LAST OPPORTUNITY TO PROTECT GROUNDWATER DETERIORATION IN LOWER BARI DOAB CANAL

By

Dr. Muhammad Nawaz Bhutta[1]

ABSTRACT

Surface water and groundwater in LBDC command are in a critical condition. Surface water supplies have been declining over the past decade. Utilisation of groundwater is now integral to water resources and agricultural production in the LBDC command but the present rate of groundwater abstraction is not sustainable because the depth to watertable is fast approaching the maximum depth at which the most commonly used pumping technology can perform; the energy costs of pumping deeper groundwater are becoming unaffordable, especially for small farmers; and the quality of the groundwater is getting worse. The groundwater levels are falling at rate of 0.15 m (0.5 ft) per year on average, although there is considerable variation in the way the watertable is moving in different areas. Even with this looming crisis, there is no management plan in place to stabilize groundwater levels and protect it from salinization and pollution. The paper has analysed water balance in the LBDC command. In order to investigate the effects of different groundwater management scenarios on the spatial and temporal groundwater conditions in the LBDC command, groundwater model was applied. Model runs were conducted for each of 4 groundwater scenarios ranging from no change from current canal flows and groundwater abstraction to increased canal flows and reduced groundwater abstraction. The main findings were that with no change in the canal water availability and groundwater abstraction, the groundwater levels in the LBDC project area will continue to decreasing at the present rate. By the year 2025 large areas of LBDC could show groundwater levels 3 to 4 m lower than today. A 10% reduction of tubewell pumping would slow down the drawdown process of the groundwater table. Nevertheless by the year 2025 most areas of LBDC would still show a significant lowering of the groundwater levels. Increased canal flows combined with the present groundwater abstraction is slightly more effective reducing the rate of the drawdown of the groundwater table, but is not sufficient to stop the depletion process in the aquifer. The combined action of reducing the tubewell pumping and increasing the canal water supply seems to be the only effective way of almost stopping the drawdown trend of the groundwater table in large areas of LBDC but will not help to restore more favourable groundwater conditions than the ones prevailing today. This is the last opportunity to introduce groundwater management to avoid the catastrophic collapse of LBDC agricultural economy.

1 INTRODUCTION

Irrigation in the Indus Basin has a long history, stretching back to Indus civilizations of over four thousand years. By the construction of barrages and reservoirs, increasingly more river water was diverted and increasingly more land was irrigated. The use of

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1. Senior Water Resources Consultant nawazbhutta04@gmail.com, National Development Consultants, Lahore, Pakistan.

groundwater for irrigation started with the installation of public tubewells (TW) in the 1960's, soon to be followed by an explosive TW development by private farmers (more than 1,000,000 at present and still growing). Most of the groundwater recharge is made up by irrigation water losses with rainfall providing only some 10%.

The installation of tubewells was unregulated with no regard to the volume of groundwater available. As the rate of extraction of groundwater became greater than the seepage available from irrigation activities, watertables started to fall. Initially, this was not a problem, but, as farmers chased the falling watertables, the cost of extracting groundwater increased and there was an increasing risk of disturbing underlaying aquifers of poor quality native groundwater were disturbed. There was a need to recognize the physical processes affecting groundwater and restore the balance between the rate of irrigation seepage and the use of groundwater.

The challenge ahead is to make the present conjunctive use practices sustainable. Even with this looming crisis, there is no management plan in place to stabilize water levels within a safe range that neither induces salt-water intrusion nor groundwater depletion. The study was conducted to analyse the present situation of water resources in LBDC command. Options for stabilizing the groundwater aquifer and protecting it from pollutions were also tested by model and accordingly recommendations were prepared.

2. DESCRIPTION OF THE LOWER BARI DOAB CANAL

The LBDC command area is located towards the Punjab, Pakistan (Figure-1). The climate of the LBDC command area is characterized by hot summers (with maximum temperatures of more than 50ºC) and moderate and pleasant winters (with daytime temperatures reaching 20ºC). The annual effective rainfall is 267 mm of which 67% falls between June and September. The head reaches of the command receive about twice as much rainfall as the tail-end reaches. General land slopes are mild towards the south-west and range from 1:4000 to 1:10,000.The soils are alluvial deposits, mainly sandy loams.

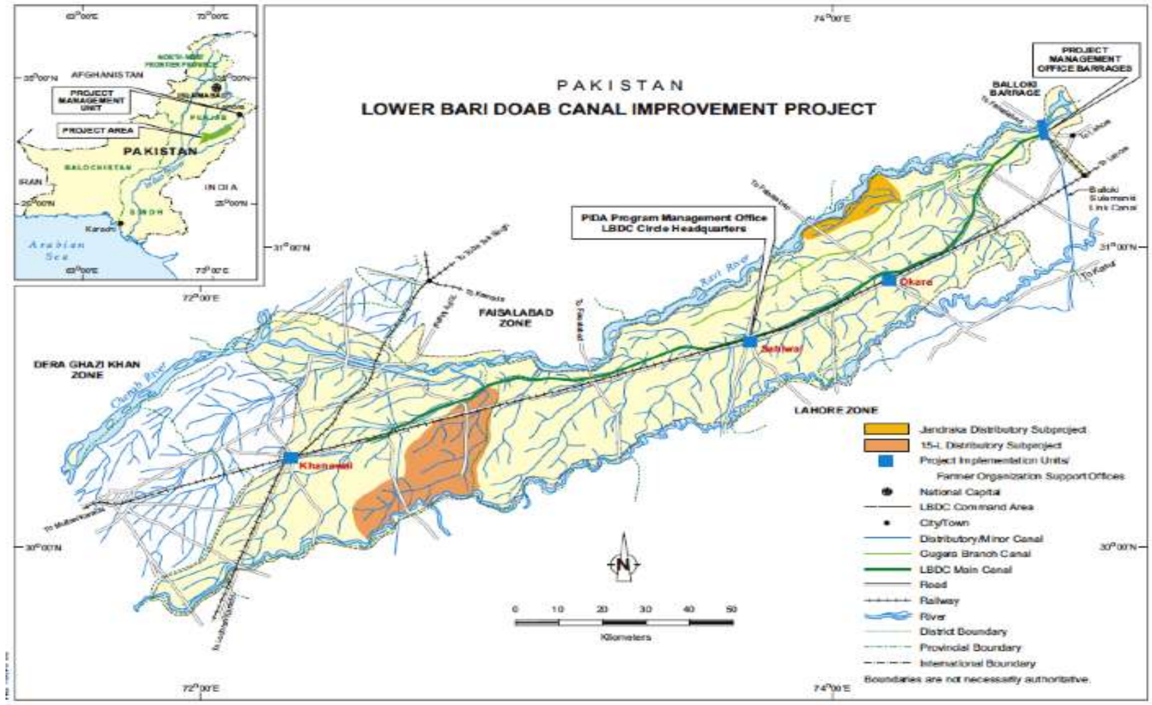

Figure-1 : Location and Layout of the Lower Bari Doab Project

The LBDC system was constructed in 1911-14 to provide assured irrigation water supplies. The LBDC Main Canal originates at the Balloki Headworks located on the left bank of the Ravi River adjacent to the Balloki Barrage. The LBDC main canal is 201 km in length and supplies water to about 1,500 km of distributary and minor canals, which feed about 3,500 watercourse outlets. The gross command area is about 760,000 ha (1,884,906 acres). The main crops are wheat, rice, maize, cotton, sugarcane, fodder, flowers, vegetables, and citrus and other orchard crops, and about 275,000 farm families derive their livelihoods directly from irrigated agriculture. LBDC was designed to thinly spread the available water throughout the command area. Hence the discharge initially allocated for LBDC at the Headworks was 190 m^3/s (6700 cfs) and this flow provided water for about 67% cropping over the cultivable command area (CCA) of 570,000 ha (1,368,000 acres). In 1984, the allocated discharge was revised to 279 m^3/s (9841 cfs) but the operational discharge was limited to 244 m^3/s (8600 cfs) due to insufficient capacity of the canals and structures.

The introduction of canal water transformed the hydrology of the area and over the following decades, seepage from the irrigation system, including the canals, watercourses and fields, exceeded regional groundwater flows and the watertable rose close to ground level, resulting in problems with waterlogging and salinization of fields in some areas. Tubewell technology was introduced during 1960’s. Tubewells became popular because they provided a reliable, accessible, on-demand and affordable source of water to supplement generally unreliable and inefficiently delivered canal water. By the 1994, 19,660 private tubewells were installed and a decade later in 2005, there were 58,102 private tubewells in LBDC with average capacities of about 15-27 l/s. By 2010, the cropping intensity and cropped area had increased to about 197% and 663,324 ha ((1,639,074 acres) respectively mainly due to the extensive use of groundwater to supplement canal water supplies. Government adopted a *laissez-faire* approach to the growth of private tubewells and these could be installed and operated with no restrictions or regulation.

Flows into the LBDC at the Balloki Headworks have been declining for many years. During the five-year period (2006-2010), flows were on average 16% less than design flows during kharif and 38% less during Rabi. If the present shortfall in diversions continues, there will be insufficient water available in the Ravi to divert the design LBDCIP flow of Q = 279 m^3/s (9841 cusecs). Farmers make up the shortfall in canal water by pumping groundwater. By utilizing groundwater, farmers have overcome the overall shortage of canal water plus inefficient and inconsistent deliveries of canal water and increased the design cropping intensity from 67% (with canal water only) to a cropping intensity of about 197% in 2012.

3. ASSESSMENT OF WATER RESOURCES IN THE LBDC COMMAND

The annual water balance for the LBDC command area is shown in **Table-1.** The inflow of canal water plus rainfall does not balance with the outflows to crop and non-cropped areas, surface runoff plus flows delivered to an adjacent command area. The difference between inflows and outflows is balanced by groundwater mining, resulting in a lowering of the watertable. About 9% of crop water needs are being provided from mined groundwater.

Table-1 : Water Balance in LBDC Command

Component	Annual Volume of Water (MCM)	Inflow or Outflow (%)
Inflows		
Canal Water	4457	64
Rainfall	1813	26
Groundwater Mining	666	10
Outflows		
Crop water use	5843	92
Non-crop water use	181	3
Canal Water delivered to adjacent command	336	5
Note: MCM is million cubic meters (10^6 m^3)		

Although in the water balance, canal water provide 64% of the inflow, only 38% of canal water is provided directly to the crop due to seepage in the canals (22%) and watercourses and fields (deep percolation) (40%). Farmers utilise the seepage by pumping groundwater to provide additional irrigation water, as shown in the groundwater balance (**Table-2**). The rate of pumping groundwater is greater than the seepage and other inflow rates and the difference is made up by groundwater mining (Recharge-TW discharge). The problem of groundwater mining needs to be addressed to prevent a deterioration of the groundwater reservoir on which the LBDC agricultural production system depends.

2. Depletion of Groundwater Table

The depth to watertable data were analysed for the period of 1981 to 2012. The changes in the areas under different depths to watertable are shown in Figure-2. During the last 31 years, the area where the watertable is less than 6 m has reduced from about 53% to about 9%. Similarly, the area where the watertable is greater than 6 m has increased from 47% to 91%.

Table-2 : Groundwater Balance in LBDC Command

Component	Annual Volume of Water (MCM)	Inflow or Outflow (%)
Inflows		
Regional inflows	70	1
Seepage from canals	729	16
Seepage from watercourse and fields	2664	58
Rainfall	490	11
Groundwater Mining	666	14
Outflows		
Agricultural tubewells	4549	98
Domestic tubewells	32	<1
Regional outflows	80	2

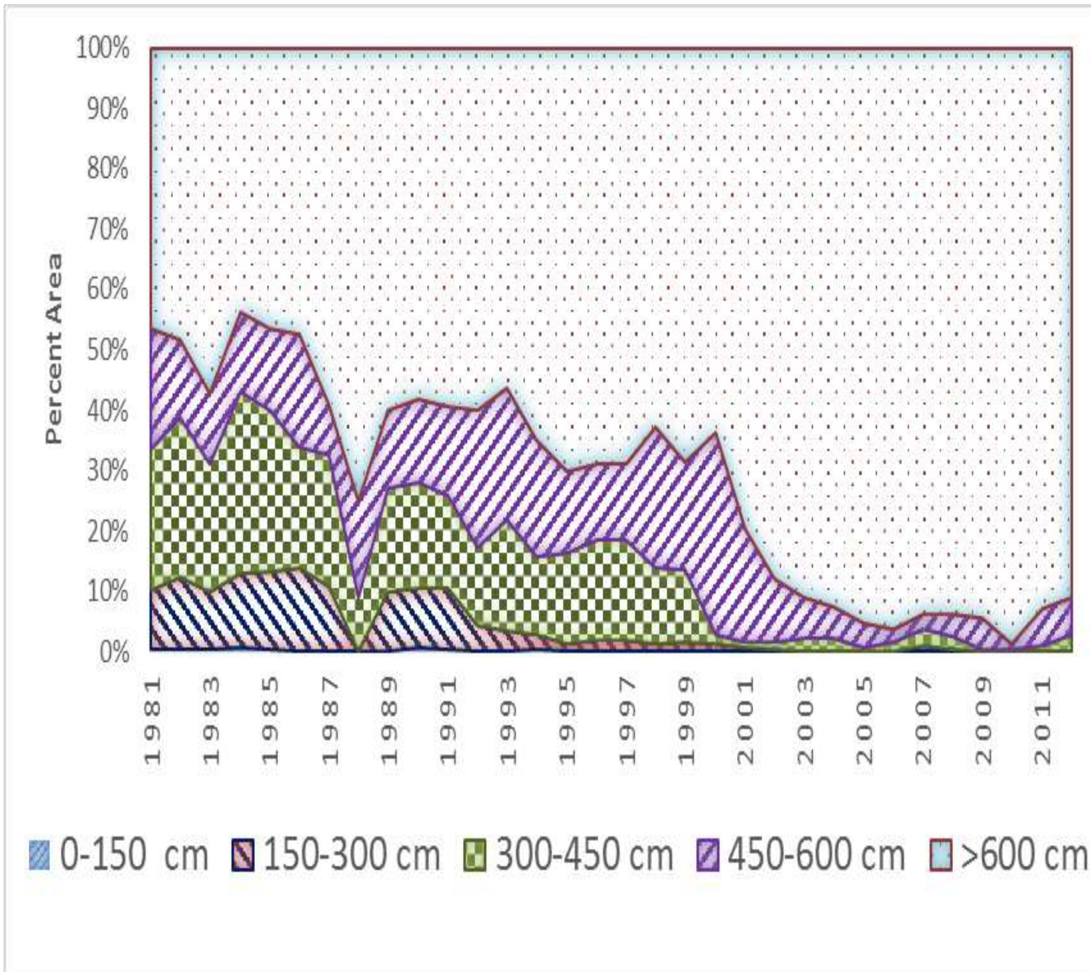

Figure-2 : Areal Change in Depth to Watertable (1981-2012).

In general, the depth to the watertable increases away from the Ravi River, towards the south west of the command and towards the centre of the doab (Figure-3). Watertable levels under the area close to the Balloki Barrage and the head of the main canal tend to be shallower. 180,530 ha (or 22% of the LBDC command) have watertable levels of more than 15 m, while 74,186 ha (or 9%) have watertable levels of less than 6 m. Once the depth to the watertable reaches about 15 m, farmers experience major problems with using the cheapest and least costly pumping and tubewell technologies that is centrifugal pumps located in dug wells. The change of watertable levels for the period 2005 to 2011 is shown in Figure-4. During this 8 year period, watertable levels declined by more than 3 m under 23,322 ha in the southwest of the LBDC command. Overall, watertable levels declined under 691,643 ha (or 84% of the LBDC command). The decline in the depth to the watertable is less in the areas parallel to Ravi River and head reach of LBDC and Gugera Branch. This may be due to following reasons:

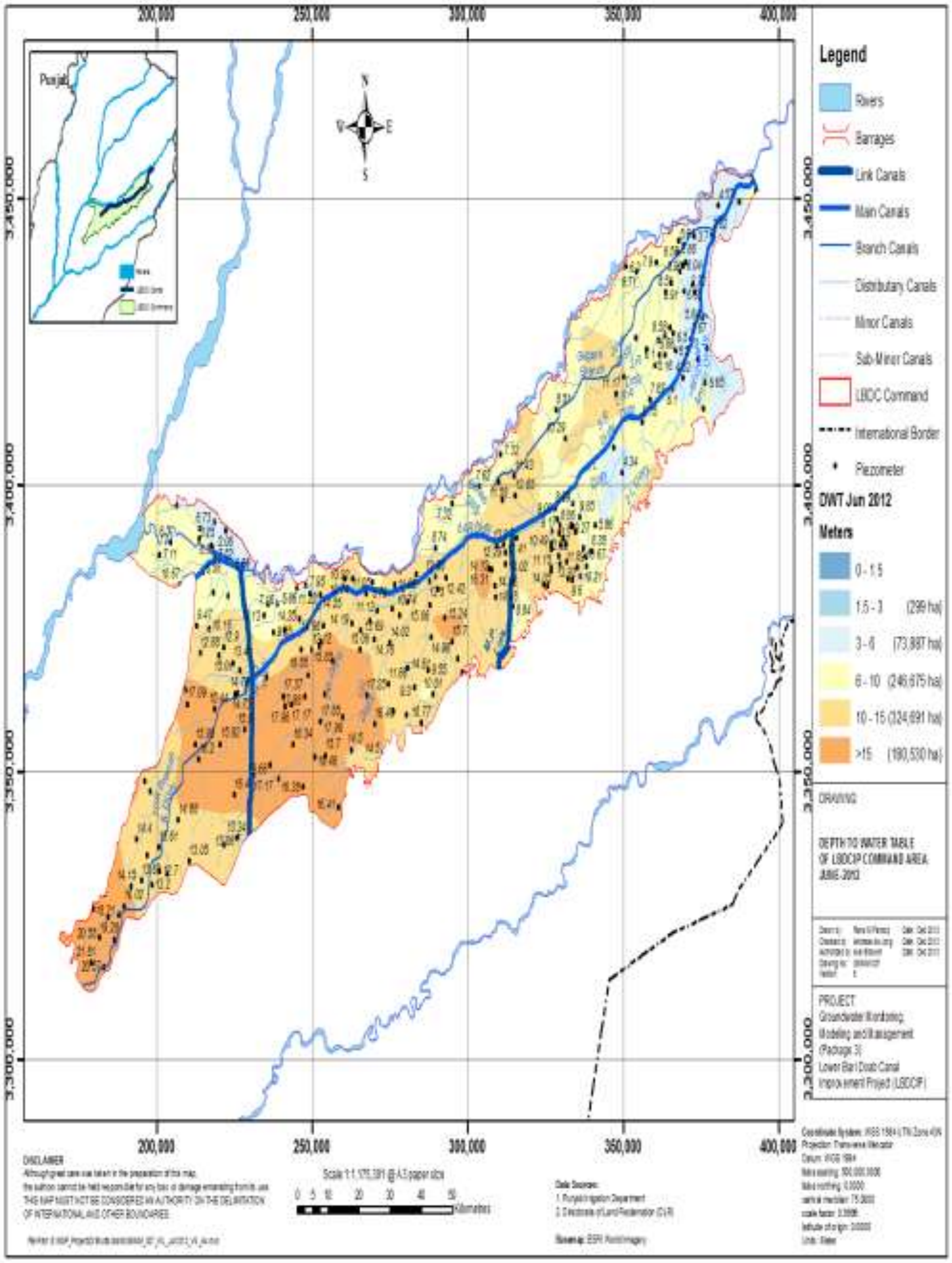

Figure-3 : Depth to Watertable (2012)

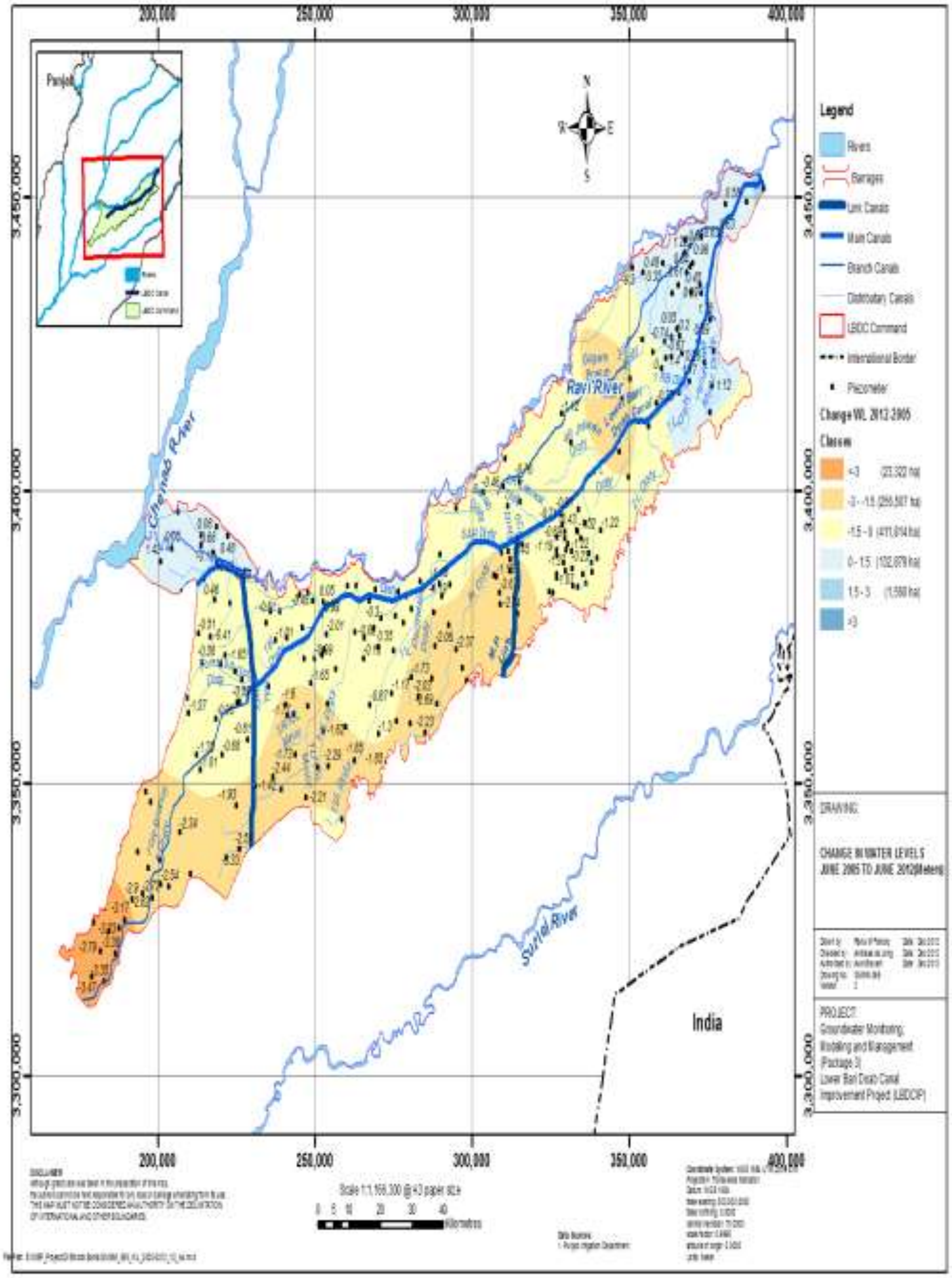

Figure-4 : Change in Depth to Watertable (2005 to 2012)

- Significant recharge from Ravi River and LBDC and Gugera Branch canal;
- Due to canal head reach farmers have better canal supplies and therefore their dependence on groundwater is less.
- Rainfall in head reach of canal is higher than tail reaches of canal.

3. Groundwater Quality and Saline Intrusion

In 1978, WAPDA characterized irrigation water quality into three categories: useable, marginal and hazardous as shown in Table-3.

Table-3 : Irrigation Water Quality Criteria

Category	**EC (mmoh/cm)**	**SAR**	**RSC (meq/L)**
Useable	<1.562	<10	<2.5
Marginal	1.562-3.000	10-15	2.5-5.0
Hazardous	>3.000	>15	>5.0

Groundwater quality data for the LBDC command was analysed for the period 1995 to 2012. Areas under useable, marginal and hazardous irrigation water quality are shown in Table-4. Over 17 years, the area with useable quality groundwater has reduced from 71 percent in 1995 to 32 percent in 2012. The area with marginal groundwater quality has increased from 22 percent in 1995 to 49 percent in 2012. The area under hazardous water quality has been increased from 7 percent in 1995 to 19 percent in 2012. The trend over the last 17 years is that groundwater quality in LBDC command is deteriorating rapidly.

Table-4 : Groundwater Quality in LBDC Command

Survey Period	**Year**	**LBDC Command Area (%)**		
		Usable	**Marginal**	**Hazardous**
LBDC Feasibility Study	1995	71	22	7
WAPDA Survey	1991-01	51	26	24
WAPDA Survey	2002-03	44	34	22
DLR Survey	2005	44.4	31.7	23.9
GMMM-LBDCIP	2012	32	49	19

The present suitability of the LBDC groundwater for use in irrigation is shown in Figure-5. Areas with hazardous groundwater are generally located towards the centre of the doab and towards the southwest of the LBDC command where the depth to the watertable is also deeper. Farmers in these areas face the double problem of deteriorating water quality and declining watertables, both of which will increase their production costs significantly.

The change of EC of the groundwater during the period 2003-2012 is shown Figure-6. In some areas near the Ravi River and along the main canal, the EC of the groundwater declined (that is the quality improved) whereas away from Ravi River and towards the centre of the doab, the EC of the groundwater increased (that is the quality became worse).

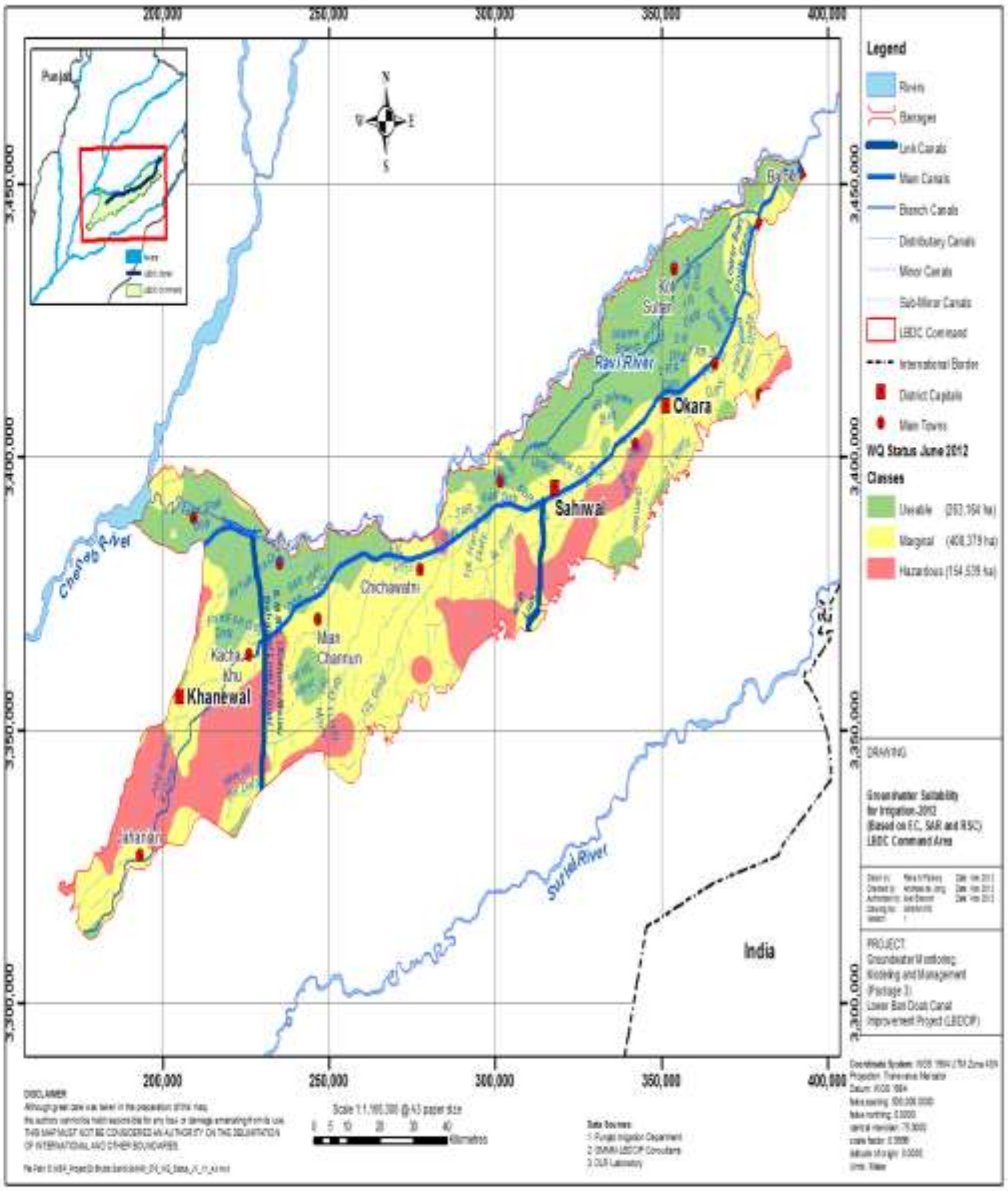

Figure-5 : Suitability of LBDC Groundwater for Irrigation (2012)

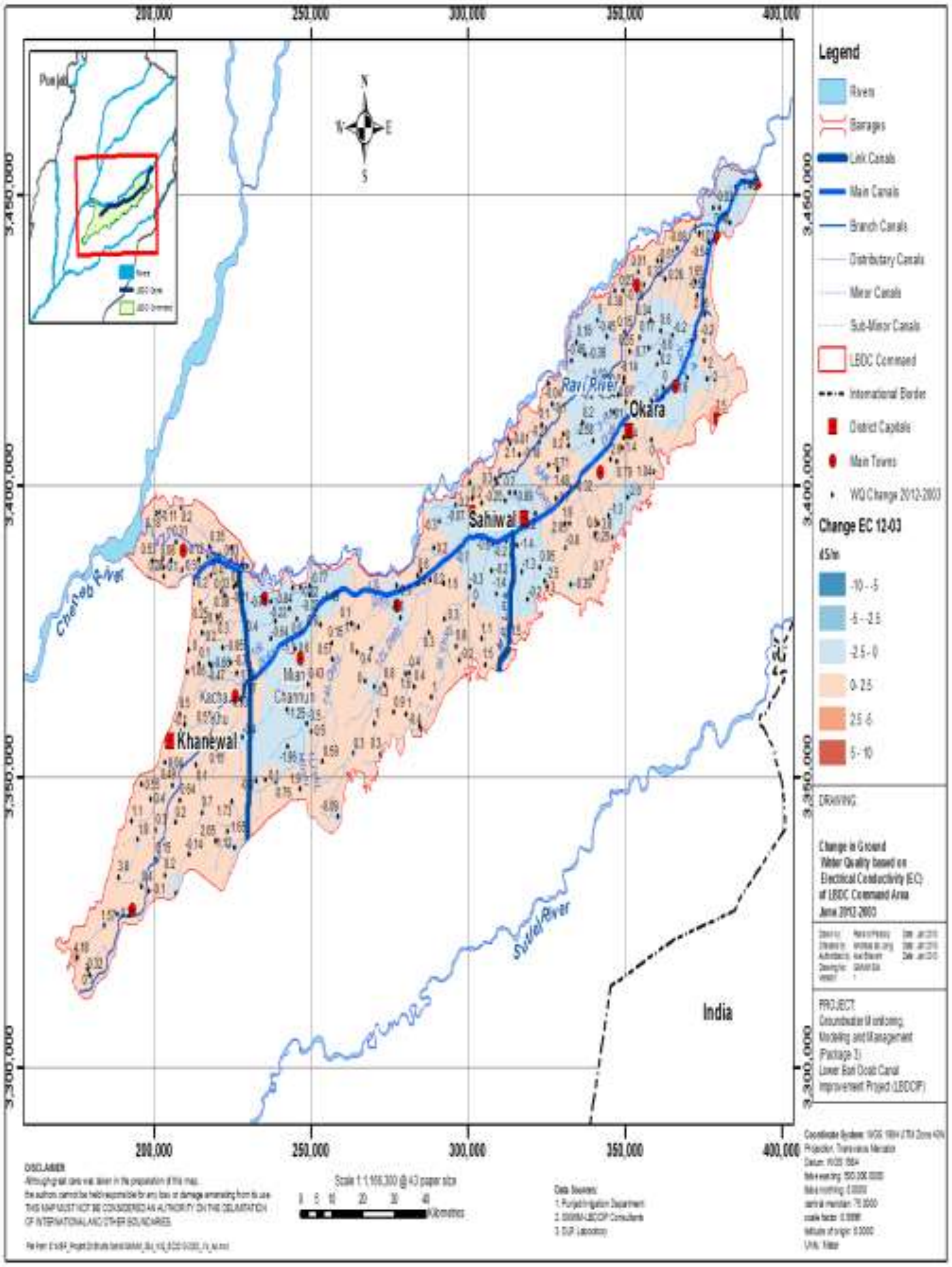

Figure-6 : Change in EC of LBDC Groundwater (2005-2012)

4. Management Options for groundwater

The groundwater model was applied to determine the impact of different scenarios for the future management of surface and groundwater resources on groundwater levels. The management options tested by the model are summarized in Table-5.

Table-5 : Groundwater Management Scenarios

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
Description	Water and land use continues as at present	Water and land use change and groundwater abstraction restricted	Water and land use changes as more canal water available	Water and land use changes as more canal water available
Groundwater	GW abstraction continues at present rate 4,782 MCM	10% reduction in GW abstraction 4,385 MCM	GW abstraction continues at present rate 4,782 MCM	10% reduction in GW abstraction 4,385 MCM
Canal water	Canal water supply continues at present rate 4,880 MCM	Canal water supply continues at present rate 4,880 MCM	Increase in canal water supply 6,057 MCM	Increase in canal water supply 6,057 MCM
Annual Rainfall	Same as average annual rainfall	Same as average annual rainfall	Same as average annual rainfall	Same as average annual rainfall

Model runs were conducted for the groundwater management scenarios 1 to 4. The main results can be summarized as follows:

- The model results of scenario 1 indicate that if no groundwater management actions are taken in the future the groundwater levels in the LBDC project area will continue decreasing at the present rate. By the year 2025 large areas of LBDC could show groundwater levels 3 to 4 m lower than today.

- The model results of scenario 2 indicate that a 10% reduction of tubewell pumping in the LBDC area would slow down the drawdown process of the groundwater table. Nevertheless by the year 2025 most areas of LBDC would still show a significant decrease of the groundwater levels.

- Groundwater management scenario 3 shows to be slightly more effective than scenario 2 regarding the drawdown of the groundwater table. But also here the proposed action of increasing annual increase of canal water of approx. 1,200 MCM is not sufficient to stop the depletion process in the aquifer.

- The combined action of reducing the tubewell pumping and increasing the canal water supply in scenario 4 seems to be an effective way of almost stopping the drawdown trend of the groundwater table in large areas of LBDC. However, implementing the actions of scenario 4 will not help to restore more favorable groundwater conditions than the ones prevailing today.

5. Reverse Groundwater Deterioration

5.1 Surface and Groundwater Management Strategy

Growth in population increased cropping and improved standards of living have increased competition for the limited water resource. Insufficient attention to water quality leads to further degradation of water resources. These problems are aggravated by shortcomings in the management of water where sectorial and top-down approaches still prevail and lead to the fragmented and uncoordinated development and management of the resource. The overall problem is exacerbated both by inefficient governance and increased competition for finite water resources.

The challenge for the management of surface and groundwater resources is to strike a balance between the use of the resources as a basis for the livelihood of the LBDC's increasing population and the protection and conservation of the resource to sustain its functions and characteristics.

Historically, water managers have tended to see themselves in a "neutral role", managing the distribution system to provide supplies to meet externally determined needs. Integrated Water Resource Management (IWRM) approaches should assist them in recognizing that their behaviour also affects water demands. Clearly, farmers can only "demand" the product supplied, but water can be supplied with very different properties, for instance in terms of quality and availability in low flow or peak demand periods. Price and tariff design will also affect water demand, as will investments in infrastructure that translates potential into effective demand.

Action is required to manage the groundwater aquifers of the LBDC command area in a sustainable way as part of an IWRM strategy. If no action is taken to change the present water-use practices, the watertable will continue to fall and the quality of the groundwater will continue to deteriorate further to the extent that water in the aquifer will become unusable and it will take decades if not centuries to repair.

5.2 Developing a Framework for the Management Strategy

The framework should recognise the linkages between the demand for groundwater by stakeholders and the supply of groundwater from the aquifer. Effective management requires action on both sides.

Activities that affect the demand for groundwater include:

- **Regulatory Framework**. The existing laws in Pakistan provide some legal framework for the management of groundwater, but no regulatory regime has been implemented to control the exploitation of groundwater. The government allowed the private sector unrestricted scope to develop private tubewells, and even encouraged the development by subsidizing, for example, electrical connections and usage. Regulations can be focused on specific targets such as licensing of tubewells and their usage or more general such as banning further tubewell installation.

- **Economic Instruments**. Groundwater resources tend to be undervalued, especially where their exploitation is uncontrolled – when the resource exploiter (in effect) receives the benefits of groundwater use but (at most) pays only part of the costs – and this undervaluation often leads to economically inefficient resource use (Strand 2010). Unfortunately, in LBDC controlling irrigation use is not as straightforward as that of industry or commerce. Alternative techniques that could be used to estimate actual abstraction or use, include:

  - Estimation of volume pumped from metered electricity use;
  - Estimation of volume abstracted from pump capacity and assumed schedule.
  - Assessment of actual consumption by crop type and cultivated area.

- **Stakeholder participation**. A degree of community stakeholder participation is essential for groundwater resources management, given the frequently very large number of individual groundwater users involved regardless of whether regulatory and economic instruments are also deployed. It can take many forms and can take place at various territorial levels ranging from village to aquifer system or even river-basin level – and should be comprehensively nurtured as an important contribution to groundwater conservation, management and protection, otherwise its effectiveness may become much reduced. It is desirable that active participation of users in groundwater resource management be promoted, in which users exert peer pressure for the achievement of management goals and collaborate through provision of data on tubewell use and water levels (Garduno and Foster, 2010). A local groundwater resource agency is necessary to provide long-term support of the sustainability of community action and coordination throughout the LBDC area.

- **Awareness raising and publicity**. Introducing regulations or economic instruments to change how stakeholders use groundwater will require a focused campaign to raise awareness amongst stakeholders as to why such changes are necessary. Small farmers are under severe financial pressures as the price of inputs increase while the prices paid for many crops are in long-term decline. The reasons for curtailing groundwater need to be explained. Farmers know that watertables are declining and the quality of pumped groundwater is deteriorating, and will need to be convinced that controls are necessary to prevent the collapse of the current way of irrigation. Awareness raising includes explaining the vulnerabilities of the groundwater system but also showing more efficient ways to irrigate and growing crops that use less water.

Activities that affect the supply of groundwater include:

- **Resource Monitoring**. Action to improve the management of groundwater is not possible without detailed resource characterization and this requires investigation and monitoring of the groundwater and canal systems. Groundwater aquifers in LBDC are complex and dynamic systems and, although there is monitoring of groundwater, there is need for regular information on watertable levels, water quality and accurate information on canal flows to increase the understanding of how the aquifer is performing.

- **Resource Evaluation**. Groundwater data has been collected for over thirty years by various government agencies but what has been missing is routine evaluation of the data to determine what is happening to the groundwater and whether action is required to prevent irreversible degradation of aquifers. Along with resource monitoring, it is essential that the monitoring information is utilised to evaluate what is happening in the aquifer to make incremental improvements in management.

- **Pollution / Contamination control**. Groundwater aquifers are very vulnerable to contamination by salinization and residues of agro-chemicals resulting from agricultural activities and point sources of pollution such as discharges from factories and wastewater from urban areas. Cleaning polluted aquifers is very expensive and technically challenging due to the slow rate of movement of groundwater. The approach should be to stop aquifers from becoming polluted, and specific attention needs to be given to identify the potential hazard from different sources of pollution and take the actions necessary to avoid the pollution entering the aquifer.

- **Abstraction and recharge**. Since the introduction of canal water, the groundwater balance recharge has been dominated by the seepage from irrigation activities and, in more recent times, by abstraction of groundwater by tubewells. Efficient mechanisms for abstraction, distribution and recharge need to identified and promoted to ensure that resources are not being used unnecessarily to abstract groundwater. For example, more efficient field application of irrigation water reduces the requirement for groundwater pumping.

5.3 Institutions

Historically, water managers in Punjab have been focused on the supply and movement of surface water and the contribution and role of groundwater in the water resources of Punjab have been neglected. Unfortunately the neglect of groundwater continues, as for example within the Pakistan Irrigation and Drainage Authority (PIDA) that was created in the late 1990's, groundwater is not seen as an integral part of their brief. The Area Water Boards (AWBs) formed by PIDA are focused only on the supply and delivery of canal water, even though in the LBDC command area 55% of the irrigation water comes from groundwater.

There are now more than a dozen agencies involved in groundwater development and monitoring, but there is no coordination, inadequate staffing and insufficient logistical support. None of these agencies have complete knowledge of the issues and none have operational responsibilities for groundwater management (van Steenbergen and Gohar 2005). A focal point for groundwater management needs to be sanctioned and developed to enforce regulation, coordinate activities by various agencies and gradually compile a database. Preferably, one agency would be responsible for groundwater monitoring and evaluation, management and regulation and that agency could be the PIDA.

5.4 Legal and Regulatory Framework

Legislation on water resources development and management aspects exist, but its focus is mostly on surface water. Provisions for groundwater mainly relate to resource development and to waterlogging and salinization. A common feature of this legislation is that, although attempts have been made at different times to turn it into practice but not implemented.

5.5 Approach for Groundwater management

Several groundwater management plans have been proposed in the past (for example, Steenbergen and Bhatti (2007), Garduno and Nanni (2007)), and the recommended approach draws upon these and makes management on the ground a priority by start to manage groundwater as soon as possible.

Past proposals to introduce multi-level groundwater management have not been successful and, therefore the proposed approach is to start developing groundwater management at a more local level, with the intention of building towards provincial groundwater management.

The recommendation is to establish a LBDC Groundwater Cell to work with LBDC Area Water Board. The Cell can be set up under existing legal/institutional framework. The LBDC Groundwater Cell would be in a strong starting position as it could use the comprehensive geo-hydrological databases.

The Groundwater Cell would comprise of three units:

- *Survey, Information and Planning Unit*. Responsibilities include:
    - Monitoring and evaluation of groundwater quality and quantity and watertable levels.
    - Profiling and monitoring groundwater users including farmers, municipalities, industries, commercial enterprises and the military.
    - Maintain database of LBDC groundwater information and data.

- *Groundwater Supply Unit* to ensure that groundwater abstraction and recharge enhancement measures are scientifically sound, follow best professional practice and are properly linked to stakeholders through:

  - Development of technical guidelines and procedures and ensuring quality control / quality assurance of well construction and related operation and maintenance.

  - Identify and investigate scope for recharge enhancement measures.

  - Promote more efficient on-farm water use.

- *Groundwater Demand Unit* to work with Farmer Organizations and other stakeholders on:

  - Promotion of community-based groundwater monitoring and management including training and capacity building of farmer organizations in groundwater management.

  - Maintenance of linkages with government agencies to ensure that farmers have access to inputs for making efficient and beneficial use of groundwater.

  - Awareness building and information dissemination.

  - Commencement of joint monitoring and management of groundwater quality with users and polluters.

  - Promoting adoption of groundwater regulations for LBDC command that have been ‘agreed’ (and thus acceptable to) stakeholders.

6. Lessons Learnt

- Flows into the LBDC at the Balloki Headworks have been declining for many years. During the five-year period (2006-2010), flows were on average 16% less than design flows during Kharif and 38% less during Rabi.

- By utilizing groundwater, farmers have overcome the overall shortage of canal water plus inefficient and inconsistent deliveries of canal water and increased the design cropping intensity from 67% (with canal water only) to a cropping intensity of about 197% in 2012. Several Government Departments collect groundwater data but quality control is insufficient and data requires considerable cleaning before it can be used with confidence.

- Farmers are free to install tubewells at any convenient location on their land. Tubewells can be constructed to any depth and capacity regardless of the distance from neighboring tubewells or consideration of the radius of influence. This results in interference drawdown, and operational problems including suction breaks when all the wells in a locality are pumping.

- On average watertable levels in the LBDC command are falling by about 0.15 m (0.5 ft) per year, although there is considerable variation in the way the watertable is moving in different areas. In head reaches of LBDC command area, the watertable is not falling, while in the tail reaches, watertables are falling rapidly.

- During the period (2004-2012) cropping intensity has increased from about 170% to 197% indicating that groundwater abstraction has increased even though watertables are falling in some areas and fuel costs have increased.

- Areas with useable groundwater quality are decreasing and areas with marginal and hazardous quality are increasing.

- Several plans to manage groundwater in Punjab have been prepared but there has been no action taken to implement the plans, even though groundwater in LBDC and elsewhere is extremely stressed.

- Pumping groundwater for irrigation is becoming unaffordable for farmers located in areas where the depth to watertable is greater than 15 m (50 ft). Increased pumping costs cause problem for farmers throughout LBDC command.

- The groundwater capabilities of PID staff are limited.

7. The Way Forward

The way forward to continue to address groundwater deterioration in LBDC in particular and in Punjab in general is to:

i. Take the opportunity to introduce groundwater management to avoid the catastrophic collapse of LDBC’s agricultural economy.

ii. Canal water supplies should be ensured to design level and groundwater pumpage should be restricted.

iii. Establish a Groundwater Cell to work with the LBDC Area Water Board (AWB).

iv. Continue to develop the groundwater capability of PID and PIDA staff.

v. Utilize the database / GIS / modeling tools to upgrade groundwater monitoring and evaluation.

vi. Adopt rules and regulations to protect groundwater from deterioration.

8. References

Bhatti, A. K. and Frank van Steenbergen 2007 Policy Guidelines, Strategy and Action Plan: The Punjab Groundwater Management Plan.

Frank van Steenbergen and M. Shamshad Gohar 2005 Groundwater Development And Management In Pakistan, CWRAS World Bank, Islamabad.

Garduno H. and Nanni M, 2007 Punjab Groundwater Policy, Mission Report. GW-MATE 2007.

Garduna, H. and Foster 2010. Groundwater Resources and Irrigated Agriculture – making a beneficial relation more sustainable: Global Water Partnership Perspectives Paper.

Strand, John 2010 Inertia in Infrastructure Development: Some Analysis Aspects and Reasons for inefficient infrastructure Choice. Policy Research Paper, World Bank 2010.

Tod, Ian, M. N. Bhutta, Mehmudul Hassan and Axel Braxein2014.Canal Water and Groundwater: Foes Or Friends. United States Committee on Irrigation and Drainage Water Management Conference. March 4-7, 2014.