. Martin Fritsch (Professor for Land Improvement and Water Management at the Swiss Federal Institute of Technology).

Primarily, this dissertation should be useful for further research in the area of LBOD carried out by IIMI. Secondly, it should give a detailed description of research that has been done on a small scale site within the LBOD Stage-1 Project Area. This should encourage and guide future research at the Swiss Federal Institute of Technology (Zurich, Switzerland) and at the local Mehran University of Engineering and Technology (Jamshoro, Pakistan) on this topic or within this site.

Acknowledgements

The authors are very grateful to Prof. Gaylord V. Skogerboe (Director IIMI-Pakistan) for giving the opportunity to write this dissertation at his Institute, to Prof. Martin Fritsch for the permission provided to attend the Master's Degree Program at his Institute and to Sam J. Gelzer for organising the dissertation program and keeping in contact (e-mail, fax) to deliver information needed from Switzerland during the students' research work in Pakistan.

The authors are also very grateful to Dr. Bakhshal Khan Lashari for his kind supervision, guidance and suggestions in completing this research work, to Dr. S.A Prathapar and Dr. Muhammed Shafqat Ejaz for their co-operation in the subjects of groundwater hydraulics, surface water hydrology and soil physics, to Dr. M. Yameen Memon, Abdul Hakeem Khan, Rubina Siddiqui, Ayaz Anwer Solangi and Ahsan Ali Kazi (all at IIMI-Hyderabad) for their valued administrative help.

The writers are extremely thankful to the staff of IIMI-Nawabshah field station, namely Nizamuddin Bharchoond, Abdul Rehman Soomro, Fateh Mohammad Mari, Parvez Ahmed Pirzado and Muneer Ahmad Mangrio for their great help in collecting all the data and supporting this research. For the list of IIMI people involved in the activities of this dissertation, see Appendix A2.

Finally, the authors want to thank the people from SMO (WAPDA), namely Chris Hall and Allah Bux Soomro, for providing data of the Physical Monitoring program on LBOD Stage-1, to the Meteorological Departments of Pakistan in Lahore and Karachi, for providing meteorological data to IIMI-Pakistan, and the Swiss Federal Institute of Technology for providing financial support, to all the people who have helped to complete this report properly way by of editing and correcting, to all the staff involved in the pumping test and the 7-day intensive discharge measuring period carried out in Nawabshah, and last of all, to all the people (friends) who made this stay a time to remember.

Executive Summary

This report describes research on a complementary study of Gabor Jaimes and Bea Keller, students in rural engineering at the Swiss Federal Institute of Technology (ETH), Zurich, Switzerland. This research was carried out in collaboration with the Institute of Land Improvement and Water Management and the International Irrigation Management Institute (IIMI) in Pakistan.

The objective of this report is an analysis of the water balance within the the Dhoro Naro Minor Command Area, an IIMI pilot site near the city of Nawabshah within the LBOD Stage-1 Project Area in Sindh, Pakistan, to get an idea of the monthly net recharge to the groundwater.

Data collected by IIMI-Nawabshah field staff since December 1996, meteorological data since 1932, as well as project impact monitored by SMO and O&M (WAPDA-Hyderabad) for several years, have been used to evaluate fluctuations in water table and crop water requirements. In addition, a pumping test was carried out to get a better idea of soil characteristics within the area and a 7-day intensive discharge measuring period was set up to study fluctuations and seepage losses.

For the purpose of analysis, most data was put into spreadsheets (Excel 5.0). Contour maps and surface plots of the water table were created for each month (April-December 1997) using the computer software SURFER. Thus, critical areas of high water tables according to the ground surface could be located. To analyse crop water requirement, the computer program CROPWAT was used.

The the Dhoro Naro Minor command area is not suffering from waterlogging and salinity much. Shortage and unfair distribution of irrigation water cause the major problems, especially during the sowing period. In order to understand the connection between irrigation and drainage, the current irrigation and drainage performances had to be checked and a list of irrigation and drainage management practices has been prepared.

Finally, some practices in collecting and analysing data have been recommended, to ensure proper and reliable monitoring within the area. The prepared spreadsheets and contour maps can be used for the ongoing collection of data for all three IIMI pilot sites in Sindh. That may be helpful for further studies carried out by IIMI, or other universities. Also, it can be useful for the ongoing monitoring of the LBOD Stage-1 project by SMO (WAPDA), or the routine work of O&M (WAPDA).

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Abbreviations

AI	Additional Irrigation
AVG	Average
CCA	Culturable Command Area
DC	Disposal Channel
DP	Disposal Point
EC	Electrical Conductivity
ET	Evapotranspiration
ETHZ	Eidgenössische Technische Hochschule Zurich Swiss Federal Institute of Technology Zurich (Switzerland)
FL	Field Loss
GCA	Gross Command Area
GoP	Government of Pakistan
GoS	Government of Sindh
GPS	Global Positioning System
GW	Groundwater
HP	Horse Power
IIMI	International Irrigation Management Institute
IRR	Irrigation
KPOD	Kadhan Pateji Outfall Drain
KVA	Kilo Volt Ampere
LBOD	Left Bank Outfall Drain
LIP	Lower Indus Project
MMP	Mott MacDonald Partners
MPR	Monthly Progress Report
NDP	National Drainage Program
OFWM	On-Farm Water Management
OFWMD	On-Farm Water Management Department
O&M	Operation and Maintenance
P1	Piezometer 1
P2	Piezometer 2
RD	Reduced Distance
SDSC	Sindh Development Studies Centre
SL	Seepage Loss
SMO	SCARPs Monitoring Organisation
SMS	Soil Moisture Storage
SSO	Supervisory Social Organiser
TW	Tubewell
WAPDA	Water and Power Development Authority
WC	Watercourse
WTD	Water Table Depth (Groundwater only)
WTE	Water Table Elevation (Groundwater only)
WTF	Water Table Fluctuation (Groundwater only)
WUA	Water User Association
WUF	Water User Federation
WUO	Water User Organisation

Expressions

Benchmark	Surveyed point (on outlet, piezometer, tubewell)
Branch	Primary irrigation canal
Distributary	Secondary irrigation canal
Chowkidar	Local tubewell operator
Disposal channel	Drainage channel fed by wells
Kharif	Summer cropping season (April - September), wet
Minor	Secondary irrigation canal
Zamindar	Landowner
Mogha = outlet	discharge regulator in watercourse
Rabi	Winter cropping season (October - March), dry
Warabandi	Schedule of rotating irrigation system
Watercourse	Tertiary irrigation canal

Conversions

Length:

1 inch	=	2.540	cm			
1 cm	=	0.3937	inch			
1 foot (ft)	=	0.3048	m			
1 m	=	3.281	ft			
1 yard	=	0.9144	m			
1 m	=	1.0936	yard			
1 mile	=	1.6093	km			
1 km	=	0.6214	mile			
1 RD	=	1000	ft	=	304.8	m

Area:

1 acre	=	43560	ft^2	=	4046.86	m^2
1 hectare	=	2.471	acres			
1 m^2	=	10.765	ft^2			
1 km^2	=	247.11	acres			

Discharge:

1 cusec (ft^3/s)	=	28.3168	l/s	=	448..83	gpm
1 gpm	=	2.228E-3	cusecs	=	0.06309	l/s
1 l/s	=	0.0353	cusecs	=	15.8504	gpm
1 m^3/s	=	35.3147	cusecs	=	15850.4	gpm

Temperature:

X ^{0}F = 5/9 (Y - 32) ^{0}C

Y ^{0}C = (9/5 X + 32) ^{0}F

Notations

Q	= Canal (Tubewell) Discharge	$[L^3T^{-1}]$
A	= Area	$[L^2]$
v	= Velocity	$[LT^{-1}]$
c_d	= Discharge coefficient	[-]
Q_f	= Discharge in free flow	$[L^3T^{-1}]$
Qs	= Discharge in submerged flow	$[L^3T^{-1}]$
G_0	= Gate opening	[L]
W	= Gate width	[L]
h	= depth of water	[L]
h_u	= upstream flow depth	[L]
h_d	= downstream flow depth	[L]
v_c	= correction factor	[-]
v_c	= velocity measured by current meter	$[LT^{-1}]$
g	= earth acceleration	$[LT^{-2}]$
H	= Saturated Thickness of the Aquifer	[L]
K	= Hydraulic Conductivity	$[LT^{-1}]$
T	= Coefficient of Transmissivity	$[L^2T^{-1}]$
S	= Coefficient of Storage	[-]
S_Y	= Specific Yield	[-]
s	= Drawdown	[L]
s'	= Residual Drawdown	[L]
t	= Time (during Drawdown)	[T]
t'	= Time (during Recovery)	[T]
r	= Distance from Tubewell to Piezometer	[L]
EC	= Electrical Conductivity	[mS]
H	= Thickness of the saturated Aquifer	[L]
RD	= Reduced Distance	[L]
CCA	= Culturable Command Area	[L2]
GCA	= Gross Command Area	[L2]
k_C	= Crop Coefficient	[-]

1. Introduction

This dissertation is about the link between irrigation and drainage on a small scale. The flow of water and local site conditions were analysed.

1.1 Objectives of the Study

The main goal of this twin-research of Bea Keller and Gabor Jaimes is to estimate the monthly net recharge (R_{NET}) to the groundwater in the Dhoro Naro Minor Command Area (Sindh, Pakistan) in order to optimise irrigation and drainage practices. Therefore, it is necessary to study the water cycle within this area as discussed with Dr. S.A. Prathapar and Prof. Dr. M. Fritsch. The main parameters concerned are shown in Figure 1 . For a more detailed diagram see Figure 7 in Chapter 2.1.

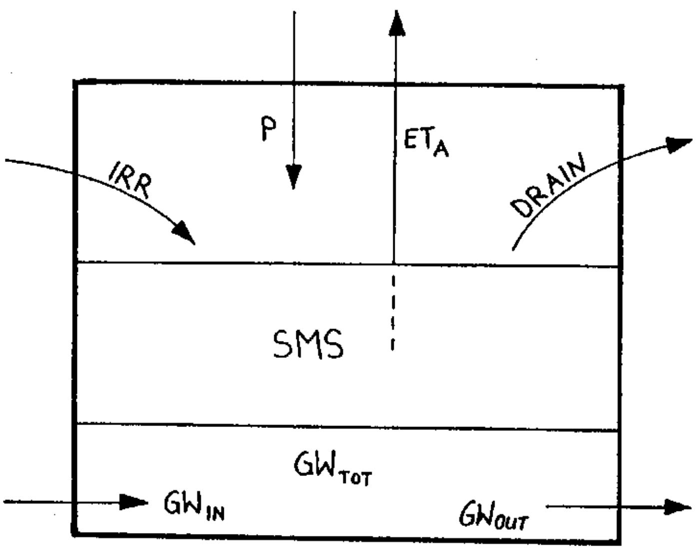

Figure 1 Schematic Diagram of the Water Cycle

Where,

IRR	Surface Irrigation from Canals
P	Precipitation
ET_A	Evapotranspiration
DRAIN	Drainage
SMS	Soil Moisture Storage
GW_{TOT}	Groundwater Flow
GW_{IN}	Groundwater Inflow
GW_{OUT}	Groundwater Outflow

This research has two areas of responsibility. Bea Keller studied the flow of surface water, measured discharges and seepage losses and estimated the recharge to the groundwater from the irrigation side. Gabor Jaimes took responsibility for the flow of the drainage water. He used the data of groundwater fluctuations monitored at the installed piezometers within the the Dhoro Naro Minor Command Area. For the detailed terms of reference, see Appendix A3.

1.2 Geographical Background

1.2.1 Pakistan

Geography: Pakistan is a big country (834,253 km^2) ranging from the Arabian Sea in the South to the mountains of Himalaya, Karakorum and Hindu Kush in the North. It borders on India, China, Afghanistan and Iran. The Indus is the main river in Pakistan, flowing about 1500 km southwards from the Himalayan range into the Arabian Sea. The MRV's passage is fed mainly by the big rivers, Sutlej, Ravi, Chenab and Jehlum in the Punjab.

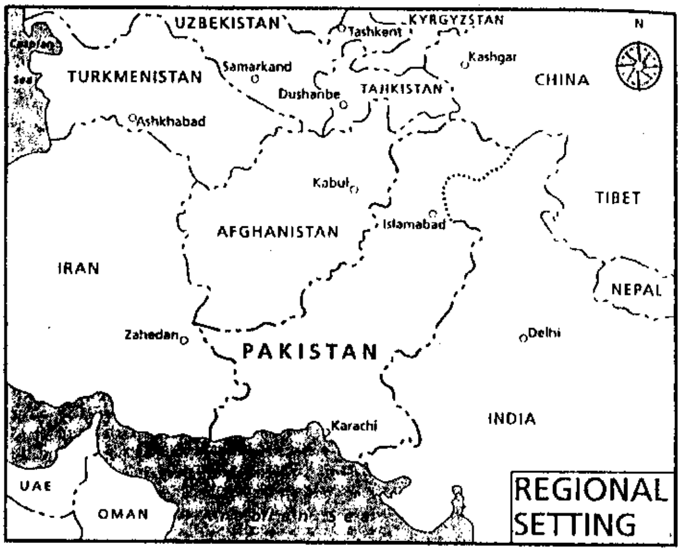

Figure 2 Map of Pakistan

Climate: Pakistan has a semi-arid to arid climate, except in the mountain areas, and is affected by the monsoon that usually brings rain from June to September. The average temperature in the Indus plain ranges between 15 degrees (in winter) and 40 degrees Celsius (in summer). The average annual rainfall is less than 250 mm, up to 500 mm in the South and up to 2000 mm in the North (Mannheim and Winter, 1996)

History: Pakistan has a very old history and there was an important civilisation from 2500 to 1500 BC at Moenjodaro (Sindh). This civilizations influence was widespread and the people cultivated the fertile alluvial soil along the Indus river. In the 8th century, Islamic culture spread from the west over the land and has maintained its influence unto now. In the 18th and 19th centuries, the whole subcontinent (India, Pakistan, Bangladesh) was under British rule. The British influenced trade, the infrastructure (railways, irrigation canals, roads), the educational system and industrial productivity. On the 14th August 1947 Pakistan was partitioned from India, and became independent. In the beginning, Pakistan consisted of two parts, with India situated in the middle. But, in 1971, the eastern part declared independence and took the name Bangladesh. Since then, Pakistan has sought to find its own identity. Unfortunately political instability and corruption have hampered the country in improving its image (Mannheim and Winter, 1996).

Economics: Agriculture (including forestry and fishing) is the biggest economic sector (employing about 50 % the labour force), especially in the fertile river plains in Punjab and Sindh. The main crops are cotton, wheat, sugarcane, fodder, oil seed, vegetables and orchards (especially mango and banana). Cattle, goats and chickens are kept for their products (milk, eggs) and their meat.

The industrial sector (15 %) and the socio-economic sector (35 %) are very often related to agriculture (cotton mills, sugar mills etc., and business dealing in these products). So, 60-70 % of the population has a direct, or indirect, income from agriculture.
The local currency is Pakistani rupee (pRs. or PKR). The actual exchange rate is:

1 US$ = 46 PKR (December 1997)
1 CHF = 32 PKR (December 1997)

1.2.2 Sindh

The province of Sindh lies in the south-east of Pakistan with an area of approximately 140,000 km^2 (more than 3 times the size of Switzerland). On the border to the west is the Kirthar range, and towards the east, the Thar and the Cholistan Deserts. In between there is the fertile Lower Indus plain with its alluvial deposits. The most noteworthy characteristics of the climate in Sindh are high summer temperatures (up to 50 degrees centigrade), low rainfall and considerable variation in the timing, location and volume of the rainfall (Mannheim and Winter, 1996).

Figure 3 Map of Sindh

Owing to the arid and hot plains of the Lower Indus plain, where the project area is located, sustainable agriculture is not possible without irrigation. That is why the Kalhoras (former rulers of Sindh) started to build big irrigation canals in the 17th century. These were inundation canals fed by the Indus river and only worked seasonally, starting in spring after the snow melted in the mountains and continuing during the summer, fed by monsoon rain. In winter the water level of the Indus river was too low. That is why, in earlier, times they only had one crop (see MFAC, 1984).

When the British took over Sindh in 1843, there existed a huge network of inundation irrigation canals. The British found canals that were in bad shape. But the situation worsened, because the officers in charge were not technicians (see MFAC,1984).

This changed in 1855, when Col. J.G. Fife (engineer) took over the Canal Department. Today he is known as the "Father" of the irrigation system in Sindh. He prepared a project to link Nara River by an artificial channel with the river Indus, in order to get perennial irrigation for these two cropping seasons. This Nara supply channel was opened in 1859. Many others followed. Col. Fife also proposed to build Sukkur Barrage, and so keep the water level of this River Indus at a constant level, but the project was delayed for a long time. Finally, this project was accepted in 1919 and work was carried out from 1923 to 1932 at a cost of PRs. 200 million (see MFAC,1984).

The total canal command area in Sindh is now 13.2 million acres, out of which 7.8 million acres is along the Sukkur Barrage canal system. 7.3 million acres receive perennial irrigation. The main *kharif* (summer) crop is cotton; the main *rabi* (winter) crop is wheat. Sugarcane is grown the whole year round (see MFAC,1984).

1.2.3 LBOD Stage-1 Project Area

In 1932 it was already known that the irrigated land would require drainage but because of the deep water tables at that time it was not yet needed. With World Bank assistance, a drainage project was carried out in 1959 in Khairpur, to the north of Nawabshah. A study was carried out for the whole of the Sindh province known as the Lower Indus Project (LIP). In 1966 the Left Bank Outfall Drain (LBOD) was proposed as part of the LIP. The first useful study was done in 1969. In 1973 the Government of Pakistan accepted the project, and work began (WAPDA, 1996).

The LBOD Stage-1 Project is designed to control groundwater levels and improve the collection and disposal of saline drainage water from an area of 1.275 million acres of the Left Bank of the Indus River. As one of the largest engineering drainage projects of the world, it permits drainage water, for the first time in Pakistan, to be discharged to the sea *(see Appendix F)* (SMO, 1996).

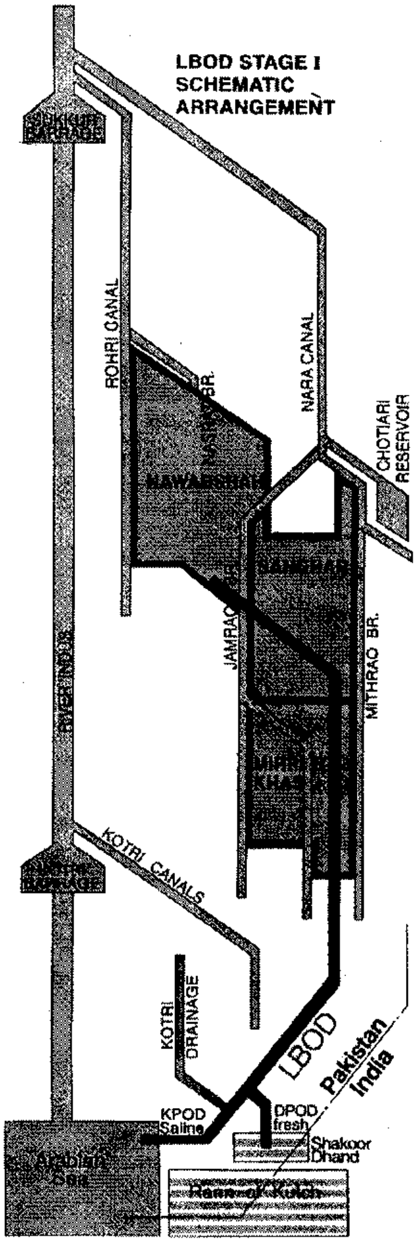

Figure 4 Schematic Location Plan of LBOD Stage-I Project Area

Project activities include the remodelling of canals and drains, the construction of new drainage networks, drainage tubewells, scavenger wells, tile drainage and interceptor drains, together with the necessary infrastructure. The principal areas covered by LBOD Stage-1 include Nawabshah, Sanghar and Mirpurkhas Districts. For detailed maps see Appendix F (SMO,1996).

A complementary activity of LBOD is the provision of additional irrigation water to serve land reclaimed by drainage. This is being addressed through the remodelling of the Nara Canal and the enlargement of the Chotiari Reservoir. Saline effluent from the LBOD Stage-1 Project Area and from the Kotri Command Area are transported through the LBOD Spinal Drain and the Kadhan Pateji Outfall Drain (KPOD), to the Arabian Sea via the Tidal Link (SMO, 1996).

1.2.4 Nawabshah Sub-project Component

The Nawabshah component covers an area of 353,000 acres. Situated in the northern part of the LBOD Stage-1 Project, it lies between the Rohri and Jamrao Canals and is the most developed at this time. It includes 628 km of surface drains, 154 km of interceptor drains, 275 standard tubewells and 189 scavenger wells *(see Appendix F)*.

The main problems in Nawabshah are waterlogging and salinity, as well as shortage of irrigation water at the tail end of distributaries and siltation of the canals. Further, there is a lack of maintenance for the existing infrastructure.

1.2.5 the Dhoro Naro Minor Command Area

The the Dhoro Naro Minor branches off from the Gajrah Branch leading from Nusrat Branch out of the Rohri Canal *(see Figure 5)* (IIMI, 1995).

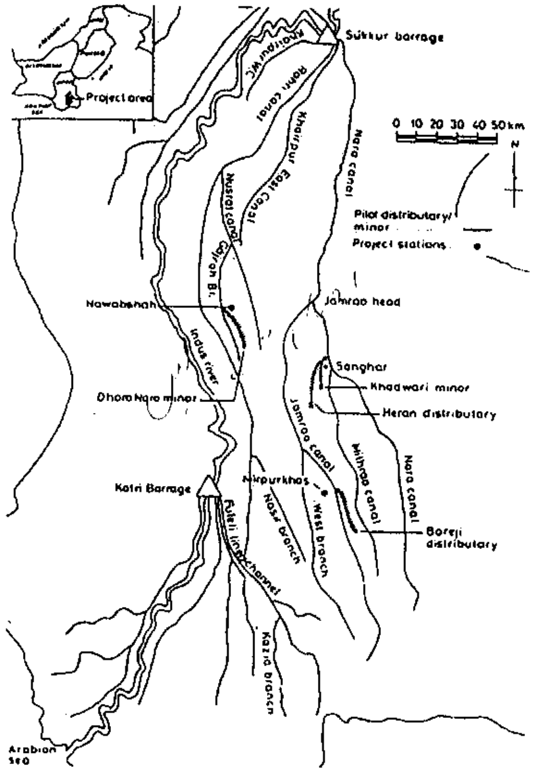

Figure 5 Location Map of the IIMI Project Areas within LBOD Stage-I

The total length of the Dhoro Naro Minor is 10.4 km. The designed discharge is 52 cusecs, which irrigates an area of about 13,000 acres of CCA. The Dhoro Naro Minor feeds 25 watercourses with a total length of 78 kilometres. Further, the area is drained by 7 tubewells and 12.5 km of their disposal channels DC. There are 70 piezometers installed, three at each watercourse, at the head-middle-and tail ends. This area is one of the three IIMI pilot sites within the LBOD Stage-1 Project Area. For further physical, technical and social features, see Appendix A4 or IIMI, 1995. A detailed layout plan of the IIMI Project Area of the Dhoro Naro Minor is presented in Appendix F.

Since September 1995, IIMI field staff have received training to improve their technical, managerial and social skills. Since then they have informed the population about the project. The first training for contact farmers was in August 1996. On all three pilot sites some basic information was collected in October 1996. An IIMI field team is made up of 5 people: 2 engineers, 2 social workers and a supervisory social organiser SSO.

The farmers of each watercourse were organised, and in November 1996 the first Water User Association (WUA) was established on a tertiary canal level. Now there are 25 WUAs and together, these established one Water User Federation (WUF) on a secondary canal level. The responsibilities of the minor had been handed over to this Water User Federation on 15th November 1997 for the first time in Pakistan.

1.3 Institutional Background

1.3.1 International Irrigation Management Institute (IIMI)

"IIMI is an autonomous, non-profit international research and training institute headquartered in Colombo, Sri Lanka. Different IIMI projects are funded separately by various donor agencies" (from IIMI, 1995).

Since 1986, IIMI-Pak headquartered in Lahore, has been conducting research about irrigation management in Pakistan, by strengthening governmental (irrigation) agencies, helping farmers to increase agricultural production and ensuring that any interventions enhance the sustainability of irrigation systems. The projects IIMI-Pakistan work on are multiple and are spread all over Pakistan, as shown in Figure 6.

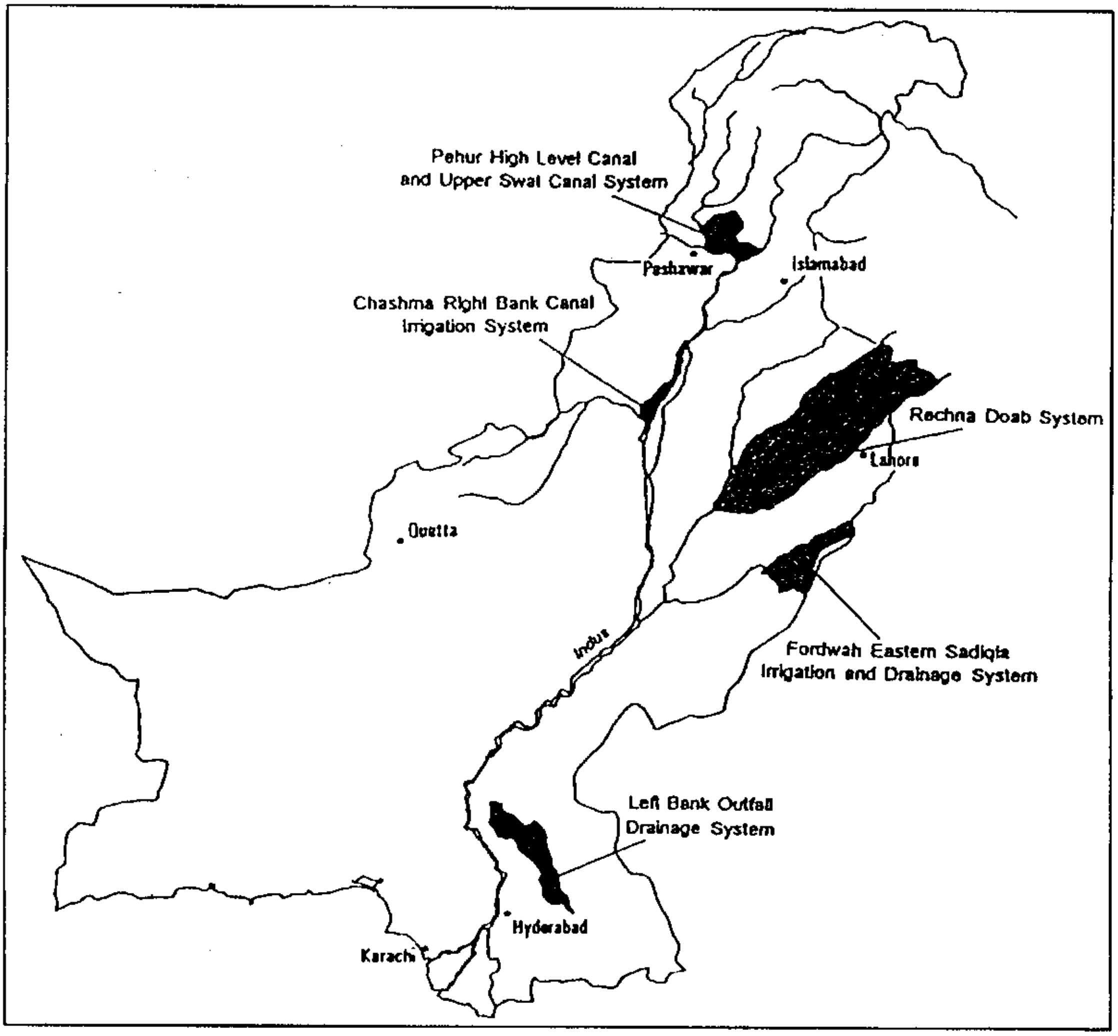

Figure 6 Project Areas of IIMI

Since 1995 IIMI has started work in Sindh, and has established an office in Hyderabad and three field stations, one at each of the pilot distributaries, Dhoro Naro Minor (Nawabshah), Heran Distributary (Sanghar) and Bareji Distributary (Mirpurkhas), as shown in Figure 5.

The pilot project was to establish three Water User Federations WUF, which were to take over the whole, or part, of the operation and maintenance responsibilities of the three selected secondary canals in the LBOD Stage-1 Project Area. Basically, this initiative seemed to rest on the fact that the completion of LBOD Project facilities would drastically increase budget requirements for proper maintenance of the canal irrigation system in Sindh, and that it is likely that the involvement of water users in a participatory management approach could effectively improve the O&M management of both, the irrigation and drainage systems (see IIMI, 1995). The responsibilities were handed over to the WUF on 15th November 1997.

IIMI's part of the LBOD Stage-1 Project was funded for 30 months up to December 1997, with 1 million US$. LBOD and SDC share (50 % each) of this fund. From 1998 the World Bank and SDC have agreed to extend IIMI's project in Sindh for the next three years.

1.3.2 SCARPs Monitoring Organisation (SMO)

SMO is the physical monitoring unit of the Water and Power Development Authority (WAPDA) with the financial help of the World Bank and other donors to evaluate the impact of the drainage system and other measures initiated by the LBOD Stage-1 Project. The elements listed below are monitored by SMO:

1) Hydrologic Monitoring of Drainage and Scavenger wells
2) Surface Water/Drainage Monitoring
3) Tile Drainage Monitoring
4) Interceptor Drains Monitoring
5) Soil Salinity Monitoring
6) Water Quality Monitoring
7) Water Table Monitoring
8) Meteorology
9) Tidal Link

(SMO, 1996)

2. Materials and Methods

2.1 Approach

The study of water-flows is the main subject in this dissertation, schematically visualised in Figure 7. The collection of available data is studied in Chapter 2.2. Some tests had to be made and some specific software was used to determine the single factors (arrows). The detailed discussion about every single flow, or storage, and their values are described in Chapter 2.5.

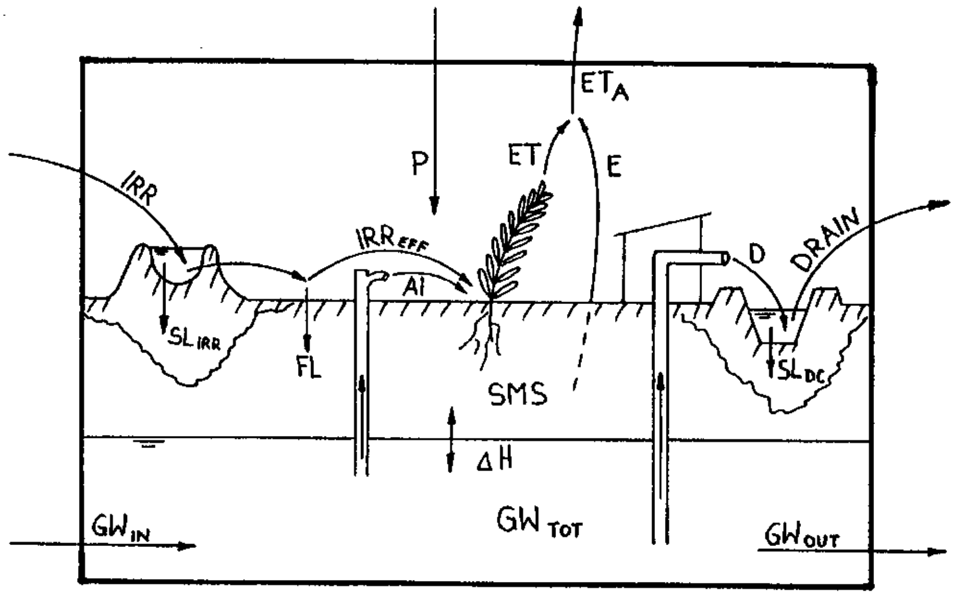

Figure 7 Schematic Water Cycle in the Dhoro Naro Minor Command Area

IRR	Surface Irrigation from Canals
IRR_{EFF}	Effective Irrigation
AI	Additional Irrigation
SL_{IRR}	Seepage Loss from Irrigation Canals
FL	Field Loss
P	Precipitation
ET_A	Actual Evapotranspiration
ET	Evapotranspiration in Cropped Areas
E	Evaporation in Non-Cropped Areas
D	Discharge of the Tubewells
SL_{DC}	Seepage Loss from Disposal Channels
DRAIN	Effective Drainage
ΔH	Water Table Fluctuation
SMS	Soil Moisture Storage
ΔSMS	Change in Soil Moisture Storage
GW_{TOT}	Total Amount of Groundwater
ΔGW_{TOT}	Change in Groundwater Storage
R_{NET}	Net Recharge to Groundwater = ΔGW_{TOT}
GW_{IN}	Groundwater Inflow
GW_{OUT}	Groundwater Outflow

2.1.1 Development of Equation I

To find an equation for calculating net recharge to groundwater, R_{NET}, a basic derivation was made:

$$\Sigma \text{ Inflow} - \Sigma \text{ Outflow} + \Delta \text{ Storage} = 0$$

In more detail:

$$IRR + P + GW_{IN} - ET_A - DRAIN - GW_{OUT} + \Delta(SMS + GW_{TOT}) = 0$$

Due to a well-balanced slope of the water table *(see Appendix E2)* and due to very little lateral groundwater flow, the amount of groundwater inflow is set equal to the groundwater outflow:

$$GW_{IN} \equiv GW_{OUT}$$

Therefore, these two factors can be neglected in further calculations, remaining:

$$-\Delta GW_{TOT} = IRR + P - ET_A - DRAIN + \Delta SMS$$

As defined, the change in groundwater storage is equal to the net recharge to groundwater:

$$-\Delta GW_{TOT} \equiv R_{NET}$$

So, the first equation for calculating R_{NET} is created:

$$\mathbf{R_{NET} = IRR + P - ET_A - DRAIN + \Delta SMS} \qquad \textbf{Equation I}$$

Some factors are split into sub-factors, as:

$$IRR = IRR_{EFF} + SL_{IRR} + FL$$

$$ET_A = ET + E$$

$$DRAIN = D - SL_{DC}$$

AI: Additional Irrigation is an internal flow that does not influence the water budget within the selected area.

Surface Runoff was never seen, and because of flat land, it is not expected to take place at any time of the year.

2.1.2 Determination of Equation II

There is another approach to estimate the net recharge by monitoring the effective change of the water table. This approach does not include any internal or external water-flows and is termed as:

$$R_{NET} = \Delta H \bullet S_Y \bullet GCA \qquad \textbf{Equation II}$$

R_{NET} = Net recharge to groundwater [cubic feet]
ΔH = Water table fluctuation [ft]
S_Y = Specific Yield [-]
GCA = Gross Command Area [acres]

2.1.3 Connection of the 2 Equations

The equations as defined above do have two different approaches, being independent of each other. The net recharge to groundwater is estimated by measuring the different water-flows as well as by monitoring water table fluctuations. At the end, the two results of R_{NET} should be the same. The results are discussed in Chapter 3.

2.2 Collection of Data

2.2.1 Water Table Monitoring

IIMI: IIMI has installed three piezometers along each watercourse. One at the head, one in the middle and one at the tail end of the watercourse. They are identified by the watercourse number and the position of the piezometer at that watercourse (for example: 3R-H[ead], 3R-M[iddle], 3R-T[ail]). Not all watercourses contain three piezometers. Some only have two (i.e. 1DL, 2R, 5R). Watercourse 10L has four piezometers; 1CL shares the piezometer at the head end of the watercourse with 1L and 7R-T is also common for 11T-H.

In total, there are 71 piezometers installed by IIMI in the the Dhoro Naro Minor Command Area (state on December 1997). The piezometer pipes have a length of 25 ft (7.6 m) with a screen length of 10 ft (3.0 m) from the bottom. The diameter of the pipes is 1.5 inches (3.8 cm).

The level of the top of the concrete platform of the piezometers (benchmark) has been taken by levelling from the outlet structure *(mogha)* of the respective watercourse to the piezometer. The ground level has been taken by calculating the average elevation of the ground surface around the piezometers in four directions *(see Appendix B1)*.

The water table is measured with Avometer and measuring tape. The accuracy with tape reading is ±1 cm. IIMI staff measure the water table at the end of the corresponding month. Missed readings are due to choked or damaged piezometers, or sometimes due to lack of time. Some missing readings have been completed by calculation. Therefore, the average was taken from the reading of the previous and the following month. These numbers are written in italics. IIMI started monitoring the water table in the the Dhoro Naro Minor Command Area in April 1997. The data collected up to December 1997 is listed in Appendix B2 and contoured in Appendix E2.

SMO: In 1986, a network of 513 observation sites was established based on an arbitrary grid of 4.34 square miles (11 km^2) covering the LBOD Stage-1 Project Area. At seven sites there are water level stage recorders which were installed in 1983. The stage recorder charts are processed manually to give daily mean water levels. These are then entered into spreadsheets and reduced to give 5 daily averages *(see Appendix B2)*. At the ordinary piezometers, or open wells, readings are taken bi-annually during April and during October *(see Appendix B2)*. Readings are confined to depth to water table from ground surface and are not converted to relative levels. The XYZ data from spreadsheet format is imported into SURFER contoured, combined with base map data developed using AutoCAD and then printed. The contour maps of 1996 and 1997 of Nawabshah Component are shown in Appendix E2 (SMO, 1996).

The data used for this dissertation are taken from the piezometers NC 109, NC 110, NC 111, NC 117, NC 118, NC 128 and the observation well NS 87 within the the Dhoro Naro Minor Command Area since April 1988. Unfortunately, they could not be located and drawn on an IIMI layout plan yet. Further, the data of the stage recorders at Sathmile and Shahpur Chakar were used to get a long term review of water table fluctuations near the command area *(see Appendix B2)*.

2.2.2 Irrigation Monitoring

The first discharge measurement at the head of the Dhoro Naro Minor was taken by IIMI staff in December 1996. From then to May 1997, a study was done to correlate discharge (Q) and gate opening (G_o), water levels upstream (h_u) and water levels downstream (h_d), as described in Equation 10. All available measurements until November 1997 are shown in Appendix E2.

Discharge measurements normally would be done through current-metering. With depth the discharge could be calculated. But, because this is a very time-consuming procedure can be taken, the irrigation structures (gate at the head and *moghas*) were calibrated. With this, tape readings can be taken from a white mark to the water level. The distance between the white mark and crest level was measured before, and the difference of these two numbers gives the water level h_u or h_d. These can then be transformed into the discharge with the calibrated formula.

Since July 1997 tape readings are taken twice a week, with about one current meter reading per month to re-calibrate the gate, due to major siltation problems in the distributary. For detailed description of calibrations, see Siddiqui *et al*, 1996.

From 8th to 15th October 1997, a special measuring period was taken to study fluctuations and seepage losses in watercourses (see Chapter 2.3.2). The calculated discharge shows a very clear correlation between gate opening and *discharge (see Appendix D7)*. This probably is not a very accurate picture, because the officer handling the gate appeared very insecure and confused through the special measuring period, and he probably felt that people were controlling him.
The officer in charge, regulating the gate openings, is normally noting down the downstream water level, read from a gauge installed by the Irrigation Department. If the water level in the distributary falls, he opens the gate; if it rises, he lowers it. Like this he tries to keep the water distribution after his own words, constant and in a fair "equilibrium", for all three distributaries. (?) One author's personal impression is that through bribery, this equilibrium can change easily and if the cash flow is not as wished, one gate is lowered very quickly.

In January / February there is normally no water for one month, due to cleaning and repairing of the big canals. On rare occasions the water level in Gajrah Branch falls due to upstream breaches of the sandy banks, but this problem is solved within hours, or a few days.

2.2.3 Drainage Monitoring

IIMI: IIMI staff collect the running hours of the tubewells within the the Dhoro Naro Minor Command Area, monthly, since March 1997, by taking the readings from the electrical units *(see Appendix B3)*. Unfortunately, there are gaps in the collection of the data due to lack of time or because the *chowkidar* (operator) of the tubewell was not available. In this case, an average operational efficiency throughout the missing month is assumed. The average daily running hours of each tubewell is shown in Figure 8. The tubewells are designed to run for 16 hours a day !

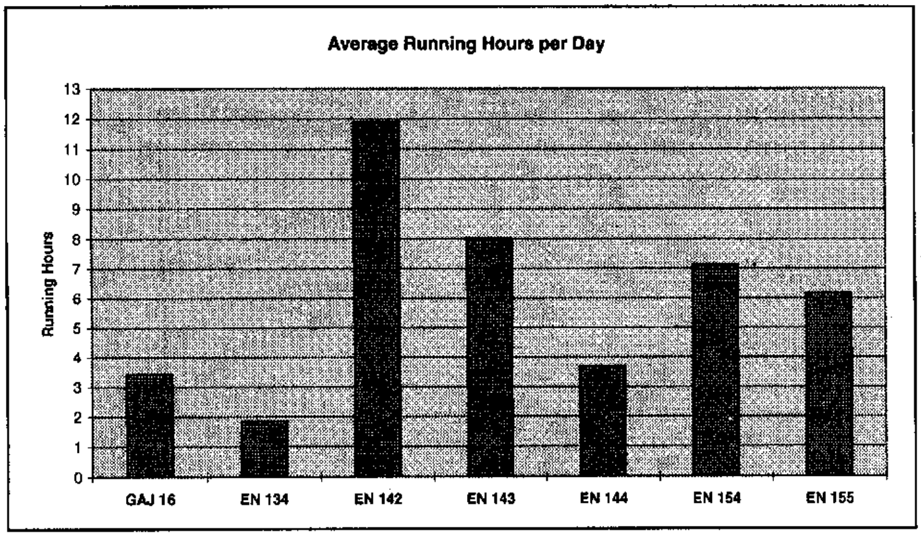

Figure 8 Average Running Hours per Day (March - December 1997) of the LBOD Tubewells within the Dhoro Naro Minor Command Area. Designed Running Hours per Day = 16 hrs.

Moreover, IIMI staff measure the discharge of the saline effluent at the source (tubewell) and at the disposal point (DP) since May 1997. The discharge at the source is measured with a ruler.at the calibrated weir of the tubewell The flow at the disposal point is measured with a current meter inside the earthen disposal channels. This set of data is very incomplete *(see Appendix B3)*.

2.2.4 Soil Data

IIMI: IIMI staff does not collect any data on the soil.

SMO: SMO has recorded the stratification of the soil at the time of drilling bore holes for tubewells, piezometers and observation wells.
Generally, the main soil types within the LBOD Stage-1 Project Area are:

- Silty clay / silty clayey loam
- Loamy fine sand / sandy clayey loam
- Fine sandy loam / silty loam

(MMP, 1984)

2.2.5 Meteorological Data

IIMI: No meteorological data has been collected by IIMI staff.

Meteorological Department of Pakistan: Information about measured monthly averages for different places in Sindh have been provided on floppy disk, free of cost, by both Meteorological Departments, Lahore and Karachi. Here, just the information about Nawabshah is of interest, and had to be prepared *(see Appendix B5)*. For the calculation of water used by plants, CROPWAT needed information about monthly means of daily minimum and maximum temperatures, monthly averages of humidity at different times, monthly average wind speed at 2 m above ground and monthly duration of sunshine. Rainfall data (precipitation, P) is used separately, for the study of the water cycle. Data available spans from 1932 to 1996. For this reason, it is difficult to compare the recharge calculated with this data with the one calculated using changes of water table depth. So, just the extreme data is used to set possible limits.

FAO: For average meteorological data CLIMWAT is used, climatic information especially prepared for CROPWAT. This data is very close to the averages of the data provided by the meteorological departments, but more uniform.

2.2.6 Cropping Data

IIMI: Data about cropping intensity for the Gross Command Area is provided by IIMI-Nawabshah field staff, collected through farmer interviews, plus estimations. Unfortunately, this information is not quite correct (too small), because of the mistrust of farmers. They probably feared that they would have to pay some fines to the Irrigation Department. In Sanghar, huge differences were observed between the information collected through farmer interviews and the ones collected through cropping intensity assessment by IIMI staff (done in October / November 1997). A detailed list is found in Appendix B7.

FAO: The default settings in CROPWAT were directly taken as crop specific data.

Literature: Planting dates were taken from a local book named "Crops of Sindh" (Khoso, 1992). For the computer program, periods were taken to simulate the different sowing and harvesting times of the different farmers. But, local farmers often do not know much about sowing dates, and therefore the calculated crop water requirement is more theoretical.

2.2.7 Geographical Survey

IIMI: The location map of the Dhoro Naro Minor Command Area produced by IIMI looks very nice, but is quite inaccurate *(see Appendix F);* drawn manually without any assistance of GPS or other surveying equipment. So, the location of piezometers and tubewells, as well as canals and boundaries within the command area, are estimated to have an accuracy of a few hundred metres. Therefore, surveying is the weakest part of the research. Even the correctness of the levels taken at the watercourse outlets and piezometers is doubtful after Beatrice Keller and Gabor Jaimes recognised some serious mistakes at some places. These inaccuracies affect the correctness of water table elevations seriously !

The coordinates of the piezometers and the boundary line have been taken by overlaying a Cartesian system of x- and y-axes with their origin at the head-regulator of the minor, by Dr. Bakhshal Khan Lashari and Gabor Jaimes *(see Appendix B1).*

SMO: Most of the tubewells and piezometers, as well as main canals, are surveyed with GPS assistance and latitudes and longitudes are converted into Northing and Easting.

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