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WATER MANAGEMENT BELOW THE MOGHA

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FOREWORD

This Volume contains the five papers on Water Management Below the Mogha that were presented at the National Conference on Managing Irrigation for Environmentally Sustainable Agriculture in Pakistan held at Islamabad, November 5-7, 1996. These papers are authored by the researchers of IIMI-Pakistan and by professionals in the organizations with which IIMI-Pakistan has been collaboration comprising of: Water Resources Institute (WRRI) of the National Agricultural Center, Islamabad; Director General, On-Farm Water Management (OFWM), Government of the Punjab; Center of Excellence in Water Resources Engineering (CEWRE), University of Engineering and Technology, Lahore; Mona Reclamation Experimental Project, Bhalwal of the Water and Power Development Authority (WAPDA); and Agro-Evo, an agricultural enterprise interested in R&D.

WATER ALLOCATION AND DISTRIBUTION AT THE WATERCOURSE LEVEL: A REVIEW OF IIMI RESEARCH

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ABSTRACT

In a context of increasing population, stagnant food production and serious environmental problems, the perforinance of the canal irrigation system is of increasing concern for policy makers, irrigation managers and researchers in Pakistan. Performance assessment studies have mainly highlighted the poor level of water supply perforinance at the secondary canal and main canal levels, However, few studies have concentrated only on performance related issues below the mogha. Thus, there is no clear (and updated) understanding of issues and trends in current canal water supply within watercourse command areas. The present paper is an attempt to fill this gap drawing on the research undertaken by the International Irrigation Management Institute from 1986 to date on issues related to allocation and distribution below the mogha. First, research activities and results are summarized. These results, complemented by results of other studies undertaken in Pakistan, stress the importance of recognizing the discrepancy between official and actual allocation and distribution rules. Official rules have been adapted by farmers to provide a more flexible service and to respond to short-term and long-term changes. The research results obtained so far are discussed in the light of three important issues: (i) the type of intervention to be implemented at the watercourse level to improve canal water supply performance; (ii) the policy objectives (whether equity, productivity, efficiency) that are to be tackled by interventions below the mogha; and (iii) the identification of gaps in knowledge and understanding and areas fur further research.

INTRODUCTION

Since the initial development of canal system in Pakistan, many issues related to agricultural production and its sustainability have been presented in discussions regarding the construction of new irrigation systems and the operation of existing ones[4]. More recently, however, these issues have become increasingly important for several reasons: (i) increasing population and demand for food products: (ii) environmental problems such as salinity, sodicity and waterlogging that have not been successfully tackled at the level of the Indus Basin albeit billions of dollars invested in drainage and reclamation projects; and (iii) reduced availability of funds to develop new (and increasingly expensive) projects or rehabilitate existing systems.

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4 Design parameters such as duties and cropping intensities have been established with regard to equity and food production objectives. And as early as the 1920s, problems related to waterlogging and salinity were officially acknowledged and solutions to mitigate these problems were identified and implemented.

The complexity of irrigated agriculture and the large number of factors that influence agricultural production and its sustainability is fully recognized (although often not well documented). For example, timely supply of fertilizers or quality of pesticides would have a significant impact on crop yields, but these aspects are not usually considered in analyses of the water factor. However, there is a clear consensus among researchers, government department officers and policy makers that water, the basic input for agriculture in Pakistan, is in fact the main culprit explaining low productivity and environinental problems. The existing irrigation system is not able to deliver appropriate water supplies (in terms of equity, variability, reliability) to farmers for optimum and sustainable crop production. Thus, to tackle productivity and environmental issues, there is a need to improve first the canal (irrigation) water supply performance[5].

IRRIGATION SYSTEM PERFORMANCE: AN HISTORICAL PERSPECTIVE

In the 1970s, as part of the efforts undertaken by the Colorado State University (CSU) program, efforts to improve irrigation water supply performance have mainly focused on the adequacy dimension of performance (i.e. to increase the water supply available at the farm gate and field level) by reducing various losses below the watercourse head or *mogha*[6]. Research results obtained under the CSU program were translated into development activities undertaken under the On-farm Water Management programs. These programs, however, have only been very partially successful; their institutional component has led to non-sustainable Water Users Associations, and technical efforts have focused on reducing conveyance losses through lining, while neglecting other losses at the farm level.

Towards the end of the 1980s, concerns related to water supply performance have shifted to higher levels of the irrigation system, i.e. the *distributary* (or secondary canal) and main canal. At these levels, the focus of performance assessment activities is not adequacy, but equity in distribution between watercourses or distributaries, and also variability and reliability of canal water supplies. Most of the studies undertaken so far have shown the magnitude of the problems of inequity in distribution and variability in supplies at the distributary and main canal levels (see for example, Bhutta and Vander Velde, 1992; Kuper and Kijne, 1992). Also, the increasing number of canal systems analyzed emphasizes that the discrepancy between official and actual operation of canals, and poor canal water supply performance, seem to be the general rule rather than the exception for canal command areas within the Indus Basin Irrigation System.

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5 The links between water supplies and environmental problems (waterlogging, salinity, sodicity) have been analyzed in some detail in the context of Pakistan. However, little is known on the relationship between canal water supply performance and agricultural production and productivity.

6 Adequacy of irrigation water supplies has also been one of the objectives of the Salinity Control And Reclamation Projects (SCARPs) that were initiated in the 1960s with the installation of public tubewells fur reclamation purposes. In areas with fresh ground water. tubewell water has been used to supplement canal wafer supplies. It was also the main objective of the Irrigation System Rehahilitation Project that followed.

During the same period, research on water management below the mogha has not been sustained at the same level as during the 1970s. The research has been limited to specific sites (see for example the MONA and LIM projects under WAPDA). And the main issues investigated relate to the development of new (improved) technologies to enhance irrigation system performance and its sustainability (for example, comparison between types of watercourse improvements, analysis of tubewell technology, identification of appropriate reclamation measures for specific conditions, etc). However, little effort is targeted towards the analysis of the irrigation system as it is, and the understanding of the current complexity, rules, and constraints faced by Pakistani farmers below the mogha.[7] Often, research on "what it is" has been superseded by research on "what it ought to be".

Two important reasons explain the need to analyze the actual situation below the mogha. The first reason relates to the relevance of research results obtained 20 years ago. There have been drastic changes in the irrigation system since the research efforts undertaken in the 1970s. The pressure on water resources has significantly increased as expressed by cropping intensities that have more than doubled during the last 20 years. The development of a large number of private tubewells and the importance of ground water use is expected to impact on canal water management by farmers. Also, changes in farm characteristics (for example, the average farm size has been decreasing since 1960) and constraints (access to credit and improved inputs) indirectly influence water inanagetnent activities.

The second reason is related to the implementation of watercourse level programs. In the context of discussions on participatory irrigation management and the future objectives/roles of the On-Farm Water Management Program, it is important to clearly understand current water management activities below the mogha and analyze their impact on production and sustainability. This will identify existing needs that require intervention below the mogha.

The present paper summarizes the results obtained by the International Irrigation Management Institute (IIMI), Pakistan National Program, in the analysis of current canal water allocation arid distribution below the mogha. The focus of the paper is circumscribed by part of IIMI's research activities below the mogha. Canal water only is investigated, although the role of groundwater use is recognized by the authors as has been analyzed in other publications. Also, allocation and distribution below the mogha are presented (i.e. between the watercourse head and the farm gate) and issues above the watercourse head and within the farm are not discussed in the present paper. Finally, the focus is on the output of allocation and distribution activities (in terms of water supply performance) and not on the process and organizational issues.

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7 It is important to note that a large amount of information on the existing irrigation system is also collected as part of the monitoring and evaluation activities of specific projects and programs. However, the main focus of these activities is on performance indicators (output) and not on the functioning and management of the system *per se*. And the information collected is rarely analyzed thoroughly and shared with (considered hy) the research community.

IIMI RESEARCH ACTIVITIES

Initial efforts undertaken by IIMI on water management below the mogha were not specifically targeted towards the analysis of water allocation and distribution at this level of the irrigation system. In fact, the understanding of issues came as part of research programs focused on other irrigation management issues, such as the analysis of canal water supply performance at the distributary level, or the analysis of the impact of irrigation water supply on salinity and waterlogging. The main research results were presented in Bhatti and Kijne (1990) and mainly focused on the difference between official rules and actual use of water turns. The authors also stressed the importance of the decrease in farm size and its impact on water turns that may not be sufficient anymore to irrigate fields in an appropriate manner. The trading of water turns is presented as an evidence of farmers' dissatisfaction with the official rules and the need to make the system more flexible.

The following years added a new dimension on the analysis of water management below the mogha. First, as part of a project titled Crop-Based Irrigation Operation in the North-West Frontier Province (NWFP), field research stressed again the differences between official rules in terms of allocation of water turns (warabandi) and actual allocation of water turns (Bandaragoda and Garces, 1992). In fact, with the very high water allowances of the two irrigation systems studied, the Chashma Right Bank Canal (0.6 l/s/ha) and Lower Swat Canal (0.77 l/s/ha) irrigation systems, the need to allocate water turns in a strict manner does not hold, and a more flexible (kachcha) warabandi has been established by farmers. Water turns are influenced by large land-owners and other influential people at their will. A large degree of flexibility in use of water turns exists due to exchange and trading, accentuated by the fact that in some watercourse command areas, several farmers irrigate at the same time sharing the flow of the same turn, thus the water turn does not become a *de-facto* "water right". Flexibility has also been added at the head of the inogha with farmers regularly opening and closing outlets to control flows entering into the watercourse. One of the conclusions of the authors is that equity is no longer a shared objective among officials, farmers and politicians.

At the same time that research was undertaken in the NWFP, some other research activities focused on current water allocation and distribution patterns in a few sample watercourses of the Fordwah Branch Canal Irrigation System, South-Punjab. Although the conditions in terms of water scarcity are very different, the analysis also showed a discrepancy between official rules and actual distribution of water turns (Strosser and Kuper, 1994). Active localized water markets had developed in all of the watercourses analyzed. Farmers were involved in tubewell water sales and purchases that formed the majority of the volumes of water transacted. In the case of canal water, farmers participated very actively in exchanges of partial or full water turns. A few canal water sales and purchases were also recorded.

As a follow up of these general studies and the results obtained, specific studies were developed in the context of the project titled Managing Irrigation for Environmentaliy Sustainable Agriculture in Pakistan, funded by the Government of the Netherlands. Initially, the two main activities focused on the analysis of current water allocation and an in-depth analysis of water markets within the watercourse command area. The results obtained as part **of** these studies led to the identification of gaps in understanding and the development of a research work plan (Strosser, 1995). This work plan was refined as a result of a workshop held in Lahore in June 1995 (Riaz and Wahaj, 1996).

The work plan included not only activities focused on allocation and distribution issues, but also specific activities on irrigation practices and an assessment of the impact of water supply on agricultural production and salinity. Planned activities include the analysis of current water allocation and identification of factors (whether technical or social) that explain this allocation, assessment of canal water supply performance within the watercourse command area, and spatial analysis of allocation and distribution using Geographical Information Systems (GIS).

The following section summarizes the research results obtained so far on the analysis of allocation and distribution of canal water below the mogha. Then, the results are discussed in the context of potential interventions to be implemented below the watercourse to improve the performance of water management below the mogha. Most of the results and conclusions presented in these sections are based on the analysis of information collected through two major field research efforts implemented by IIMI during the period 1993-95.

The first field research effort includes **a** detailed survey of 22 sample watercourses located in 3 canal command areas; Upper Gugera, Lower Gugera and Fordwah Branch (Bandaragoda and Rehman, 199.5). The survey focuses on the establishment of current allocation schedules and on the discrepancies between official and actual water allocation practices. The survey has been followed by the monitoring of water distribution activities during the *kharif* (summer) 1993 season for the 22 sample watercourses. An important aspect of this research **is** its cross-sectional dimension with **sample** watercourses taken from different agro-ecological zones and physical environments.

The second field research effort has built on some of the findings obtained from the survey **of** 22 watercourses, along with initial results obtained in sample watercourses in the Fordwah Branch Canal Irrigation System. Detailed monitoring of allocation and distribution of canal water has been undertaken for 8 sample watercourses and for 5 seasons (Kharif 1993 to Kharif 199.5) in the Fordwah Branch Canal Irrigation System. The watercourses selected represent different canal water supply and ground water use environments. The main focus of the study is the analysis of current allocation and distribution, the identification of its spatial and temporal variability (as a result of different water scarcity conditions), the assessment of canal water supply performance at the farm level, and the analysis of factors (whether watercourse related or farm related) that explain different levels of performance.

LESSONS FROM IIMI'S EXPERIENCE

Current water allocation below the mogha

In Pakistan's canal irrigation systems, the most prevalent water allocation method below the outlet (niogha) is the warabandi schedule, which literally means the schedule of fixed time turns. The origin of warabandi was somewhere in the pre-colonial period, and during the early period of the canal irrigation tradition, the warabandi time allocation schedule was locally determined with mutual consent of the farmers in the watercourse command. However, with changes in social conditions, intermittent water-related conflicts among the farmers led to increased official interventions in this original farmer-managed unofficial (kachcha) warabandi tradition, resulting in widespread conversion of kachcha warabandi practices into more rigid official (pucca) warabandi schedules during the period itself. Today, there are only a few watercourses in the Central Punjab, which are not covered by pucca warabandi.

Theoretically, water allocation below the mogha is supposed to be implemented according to an officially recognized fixed water turn schedule. This is popularly known as the official warabandi schedule, which is meant to be strictly adhered to by all of the water users so that its underlying objective of equitable distribution can be achieved. If properly executed, this official warabandi schedule provides an equal share of water per unit of land to be irrigated. Most government officials believe that this schedule is in operation as prescribed in the manuals.

The real practical meaning of the official warabandi appears to lie in the fact that it fixes the right to irrigation water for the participating water users, a right that they can exercise if they have to, or can relax in actual practice, but use in any litigation, or in any appeal for further arbitration or adjudication, when their access to water is jeopardized in any way. Farmers refer to this function of warabandi as *"haqooq"*. The form of rights defined by an official warabandi in canal irrigation assumes a more formal "legal right". Studies indicate that the majority of small farmers tend to prefer official warabandi as it is based on equitable water distribution. The flexible water turns which have gradually replaced them are often determined by a few powerful rural elites. This explains how the officially detcrminetl or recognized pucca warabandi schedules underwent change, as the informal pressure from the local elites tended to supersede the formal rules in the long-rim.

According to official procedure, a Canal Patwari is required to keep updated records of the latest sanctioned official warabandi list for their Patwar area. Surprisingly, for only two watercourses in the sample of 22 watercourses were the required lists readily available. Most of the concerned officials could not provide the latest warabandi lists for their respective watercourses in the study sample. Failing to collect all of the official warabandi schedules from the Patwaris, an effort was made at the Divisional Canal Offices to retrieve the remaining lists For the sample watercourses. The study team could collect only 15 official warabandi schedules (7 or 10.5 days) from the Irrigation Department for the 20 pucca warabandi watercourses in the sample (2 sample watercourses were on kachcha warabandi).

Canal Patwaris are basically responsible for drawing official warabandis based on formal requests by the water users. However, field interviews showed that most of the Irrigation Department field personnel dealing with warabandi operations were not fully conversant with the procedure and not skilled enough to frame the roster, or even to explain the procedure. They acknowledged the existence of agreed warabandis based on consultation and compromise amongst the farmers. When a dispute arises, some of the serving officials seek advice from retired and experienced Patwaris for guidance and try to resolve the dispute informally. This may also explain why farmers have resorted to evolve their water turn schedules, which are a product of inevitable power and authority relationships that exist in the rural areas.

Gap between official and actual warabandi

An important lesson drawn from the analysis of canal water allocation in all the watercourses is that the official warabandi developed and kept by the Irrigation Department officials is no longer in practice. It has been replaced by a warabandi developed by farmers themselves defined by Bandaragoda and Rehman (1995) as the *Agreed Warabandi*. Similar to the official warabandi in its format (i.e. defining water turns in terms of starting and end time, in and out nakkas), the Agreed Warabandi is regularly updated at the beginning of each season, and rotated by 12 hours in most of the cases after the canal closure period. Most of these Agreed Warabandi resemble *pucca* warabandi schedules with fixed allocations of water turns as opposed to the more flexible *kachcha* warabandi. Some of the differences existing between the official and Agreed Warabandi are noted below.

(i) The official warabandi allocates water turns to land owners, while the Agreed Warabandi considers all water users (i.e. land owners or tenants and lessees).

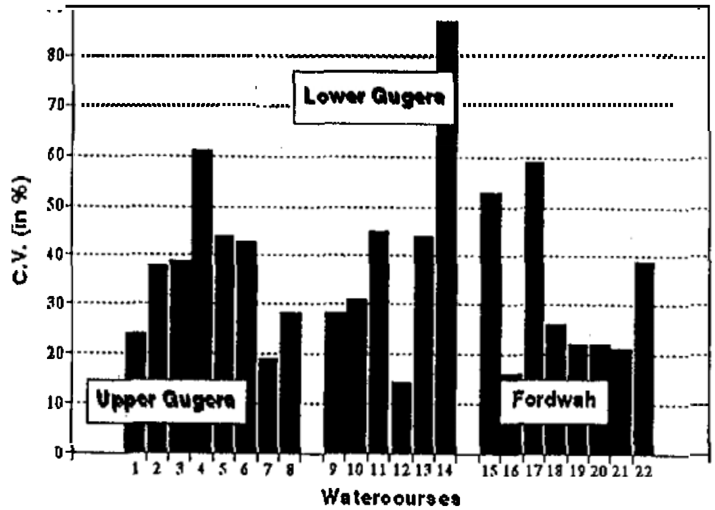
(ii) The Agreed Warabandi is regularly updated (usually at the beginning of each season, to take into account changes in command area, tenure, etc) while the official warabandi is updated mainly when water allocation conflicts occur on a given watercourse. In most of the watercourses surveyed, official warabandi schedules were more than 15 years old and had little in common with the Agreed Warabandi.

(iii) Unlike the official warabandi that is based on the principle of equity, large inequities are present in the Agreed Warabandi. Technical, physical and social factors explain this inequity in allocation of water turns.

(iv) Staff from the Irrigation Department and farmers are involved in the development of the official warabandi, while the agreed warabandi is a farmers only matter.

In order to quantify the actual level of equity in canal water allocation within the watercourse command area, the Coefficient of Variation (C.V.) of all the water turns per unit area has been computed and used as an indicator for equity (a coefficient of variation of 0 means perfect equity). Values of C.V. for 22 watercourses are presented in Figure I. These values range from 0.15 (or 15 percent) to more than 0.8 for one watercourse of the Lower Gugera irrigation system. Although the variability among watercourses is high, large levels of inequity in water allocation are the rule for most of the watercourses analyzed.

Figure 1. Equity in allocation of canal water turns (agreed warabandi) for sample watercourse command areas (kharif 1993).



Although the Agreed Warabandi is developed informally by farmers, some of the criteria used to develop it are similar to the ones used for the official warabandi. Although a large inequity in the allocation per unit area is observed, the area cultivated is still an important factor explaining canal water allocation. Advance and drainage times are taken into account in most of the watercourses (values used by farmers are the same as the ones used by the Irrigation Department officials). And water turns are to be taken at specific locations along the watercourse (but not necessarily at the official nakkas).

An interesting point is that time, duration of turn, and location at which the water turn is to be taken as defined in the Agreed Warabandi are well enforced in most of the watercourses monitored. Thus, although the allocation of water turns is informal, farmers are able to enforce their Agreed Warabandi mainly by social control. The allocation of water turns (seen as de facto water rights) in the Agreed Warabandi is not equitable, but accepted, and enforced by farmers themselves with little or no intervention from officials.

The shift from the flexible *kachcha* warabandi to *puccaa* warabandi can also be seen in the context of enforcing water rights. In the past, the kachcha warabandi with its more flexible allocation of water turns gave opportunity to powerful water users to have better access to surface water resources, whatever the canal water supply at the head of the watercourse. In **a** large number of watercourses, the increasing pressure on water resources recorded during the past **20** years **(as** illustrated by significant increases of cropping intensities during the **last** 20 years) has been accompanied by **a** shift from the flexible kachcha warabandi to the fixed pucca warabandi, with water rights respected and enforced by water users.'

The impact of water scarcity on water allocation, with the shift from kachcha to pucca warabandi analyzed in an historical perspective, is also stressed by results obtained in the two irrigation system of NWFP with higher water allowances **as** mentioned in the previous section. In most of the watercourses of the Chashma Right Bank Canal irrigation system, for example, the very high water allowances have **led** to **a** high degree of flexibility in water allocation and the development of improperly defined water turns. **As** water is plentiful, to develop strict schedules **of** water turns is not required. However, during periods with higher water demand (for example, during the rice transplanting period), stricter warabandi schedules were followed in some parts of the irrigation system.

Fined agreed allocation but flexible distribution

Another important dimension added by farmers to the traditionally fixed warabandi system relates to the flexibility of canal water distribution. **As a** response to inadequate, variable and unreliable canal water supplies at the watercourse head, farmers have developed active and localized water markets. Water users are involved in different types of canal water transactions with specific objectives. The main water trading activities for canal water are listed below:

(i) Trading of full or partial canal water turns, in order to finalize the irrigation of **a** given field or when other water users do not need water at the time of their turn (competition with other farming activities);

(ii) "Time for location" trading, to take into account drainage and advance time that may be involved due to the use of canal water at locations different than the ones specified in the agreed warabandi;

(iii) Purchase and sale of canal water, whether for a short period of time (one week only) or for a full season **(sale** of water turns of abandoned land, or **sale** of water turns by tail farmers to head farmers);

(iv) Intra-farm (inter-plot) allocation of canal water turns, by using canal water turns allocated to one plot on another plot located at **a** different location along the watercourse,

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8 Differences between Azim xnd Fordwah should **he** noted. This difference implies that probably the Sindh situation is similar to Azim Dislrihutary.

but belonging to the same cultivator; and

(v) Exchange of canal water for tubewell water, often related to the use of irrigation water at different locations within the watercourse command area in order to reduce losses that may take place for low canal water discharges and long distances between the watercourse head and the farm gate.

Water trading activities in all of the monitored areas are always informal. Most of the time, trading activities involve a few neighboring farmers. The analysis undertaken by Debernardi (1996) using a Geographic Information System stresses the existence of independent water management units within the watercourse coininand area. These units, of approxiinately 25-50 acres and 5-8 farmers, operate autonomously with joint allocation of turns and rotation among turns, active water trading activities, and often active purchases and sales of tubewell water. In some cases, negotiation processes similar to auctions take place at the beginning of the season for tail farmers to sell their water turns to head farmers that are ready to pay the highest price'.

The importance of canal water trading activities is illustrated in Table I for 8 sample watercourses in the Fordwah Branch Canal Irrigation System.

Table 1. Importance of canal water trading within watercourse command areas (weekly values for kharif 1994).

Watercourse	Average number of turns received	Water turns borrowed			Water turns purchased (NIL)
		Total (%)	Full turns (No.)	Partial turns (No.)	
Fordwali 14-R	53	32	23	12	0
Fordwali 46-R	44	24	16	17	0
Fordwali 62-R	50	8	4	8	0
Fordwali 130-R	40	13	7	12	2
Aziin 20-L	21	48	4	11	0
Aziin 43-L	44	34	16	17	I
Aziin 63-L	12	17	2	5	0
Aziin II I-L	-	-		-	-

Note: 1. Partial turns include exchanges of Nikkal and Khal Barai time due to location shift along the watercourse
2. Canal water did not reach Aziin I I I-L Watercourse during the kharif 1994 season.

9 Such situations have been found in different irrigation systems throughout the Punjab. A rapid survey in 31 watercourses of the Chishtian Sub-division has shown that auction-like mechanisms were still rare and found in only a few watercourses.

Table 1 highlights the importance of borrowing (in terms of percentage of the total water turns) for watercourses that have good canal water supplies such as Fordwah 46-R or Azim 20-L. However, other factors influence the importance of water trading activities as highlighted by Fordwah 62-R Watercourse that has a very good canal water supply, but records a low level of water trading activities. Table 1 also illustrates the limited intensity of sales and purchases of canal water turns (recorded only in Fordwah 130-R and Azim 43-L Watercourses).

Little is known about factors (whether physical or social) that influence the variability of intensity in canal water markets within the watercourse command area. A survey undertaken by the Watercourse Monitoring & Evaluation Directorate (WMED) in 1990 for 100 watercourses in the four provinces emphasized the importance of this phenomenon with 30 percent of the watercourses surveyed reporting the trading of canal water turns, and canal water being sold and purchased by 20 percent of the water sellers and 30 percent of the water purchasers, respectively (WAPDA, 1990). However, the study did not identify factors explaining the differences in canal water trading from one area to the other.

The comparison between the 22 sample watercourses provides some insight on the impact of canal water supply and cropping pattern on canal water transactions. The comparison between these watercourses shows that water trading activities are more developed in the Upper Gugera irrigation system, with a rice-wheat rotation and a large number of water users per watercourse (thus, an average short time duration for canal water turns). Farmers face simultaneously a high demand for each irrigation due to the rice crop and a low weekly supply due to short canal water turns. In order to irrigate their paddy fields efficiently, farmers get involved in canal water transactions. In fact, in most of the watercourses of the Upper Gugera irrigation system, all farmers/water users are intensively involved in various types of canal water transactions.

Water supply performance below the mogha

The level of inequity and variability in the allocation and distribution of canal water turns (in terms of hours, or hours per unit area) has been highlighted in the previous sections. The focus of this section is the actual canal water supply performance, with two main issues being considered: (i) the current level of canal water supply performance within the watercourse command area; and (ii) the coinparison of perforniance results obtained for different levels of the irrigation system (watercourse versus distributary and main canal).

Current canal water supply performance at the farm gate is characterized by a high temporal variability in canal water discharge resulting from variability upstream in the irrigation system (Kuper and Strosser, 1996). To tackle this variability, farmers are exchanging canal water turns to be in a position to complete their irrigation event for a given field in an proper way. Also, farmers have kept a certain variability in the size of their plots to partly tackle the variability in discharge.

Results of analysis shows that the inequity in allocation, along with the temporal variability in canal water supply at the watercourse head, is transformed into an inequity in canal water supply at the farm gate. To represent tlie level of equity for different watercourses, tlie coefficient of variation of the actual canal water supply is calculated and presented lor 8 sample watercourses of the Fordwah Branch Canal Irrigation System in Table 2.

Watercourse	Agreed warabandi	Actual water supply	
		Water turns per unit area	Volume per unit area
Azim 20-L	59	39	35
Aziin 43-L	23	41	49
Azim 63-L	22	86	55
Aziin 111-L	88		
Fordwah 14-R	30	85	100
Fordwah 46-R	19	61	43
Fordwah 62-R	19	85	87
Fordwah 130-R	21	76	62

For most of the watercourses, the inequity in volume is lower than, or equal to, the inequity that has been computed using the actual water turns. This is the result of the development of canal water transactions to smooth tlie variability in discharges observed at the watercourse head. However, the inequity in volume is higher for all **cases,** but Azim 20-L watercourse[10], than the inequity recorded in the Agreed Warabandi.

Further analysis in the same 8 watercourses emphasized the importance *of* the allocation of canal water turns to explain the variability in actual canal water supplies (Barral, 1994). Using a volume-balance model for the watercourse, tlie analysis considered different (actors, such as allocation, seepage losses, discharge variability at tlie watercourse head, etc, and estimated the marginal impact on canal water **supply** and **equity** of each factor.

Although the expectation was that seepage losses would be tlie main Factor explaining inequity in water distribution within the watercourse command area, the results showed that allocation **of** water turns is tlie main cause for inequity in watercourse command areas. Out of 8 watercourses, seepage losses were found of significant importance in only one watercourse where the distance from the watercourse head has **a** significant impact on water supply. The result for this watercourse are illustrated in Map 1.

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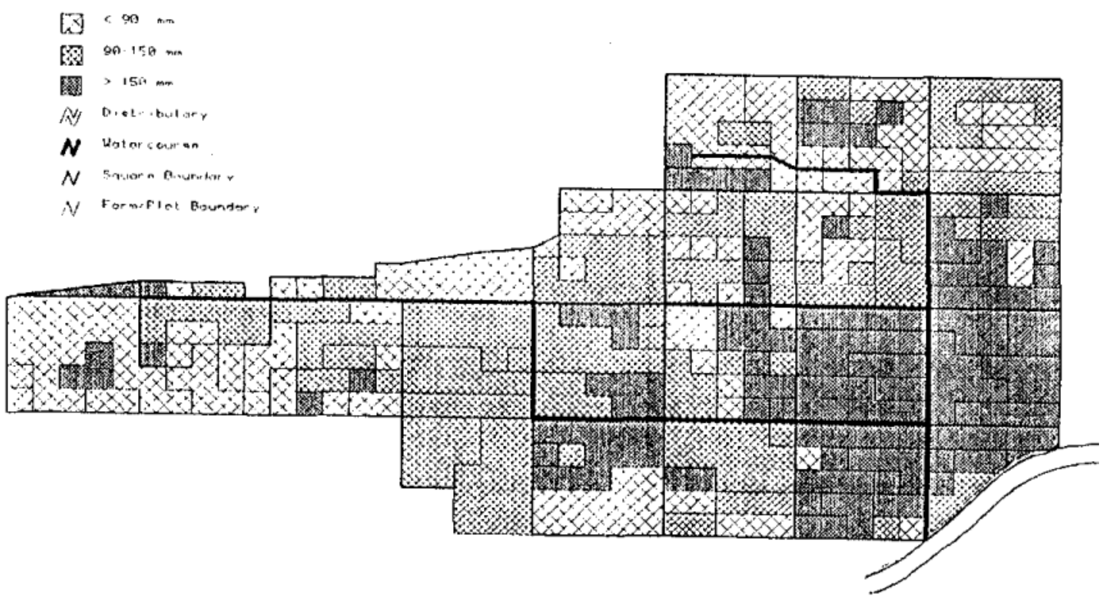
[10] The excellent canal water supply per unit area for this watercourse may explain the reduced inequity observed *for* volumes of canal waler delivered to farmers.

Map 1. Spatial distribution of canal water supply within Fordwah **14-R** Watercourse command area.



A second issue relates to the relative importance of perforinance at tlie watercourse level **as** compared with other levels ***of*** the irrigation systems. The comparison between canal water **supply** performance at different levels of the irrigation system has been undertaken in ***the*** Chishtian Sub-division. Results obtained so far with regard to equity are summarized in the following table.

Table 3. Inequity at different levels of the Chishtian Sub-division.

Level of the irrigation system	Coefficient of variation of canal water supply
Between farms of a given watercourse[1]	0.3
Between watercourses of a given distributary[2]	0.3-0.8
Between distributaries of the Chishtian Sub-division[3]	0.4

1 : Average of 8 sample watercourses (Azim and Fordwah distributaries)
2 : Coefficient of variation estimated for all watercourses of each distributary of the Chishtian Sub-division (thus, 14 coefficients of variation estimated)
3 : All distributaries of the Chishtian Sub-division

The comparison between coefficients of variation at different levels of tlie irrigation system presented in Table 3 stresses that inequity is first to be addressed at the secondary canal level. Inequity is the highest between watercourses of given distributaries, then of similar importance for farms within a given watercourse command area, or between secondary canals along the main canal.

DISCUSSION

Three issues are discussed in the present section. The first two issues relate to potential interventions targeted towards allocation and distribution of canal water below the mogha, i.e. intervention for which objective (improvement of equity, adequacy, variability of canal water supply) and which intervention? The need for furtlier research to fill existing gaps is the third issue discussed in the present section.

Which objectives to tackle at the watercourse level?

With the increasing importance of private tubewells that have added flexibility and have increased volumes of water available to improve the canal water supply, adequacy may not be of significant importance. In some cases, however, with no access to tubewell water due to poor quality ground water, and with high conveyance losses along the watercourse, adequacy of canal water supply may be the main issue to be considered. In this context, to reduce conveyance losses through lining or other improvements may be an appropriate option to increase adequacy. Other options targeting adequacy would require interventions at higher levels of tlie irrigation system (distributary, main canal) with an expected impact on the average discharge entering the watercourse command area.

The analysis of tlie variability issue leads to similar comments. Variability in canal water supplies is a phenomenon that has its origin above the watercourse head. Within the watercourse command area, farmers have succeeded in tackling part of the variability in canal water supply. For example, by exchanging (partial) canal water turns, or having bunded units of different sizes adapted to different discharges. However, further reductions in variability cannot be tackled within the watercourse command area and interventions are required at higher levels of the irrigation system (see, for example, Litrico 1995 for examples of potential interventions at the main system level).

Equity is an issue that can be tackled within the watercourse command area. The analysis of canal water supply performance highlights the high spatial variability in volumes per unit area received by farmers of a given watercourse. The analysis shows also that tlie inequity in allocation is the main factor explaining inequity at the watercourse level, and that seepage losses have a significant impact on inequity in some cases only.

However, the comparison of tlie equity indicators at different levels of tlie irrigation system, as presented in Table 3, shows that equity should first be tackled along the distributary between watercourses. Within the watercourse, the existing equity or inequity in canal water distribution is often related to an inequity in allocation of water turns that results from a specific social balance between farmers of the watercourse.

Whether the outcome of this social balance is good or bad should not be judge too rapidly. In fact, an inequitable but socially accepted allocation may be seen as more appropriate than an equitable and socially not accepted one[11]. In any case, to modify current allocation patterns would require significant efforts (or drastic changes in the existing social relationships) that may require external interventions and may not be sustainable after all.

Potential for intervention below the mogha

Several interventions may be proposed within the watercourse command area to improve canal water supply performance. As specified above, however, the prospect for significant improvements seem rather limited, whether because there are limited possibilities for improvements due to characteristics of the existing physical system with limited control points, or because the main impact would be obtained at different levels of the irrigation system.

Interventions may be related to allocation and definition of water turns or water rights in order to establish an official warabandi as a recognition of water rights, to update the official warabandi on a regular basis, to recognize long-term water trading (sale and purchase of water turns), to modify the definition of water turns by adding extra allowances for seepage losses, or may be related to distribution (to recognize short term water trading or implement technical interventions, such as lining to reduce seepage losses). These interventions are summarized in Table 4, along with information on their expected impact on canal water supply performance, difficulties for implementation, expected costs, constraints, etc.

These interventions were analyzed in the context of their expected impact on water supply performance, and difficulties of implementation based on the existing situation are listed and discussed below in light of the results obtained and presented above.

[11] The point to be made is that a system with an equal share of water may not be considered equitable by a given society, or group of people, as it does not necessarily fit with their own system of norms and rules.

Table 4. Potential interventions to improve canal water supply performance below the mogha.

Intervention	Expected impact on performance	Expected cost of intervention	Social acceptance	Sustainability	Comments
To re-establish official warabandi	Significant impact on equity	High. need to re-establish enforcement power of irrigation officials	Opposition from water-rich farmers	Low	It is doubtful whether a strict official warabandi was ever in practice
To update official warabandi based on current changes (with equity principle)	No change in the short-term - possible change in equity in the long-term	Little cost (only cost of registers and proper filing)	Social acceptance - increasing awareness of water-poor farmers about their rights	Medium to low (depending on interest from concerned department)	Can be used as indicator of water rights in dispute settlements
To legalize long-term water trading	No change or expected slow increase in long-term water trading	Costs (minimum) to modify/up-date the Canal & Drainage Act	Social acceptance - rich landlords becoming water lords?	High, but need to have proper legal documents for each transaction	Can work against less powerful farmers
To modify definition of water turns and include losses	Little impact on equity in most cases	Cost similar to re-establishment of official warabandi	Acceptance by tail farmers and opposition from head-farmers	Medium to low, depending on the importance of losses within the watercourse command area	
Watercourse improvements	Little impact on equity. some impact on adequacy	High costs	Acceptance by farmers, but possible problems at construction stage	Highly variable, depending on quality of initial construction	Success depends on selection of areas for improvement
Development of effective Water User Associations[12]	Expected impact on equity	Potential high costs (social organizers, technical assistance to associations)	Opportune for less powerful users	High sustainability	Collective action can supervise warabandi practice - Success depends on selection of areas for development of associations

[12] The purpose here is not into enter in the debate regarding the potential need for water user associations. However, the development of effective water user associations may lead to modifications in the allocation of canal water turns and have an impact on equity and water supply performance.

Research gaps and research issues

The results presented in this paper stress the importance of field research to understand the current issues **related** to water management activities below the mogha and identify appropriate interventions to address these issues. In itself, the significance of the gap between official rules, and rules in practice, justifies the need for more field research based on real world situations.

At this stage, although the magnitude of efforts spent to collect information for the largest samples is recognized, there is a need to increase the number of samples to test specific hypotheses. For example, research results have shown that inequity in allocation of water turns, and not seepage losses, are responsible for the larger share of inequity within the watercourse. But this conclusion is expected to vary from environment to environment based on the absolute values of conveyance losses, the relative water scarcity within **a** command **area,** and social and organizational characteristics of populations that are expected to influence the allocation process. Research results have mainly been based on data collected in the Punjab and the NWFP, but differences are expected in the Sindh.

Although IIMI's research has shown that inequity in allocation of canal water turns within the watercourse command areas is **a** common phenomenon, little has been done to analyze the physical and social factors that explain inequity in allocation. What are the main characteristics of farmers that receive turns longer or shorter than the average? Are they owners or tenants, small or large farmers, affected by salinity or waterlogging, head or tail farmers, influential or common farmers, etc? With the recognition of the role of social factors in the allocation process, watercourse level studies focused on water management activities may need to be complemented by village level enquiries that would investigate the social complexity of **a** given population and its impact on water allocation and distribution.

Finally, most of the analysis presented above focuses on performance in terms of canal water supply. Further analysis is required to also integrate issues related to performance in terms of agricultural production and environment. Also, the expected impact of different allocation scenarios, or watercourse level interventions, on agricultural production and salinity would need to be assessed.

EPILOGUE

In the research conducted so **far,** an analysis of water allocation and distribution within the watercourse command areas shows that there exists **a** considerable gap between the "official" norms and the actual practices. However, the system **is** not in total anarchy **as** it uses clearly understood sets of rules and rights, which are informal but socially accepted and enforced (or practiced). A large degree of flexibility is observed, and this is caused by an emerging market-oriented behavior in water trading, particularly with tubewell water. The lining of watercourses, which is a major intervention pursued by successive phases of "on-farm" water management projects seems to have eclipsed **a** much more needed attention in two other **areas.** While watercourse improvement seems useful in areas where seepage losses are high, a greater need for research and policy initiatives remains unfulfilled below the farm-gate where improved irrigation practices need to be adapted to suit farmers' current requirements, and above the watercourse head, where improved water allocation practices would help to liberate the present physical and social constraints faced by the farmers.

On-going research activities by IIMI continue to explore the history of water allocation practices in Pakistan, and to clearly identify physical **and** social factors that influence water allocation and distribution patterns. In two field sites in the Punjab, studies are aimed at analyzing the relationship between physical and social factors, water management activities and water supply performance. A more general comparative study is under way in collaboration with the Wageningen Agricultural University and the Department of Water Management of the University of Pehsawar. This comparative study covers several irrigation systems to address the issues of variability in the environment within the Indus Basin.

The research efforts by IIMI and other institutes need to be closely linked with **a** dynamic policy support that **takes** into account the changes that **are** taking place in the context of irrigated agriculture. **A** weakness in the linkages between research and policy has been identified as the main cause for the failure of many development interventions in irrigated agriculture sector in Pakistan (Bandaragoda, 1993). For the physical environment and the legal framework to fit with reality on ground, the research institutes including IIMI need to effectively disseminate research results to policy makers and implementing agencies. The rules need to reflect the demand in the operational context. These are challenges that continue to confront the researchers.

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IMPACT OF IRRIGATION WATER SUPPLY ON FARMERS DECISIONS AND AGRICULTURAL PRODUCTION

Pierre Strosser and Khalid Riaz[1]

ABSTRACT

Poor canal water supply performance has been well documented in irrigation systems in Pakistan. Technical and institutional options have been proposed to solve this problem. However, little is known about the expected impact of these options on farmer's decisions and agricultural production. Part of this knowledge gap relates to the difficulty in establishing the link between water supply performance and agricultural production. The present paper proposes a framework for the analysis of the relationship between irrigation water supply. farmer's decisions and agricultural production and productivity. Several levels of decisions that may influence agricultural output are identified. Research methodologies and results pertaining to two of these levels are presented in the paper. First, the paper analyses the link between canal water supplies and agricultural production at the farm level. Using stochastic linear programming models developed for individual farms, the impact of the quantity and variability of canal water supplies on crop choices is analyzed. Second. the paper concentrates on the analysis of the link between water use and crop yields. The impact of irrigation water supplies (in terms of quantity and timeliness) on crop yields is illustrated using production functions for a wheat crop. The results of the two studies are summarized and discussed in the context of the identification of the intervention (or set of interventions) that would improve canal water supply performance and yield to the higher benefits in terms of agricultural production and productivity. Using the analytical framework developed for the paper, follow-up research activities are also identified in the conclusion part of the paper.

INTRODUCTION

The discrepancy between stagnant agricultural production and increasing demand for agricultural and food products has been well documented (World Bank, 1994) and is clearly an important issue in the agenda of policy makers and funding agencies in Pakistan. With the importance of irrigated agriculture (covering 16 million hectares and providing more than 90 percent of the exports of agricultural products), a lot of attention is given to potential improvements in the irrigation sector that would then lead to (expected) large increases in crop yields and agricultural production.

While in the past, equity has been the main objective of irrigation sector policies, the discrepancy between supply and demand of food products has shifted the emphasis from equity to productivity and sustainability objectives, with efficient and lasting use of water resources being the key words of current policy efforts (see for example the opening speech of President Leghari of Pakistan at the inauguration of the IIMI building in Lahore in 1995). With regards

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to canal water supplies, high concerns have been raised with the poor quality of irrigation services supplied to farmers. Canal water supplies to watercourses are highly inadequate (as compared to design values) in a large number of cases, are inequitable at all levels of the irrigation system (Kuper and Strosser, 1996), and highly variable (Bhutta and Vander Velde, 1992; Kuper and Kijne, 1992; Kuper and Strosser, 1996).

Several options have been proposed for the improvement of canal water supply performance. These options include purely technical interventions such as lining of secondary and main canals, or construction of extra storage capacity, and also institutional innovations such as the development of Water Users Associations .(whether at the watercourse or distributary levels) and the establishment of financially autonomous public authorities. Also, changes in the level and structure of water charges have been proposed (hut only very partially implemented so far),

For most of the options proposed, however, very little is known on two important aspects. First, what is the expected impact on technical and institutional options on water supply performance itself? To identify potential changes in water supply performance as a result of maintenance activities or lining of canals may be a possible task. However, how much can be said about the expected improvements in canal water supply performance as a result of the development of Water Users Associations? It is only recently that the literature on water user associations started to address the issue of impact in a comprehensive manner.

Second, the relationship between water and agricultural production is to he better understood. What would be the expected impact of proposed options on agricultural production and productivity, as a result of changes in canal water supply performance? Whether water is the main constraint on agricultural production is also an issue that is to be addressed before starting allocating financial resources to innovations in the irrigation and drainage sector. Improvements in water supply performance may not lead to expected changes in production and productivity if the main problems faced by farmers relate to the availability of certified seeds or proper quality fertilizers.

To take policy decisions (in terms of allocation of water resources and financial resources) and select the "right" innovation or change without understanding these two aspects would be a very difficult (and doubtful) task. A review of the literature shows that research results that would help answer these issues are rather rare in the context of Pakistan (and most often are derived from research activities undertaken in research stations under controlled conditions that often do not exist in the real irrigation world in Pakistan). In some ways, the low level of importance given by the research community to the analysis of the relationship between interventions in the irrigation sector, water supply and agricultural production under existing conditions is rather surprising coinpared to the issues at stake. More field research targeted at the understanding of this relationship would decisively help policy makers in selecting improved management options to be implemented in the huge irrigation system in Pakistan.

The second issue, i.e. the **relationship** between **canal/irrigation** water **supplies and** agricultural production, is further investigated in the present paper. This paper presents methodologies and tools that have been developed during the last two years by the International Irrigation Management Institute (IIMI) in Pakistan. Research results obtained so far are presented to illustrate the complexity of the relationship between water and agricultural production, and propose directions that may be followed to address this complex issue.

ANALYTICAL **FRAMEWORK**

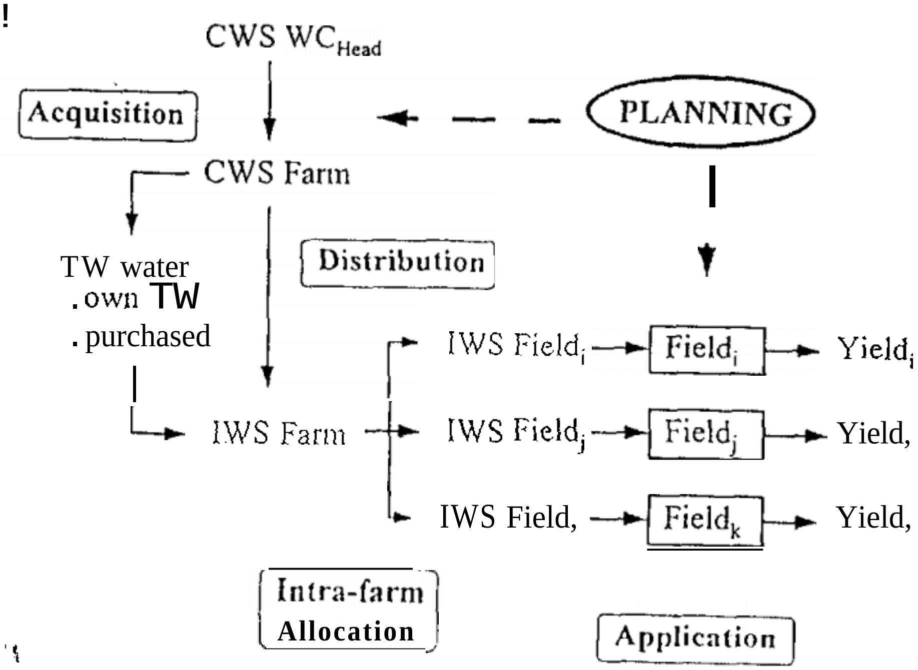
The link between water supply and agricultural production is complex as it integrates several decisions taken by farmers at different periods of time. Decisions are taken at the planning stage, but also regularly for scheduling of irrigation events and application of irrigation water to specific fields. The information used by farmers to take each decision varies also, from a composite view based on events faced during the past seasons (for example, knowledge about past irrigation water supplies that influence crop choices) to more simple and straightforward information collected shortly before taking **a** given decision (for example, to chcck the water level at the distributary a few hours before an irrigation event).

In the case of a farm, different levels of decisions may he considered that relate to irrigation water supply.

> **(i)** Which crop(s) to plant on the farin for an expected canal water supply at the farm gate'? This planning decision considers also potential access to (and price **of)** groundwater resources (whether own tubewell or purchase), **based** on experiences confronted during the past seasons.
>
> **(ii)** How to allocate irrigation water to the different fields of the farin'! Once canal water arrives at the farm, farmers are to take decisions regarding intra-farm water allocation and tubewell operation: which field to irrigate, for how long, with which duration and quantity? Past irrigation events, crop types and physical characteristics of fields, along with farmer's strategies and priorities are important elements that will influence these choices.

The different elements of the relationship between water and agricultural production are summarized in Figure 1. The abbreviations used in figure 1 are as follow: CWS for Canal Water Supply; WC for Watercourse: **TW** for TubeWell; **IWS** for Irrigation Water Supply; $Field_i$, $Field_j$ and Field, represent different fields within the farm (with different soil, salinity conditions, crops, etc); Yield,, $Yield_j$ and Yield, are crop yields obtained from Field,, $Field_j$ and Field,, respectively.

Figure 1. **A** simple framework for analyzing the relationship between water and agricultural production.



OBJECTIVES OF THE PAPER

Two sub-components of this analytical framework are investigated and illustrated in the present paper. These two approaches, that have been developed and tested by IIMI to address issues related to the impact of irrigation water supply on agricultural production, are described, tested and evaluated in the following sections of this paper. These two approaches are:

(i) at the farm level, the analysis of the **impact of canal water supply on cropping pattern and agricultural production.** The marginal impact of **quantity and variability** of canal water supply is investigated. The analysis provides also information on the way private tubewells are operated to increase the quantity of irrigation water available or *to* reduce the variability of canal water supplies. The approach looks at the planning stage, i.e. which cropping pattern to **be** developed based on expected canal water supplies for each month.

(ii) at the field level, the investigation of the **impact of actual irrigation water use/application on crop yields,** taking the example of the **wheat crop.** The two main aspects of irrigation water supply performance that have been considered are **quantity and timeliness** of irrigation water supplies.

Both approaches have been developed using information collected in eight sample watercourses of the Azim Distributary (non-perennial) and Fordwah Distributary (perennial) of the Chishtian Sub-division, South-Punjab (for the characteristics of sample watercourses, see Pintus, **1995).** Basic farm level information for the *kharif* (summer) **1993** and *rabi* (winter) **1993-94** seasons has been collected through a farm survey for all farmers (total 280) of these sample watercourses. Also, a limited number of sample farmers (15) have been monitored intensively for the Rabi **1994-95** and Kharif **1995** seasons regarding their practices for crop production. The information collected in the sample watercourses and used in the present study is summarized in Table 1.

Table 1. Data sets and data collection methods

Component	Main variables considered	Data collection methods
Farm typology & economic modelling	Farm Characteristics Farm constraints: land, labour. water (adequacy, variability), credit) Farm strategy (level of intensity. diversification. autoconsumption or market orientation)	Informal interviews with key informants & farm survey (280 farmers in 8 sample watercourse command areas) Daily monitoring of canal water supply at the WC head, seepage losses along the WC
Production function	Canal water supply (adequacy, timeliness) & tubewell water use Input use Labour Cash-flow Yields	Daily monitoring of canal water supply at the WC head, seepage losses along the WC Daily monitoring of tubewell water use Monitoring of farm practices for 2 seasons (cotton and wheat field for 15 sample farmers) In-depth interviews and restitution with sample farm!

Importantly, a very good estimate of canal water supplies is obtained for all farms of the eight watercourses through daily monitoring and water levels at the head **of** each watercourse. Water levels are transformed into volumes by using specific discharge formula calibrated for each watercourse, then multiplying discharges by the expected time of use and adjusting the results to take into account conveyance losses from the watercourse head to the **farm** gate. The daily information is used to compute monthly average canal water supply and monthly standard deviation as a proxy to canal water supply variability as perceived hy farmers. **Also,** tubewell water use has been monitored for all fields of the 15 sample farms to compute total irrigation water supply and average irrigation water quality.

The following sections present first the methodology, models and results of the farm **level** analysis, and second the methodology and statistical results of the production function for wheat. The final section of the paper discusses the results obtained and the limitations and advantages of the methodologies.

IMPACT OF CANAL WATER SUPPLY ON CROPPING PATTERN

Methodology

The methodology developed for the analysis of the relationship between irrigation water supply and crop choices draws on similar studies and experience developed by the Irrigation Division of Cemagref, a French institute involved in agricultural and environmental engineering research. The rationale behind the methodology that has been developed and tested in a Pakistani context is the recognition of the large heterogeneity of farming systems, along with the assumption that this large heterogeneity can be described and summarized by a limited number of well-defined farm types or groups with specific farm strategies and constraints.

In order to identify these farming systems, a classification procedure is applied on a selected set of variables expected to represent strategies and constraints in the area investigated. A cluster analysis is performed using the farm survey inlormation, and farm groups or farm types are identified. Overall, 11 farm groups have been identified that represent the farm population of the eight sample watercourses (Rinaudo, 1994). Each group is homogeneous for the main variables characterizing this group. For other variables that are seen as less important to explain farm strategies, a heterogeneity remains within the group. Table 2 summarizes the main strategy and characteristics of the different groups (see Rinaudo, 1994, for more information).

Table 2. Farming systems in the Fordwah area: main characteristics of farm groups.

Farm group	Farm strategy (*)	Family member/ha cultivated	Tractor owners	Tubewell owners	Cultivated area (in ha)	Area rented in (in % of cultivated area)	Yearly cropping intensity
1	Autoconsumption	1.9	No	NO	4.I	45	140
2	Diversification	1.7	NO	No	4.7	55	130
3	Diversification	1.9	No	No	5.8	55	140
4	Market orientation	1.6	No	NO	4.4	65	135
5	Market orientation	1.6	NO	NO	4.5	70	160
6	Market orientation	I.6	NO	No	6.0	75	140
7	Autoconsumption	5.9	No	Yes (**)	1.5	10	180
8	Autoconsumption	4.9	Nll	Nu	3.5	30	120
9	Diversification	1.5	Yes	Yes	8.2	30	155
10	Diversification	I.7	Yes	*Yes*	4.3	20	145
11	Diversification	0.2	Yes	*Yes*	42.5	60	130

(*) : Diversification refers to diversified cropping pattern including rice and sugarcane instead of only wheat and cotton as commonly found in the area. Autoconsumption characterizes farmers that favour wheat production for their own consumption, as opposed to market orientation that stresses the importance of sales of agricultural products and links with input and output markets.

(**) : Joint tubewell ownership mainly.

Then, representative farms are selected for each group, and micro-economic models are developed for each farm (i.e. 11 distinct micro-economic models). In the study presented in this paper, linear programming (LP) models have been developed, using the Micro-LP Software (Scicon, 1989). So far, the main constraints that have been included in the models relate to land, water, cash-flow, autoconsumption of wheat and tubewell water use[2]. Each model is then calibrated using information obtained from the farm surveys, informal interviews and regular monitoring of farm practices (irrigation management, input use, impact on yields, etc).

The LP models developed are stochastic models, including aspects of risk that are taken into consideration by farmers to take decisions. The method selected for the inclusion of risk in the LP models is the MOTAD developed by Hazell (Hazell and Norton, 1986). Risk has been considered for wheat production (variability in wheat yields related to pests and variability in rainfall) and for gross margin for cotton (variability in gross margin related to virus attacks along with high variability in cotton prices). Risk on wheat production will be of importance for farms with autoconsumption objectives, while variability in cotton gross margin will affect mainly market oriented farms relying on cotton sales. Risk aversion factors attached to each type of risk are specified as part of the calibration process.

Also, risk aspects have been included in the irrigation water supply constraints faced by farmers. As highlighted by Figure 2 that displays the monthly Coefficient of Variation (C.V.) of canal water supplies[3] at the head of two sample watercourses off-taking from the Fordwah Distributary, temporal variability in canal water supplies is relatively high (especially for the Fordwah 130-R Watercourse) and is expected to impact on farmer's decisions. With a highly variable canal water supply, farmers would put less area under crop on their farm, but would favour crops that are less water sensitive and that may better resist water stress.

Similar to the approach selected for including risk in yields and gross margins, to include canal water supply variability in the LP micro-economic models follows a MOTAD-like approach. The standard deviation of canal water supply is used to express its variability, and risk aversion factors related to water supply are included in the LP micro-economic models. Using water supply information obtained from daily monitoring of watercourse head water levels (as presented in Table 1), monthly averages and standard deviations of canal water supply are computed for each representative farm model,

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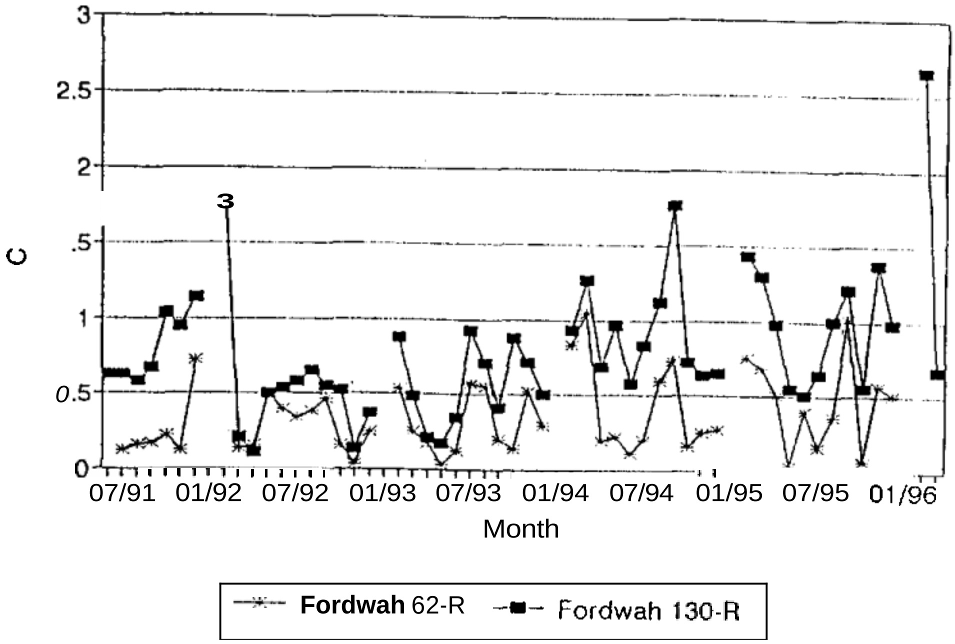
2 Information is currently analyzed to add labour constraints in the models. Discussions with farmers and the analysis of data shows that this constraint may not be important in the current context. However, simulations of scenarios may modify this situation and lead to potential labour shortages during specific periods such as harvesting periods for wheat and cotton. or transplanting of rice.

3 The monthly Coefficient of Variation (C.V.) of canal water supplies is computed to express variability, using daily discharges at the watercourse head monitored by IIMI field staff. No C.V. can be computed for the months of lanuary as canals are closed for their annual maintenance.

Figure 2. Monthly variability **(C.V.)** in canal water supplies at the head of the Fordwah **62-R** and Fordwah **130-R** watercourses (June **1991** - March **1996).**



The following sections illustrate the use of the micro-economic farm models to **assess** the impact of changes in canal water supply on **farm** decisions. Also, the heterogeneity in **farmer's** behaviour among **farm** groups is presented by comparing the output of some of the models **for** different scenarios of canal water supply adequacy.

Impact of canal water supply on farm decisions

The **first** example focuses on the impact of canal water supply on farmer's decisions, cropping pattern, tubewell water use and gross income (the main output of the LP micro-economic models). **A** farm model (representative of Group **9,** see Table **2)** is used to assess the impact **of** different canal water supply scenarios. Four scenarios have been tested, each one having a specific impact on the adequacy and variability of canal water supply (expressed by the average and standard deviation of daily canal water supplies, respectively). The characteristics of the four scenarios are **as** follow[4]:

[4] **Changes in canal water supplies from one scenario** to the other **are applied** to each monthly **canal water supply.**

(i) **Scenario 1 (base scenario):** Current water supply in terms of its average and variability;

(ii) **Scenario 2:** Actual average canal water supply and variability reduced to 0;

(iii) **Scenario 3:** Design average canal water supply and current variahility;

(iv) **Scenario 4:** Design average canal water supply and variability reduced to 0

Results of the simulations for these four scenarios are summarized in Table 3. It is important to note that for the farm considered, current canal water supplies are on average higher than design. Thus, a shift from actual to design values is equivalent to a dccrcase in average canal water supplies.

Indicator	Scenario 1 (Average = actual; Variability = actual)	Sceiiario 2 (Average = actual. Variability = nil)	Sceiiario 3 (Average = design; Variability = actual)	Sceiiario 4 (Average = design; Variability = nil)
Gross Income (in rupees)	**35370**	57440	**32310**	**50790**
Gross **Income/unit area (rupees/ha)**	**3500**	**5680**	**3200**	**5020**
Gross **Income/unit water (rupees/1000m³)**	400	500	410	540
TW water use (1000m³)	57	45	**57**	47
TW **water supplies in %** of **total supplies**	**64%**	39%	72%	50%

Several interesting results can be drawn from the analysis of the results of the simulations. First. the model shows a relative stability of gross income per unit of water and tuhewell water use for different canal water supplies compared to the other indicators such as gross income, gross income per unit area and percentage of total water supplied by tubewells.

Second, the results highlight the important impact of variability in canal water supply on farm decisions and economic indicators at the farm level. Although the scenarios tested with a zero variability may he extreme scenarios, they highlight the potential gains in terms of agricultural production that may he expected from a reduction in canal water supply variahility. In cases such as the farm analyzed, the last scenario suggests that a reduction in the average quantity **of** canal water supplied to farmers could be more than compensated by a reduction in the variability of this supply.

This result is in fact very important in the context of the equity issue within canal command areas. In a large number of cases, to restore equity means to increase supplies to some and to reduce supplies **to** others. The results of the simulations presented above highlights that this reallocation of canal water could be made acceptable for **all** farmers **(in** terms of agricultural production and productivity) if accompanied by a significant reduction in the variahility of these supplies.

Third, although the variation in total tubewell water use was not as significant **as** what would have been expected, differences in the percentage of water coming from tubewells are very large among scenarios. In areas with groundwater of poor quality, a high ratio of tubewell water over total water supplies may add large amounts of salts to the soil and may represent a serious threat for the sustainability of agricultural production.

Heterogeneity in farm responses

The main purpose of this second example is to illustrate the heterogeneity in farm responses to a given change, and indirectly to justify *the* need for the initial analysis **of** farming systems and development of several economic models for farms representative of different strategies and constraints. Models developed for four groups of farms are used to assess the impact of a change in monthly average canal water supply (expressed in percentage of the average design or Q_{des}) on tubewell water use. Table 4 summarizes the quantity of tubewell water use for each group as estimated by the economic models for different water supply situations (expressed by different percentages (from 50% to 150%)of the design canal water supply (i.e. 100% Q_{des})

Table 4. Changes in tubewell water use for representative farms of four groups (quantities expressed in m^3).

Group[5]	50% Q_{des}	75% Q_{des}	100% Q_{des}	125% Q_{des}	150% Q_{des}
1	8090	6000	6930	7860	6700
4	17790	15500	15700	14650	10900
7	-	14780	12080	8930	7680
9	92970	83800	74630	65450	51690

5 Group numbers used in this table refer to group numbers specified in Table 2

Table 4 highlights the specific reactions of particular farm groups *to* changes in canal water supply. It is interesting to note that a 25 percent reduction in canal water supplies from the design values does not lead to an increase in tubewell water use as one would have expected. For Groups 1 and 4, tubewell water use decreases or remains constant. For Groups **7** and 9, however, the ***25*** percent decrease in canal water supply is directly translated into an increase in tubewell water use. If canal water supplies decrease further up to 50 percent of the design values, tubewell water use increases significantly for Groups 1, **4** and 9. Group **7.** however, can not deal with such a reduction as the increasing costs related to tubewell water use are too high and the group cannot satisfy its minimum income requirement anymore,

The differences between groups are particularly clear when comparing Group 1 (non-tubewell owners) and Group 9 (tubewell owners). Tubewell water use is not significantly modified for Group 1 farmers within the proposed range of canal water supplies. At the opposite, Group **9** farmers react rapidly to changes in canal water supply, and their tubewell water use is nearly doubled when canal water supplies are reduced from 150 percent to 50 percent of their design values.

In summary, **the** results of the simulations presented above illustrate the use of the LP micro-economic models that show the importance of canal water supply variability in farm decisions, and stresses the need to investigate the heterogeneity in fanner's strategies and constraints as it influences the output of farmer's decisions in terms of cropping pattern and tubewell water use. The models presented above can also be used to analyse the impact of policies that try to affect the demand of irrigation water. For example, changes in canal water charges or changes in energy costs with impact on tubewell operation costs. The results of simulations can he used *to* assess the overall impact of such policies, and also to understand differences among farm types. **As** a result, accompanying measures may be developed for specific groups that may he more disadvantaged as a result of the implementation of proposed changes.

PRODUCTION FUNCTION FOR WHEAT

This section deals with the issue of timeliness and adequacy of irrigation water supplies and its impact on crop yields, using the example of wheat crop (the major rahi crop in the Chishtian Sub-division). Timeliness is defined with respect to the correspondence between crop water requirements at any stage of crop growth and available irrigation water supplies during that stage. Timeliness of water supply is investigated from an agronomic point of view, looking at ***the*** plant itself and factors affecting plant growth at the field level where greater control/understanding of other agronomic influences is possible.

Methodology

Data for this investigation have been obtained from 11 sample farmers (out of a total of 15
4 monitored by IIMI field staff) located in the eight sample watercourses mentioned above. These farmers have been selected as representative of the different farm groups presented under the

Methodology

Data for this investigation have been obtained from 11 sample farmers (out of a total of 15 monitored by IIMI field staff) located in the eight sample watercourses mentioned above. These farmers have been selected as representative of the different farm groups presented under the section *Impact of Canal Water Supply on Cropping Pattern* (see Table *2* for information on these groups). **As** explained above, all wheat fields (totally 56 wheat fields) of these farms have been selected for daily monitoring of farming and irrigation practices. At the end of the season, wheat yields have been collected through standard crop cut methods (Pintus, 1995).

The information collected has been used to establish the relationship between wheat yields and farmer's practices at the field level, with special interest in the role of irrigation water during different crop growth stages. The methodology developed includes an analysis of current farming practices from an agronomic point of view (i.e. in the context of physiological development and basic needs of the plant). Based on this analysis, specific practices that are expected to significantly influence crop yields are identified and used for econometrically estimating a production function relating wheat yields to these practices. **Also,** results of the analysis are discussed with individual farmers during restitution events, to identify unforeseen factors that may influence wheat yields and explain farmers' current practices.

The estimated production function has the following form

$$(1 - Y_a/Y_m) = f(1 - ET^j_a/ET^j_m;\ X_i) \qquad (1)$$

The left-hand side of the equation is the reduction in actual yield **(Y,)** relative to the maximum obtainable yield (Y_m). The right-hand side of the equation refers to the actual reduction in evapotranspiration (ET_a) relative to the maximum evapotranspiration for the crop **(ET_m)** during the jth stage of growth. X_i represents other variables affecting crop yields such as fertilizer application, sowing date, etc. The function developed relates yield reduction to moisture stress, something that differs from most of the production function approaches developed by economists, but that is more common in the agronomic literature. The advantage of this approach is that quantity and timing of irrigation application is synthesized in a single variable. **Also,** the results obtained can more easily be transposed to other irrigated areas as they are less influenced by local conditions.

Econometric results

The production function has been estimated using the Ordinary Least Squares method available in the statistical software SPSS. Estimated coefficients are presented in Table **4** below. The fit of the regression is rather good for cross-section data, with an R^2 of 0.73 and an adjusted R^2 of ***0.67.*** The coefficient of all variables (expect the one for water stress during the flowering stage, or Stage D, and the one for the quantity of urea applied per acre) are significantly different from zero at conventional significance levels as highlighted by the values of the T-test. When looking at the signs of the coefficients estimated and presented in Table **4,** it is important to **keep** in

The results of the quadratic form for the moisture stress variables contrast with those obtained with the linear form[6] where only moisture stress in Stage B was found statistically significant. The results obtained indicate that yield reduction increases with delay of sowing and irrigation stress during Stage B and Stage C of the wheat crop cycle.

Usings own seeds instead of market purchased seeds also depressed wheat yields significantly. The variables related negatively with yield reduction (and thus positively with yields) are quantities of Di-Amino Phosphate, urea and Single Super Phosphate (although the coefficient before urea **is** not statistically significant). And Di-Amino Phosphate has a greater influence on yields than Single Super Phosphate.

Table 4. Estimates of the wheat production function (dependant variable: YLDRED)

Variable	Parameter estimated	T for H0: Parameter = 0
INTERCEPT	0.79	9.67
SOWDATE	0.006	4.49
ETBSQ	1.22	3.38
ETCSQ	0.37	2.44
ETDSQ	0.068	1.05
SEEDORIG	-0.33	-5.99
QDAP	-0.0045	-5.65
QUREA	-0.00056	-1.20
QSSP	-0.0013	-2.12
QPOTASH	0.0072	4.33
Fit of estimated regression	R^2: 0.73	Adjusted R^2: 0.67

With,

YLDRED	=	Reduction in actual yield relative to maximum obtainable yield (Y_m=2631 kg/acre)
SOWDATE	=	Delay in sowing (in days) alter November 15
ETBSQ	=	Square of moisture stress ($1 - ET_a/ET_m$) in booting stage or stage B
ETCSQ	=	Square of moisture stress ($1 - ET_a/ET_m$) in flowering stage or stage C
ETDSQ	=	Square of moisture stress ($1 - ET_a/ET_m$) in grain filling stage or stage D
SEEDORIG	=	Origin of seed (equal to 0 if seed purchased, equal to 1 otherwise)
QUREA	=	Total quantity of urea applied in kg/acre
QDAP	=	Total quantity of Di-Amino-Phosphate applied in kg/acre
QSSP	=	Total quantity of Single Super Phosphate applied in kg/acre
QPOTASH	=	Total quantity of potash applied in kg/acre

A surprising result is the sign of the estimated parameter before the potash variable (QPOTASH). This variable is positively related to yield reduction and the parameter is statistically significant. Moreover, this result is very robust with respect to changes in functional form (linear or quadratic) and other variables included in the regression. Farmers use potash to

[6] The estimated coefficient for the linear form are reported in Pintus (1995).

mitigate salinity problems, and the assumption is that potash is only partially successful in tackling salinity. Thus, the variable would translate the remaining salinity effect that affects yield deficit positively rather than the direct effects of potash on salinity, and thus on yield.

For more practical use of Equation **(1)** to study economic efficiency and other economic concepts, the relationship between yield reduction and moisture stress is transformed into a relationship between wheat yields and water application at different stages of the crop growth. The first step is a transformation of Equation (1) into Equation (2) that relates actual yield Y_a and evapotranspiration ET_a/ET_m (names of variables are defined in Table 5).[7]

$$\begin{aligned} Y_a \quad = \quad & -3811 + 6404 * ET^b_a/ET^b_m - 3202 * (ET^b_a/ET^b_m)^2 + 1954 * ET^c_a/ET^c_m \\ & 977 * (ET^c_a/ET^c_m)^2 + 358 * ET^d_a/ET^d_m - 977 * (ET^d_a/ET^d_m)^2 \\ & + 865 * SEEDORIG + 12 * \mathbf{QDAP} + 1.5 * QUREA\ 3.5 * QSSP \\ & + 19 * QPOTASH - 16 * SOWDATE \end{aligned} \qquad (2)$$

The interpretation of the estimated parameters in Equation (2) becomes straight forward for the non-water related variables. Parameters represent the marginal increase in wheat yield as a result of an increase in a given input. For example, the coefficient before QDAP means that increasing Di-Amino Phosphate applications by **1** kglha increases wheat yield hy I2 kg/ha.

The second step consists in transforming evapotranspiration parameters into quantities of irrigation water effectively applied to the fields. To do so, two separate regressions relating ETa/ETp (dependant variable) and quantities of irrigation water applied (independent variable, measured in cubic meters) have been run for Stage B and Stage C, respectively. The results of both regressions are presented below.

For Stage B:

$$ET^b_a/ET^b_m \quad = \quad 0.003 * QWAT, - 0.0000021 * (QWAT_B)^2 \qquad (3)$$

For Stage C:

$$ET^c_a/ET^c_m \quad = \quad 0.0025 * QWAT, - 0.0000015 * (QWAT_C)^2 \qquad (4)$$

where QWAT, is the quantity of irrigation water in cubic meters applied during Stage J. The quadratic functional form was used to allow ET_a/ET_m to level off as water applications increase.

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7 The maximum obtainable wheat yield in the Chishtian Sub-division **has** been established **at** 2631 kg/acre (Pintus, 1995). Notice that irrigation related variables in Equation **(2)** have both the linear **and** quadratic form, as the result **of** replacing moisture stress (I - $\mathbf{ET_a/ET_m}$) by evapotranspiration ET_a/ET_m.

Using regression results to analyse allocative efficiency of irrigation water use

Allocative efficiency will be defined here from an economic point of view with reference to an optimum allocation of irrigation water to crops (maximum profit under given constraints). Economic theory suggests that a **profit maximizing farmer will use an input only up to the point where its Marginal Value Product** is equal **to the price of the input**. This efficiency criteria will result in most of the cases in an economic optimum different from the biological potential of a given crop (with lower use of the input than required for the biological potential). This efficiency criteria will be used to analyze water use patterns in the Chishtian Subdivision, using the results of the regression analysis presented above.

Substituting Equation (3) and Equation (4) into Equation (2), a relationship is obtained between the actual yield **Y**, and the quantities of irrigation water used at different stages of the crop growth (the $QWAR_j$ in Equations (3) and (4)). The Marginal Value Product with regard to water is obtained by estimating the value of the derivative of the yield function against water for a given quantity of water applied (other inputs being fixed at the average value for the sample considered), and multiply this value by the wheat price.

The analysis of the coefficients presented in Table 4 shows that water stress in Stage B and Stage C is detrimental to wheat yield. However, stress can be justified from an economic point of view. As specified above, to analyze water stress from an economic point of view requires a comparison between the Marginal Value Product of water and the price of water. In the context of Pakistan, it is difficult to estimate the *true* price of water. For the purpose of this study, tubewell water price has been selected as the price of water. Although this choice is not completely satisfactory, it can be pointed out that canal water is scarce and that all farmers in IIMI sample areas use tubewell water. Thus, tubewell water price represents farmers' willingness to pay for water *at the margin*.[8]

Although irrigation in both Stage B and Stage C was shown to be significantly related to yields, the marginal contribution of irrigation may be different for each stage. Therefore, the Marginal Value Product of water was evaluated separately for each stage. Table 5 summarizes the different indicators computed based on values for the sample of fields, and also for groups of fields located along the Fordwah and Azim distributaries[9]. Fordwah and Azim values are computed to compare farm practices under perennial and non-perennial canal water supply conditions.

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[8] Tubewell water prices have been computed based on hourly tubewell water prices, tubewell discharges and an estimated 10 percent value for seepage losses between the tubewell and farmers' fields.

[9] The Fordwah Distributary is a perennial distributary receiving canal water supplies the year round, while the Azim Distributary is non-perennial and receives canal water during the kharif season only (from April 15 to October 15).

In Stage B, average irrigation application for tlie sample considered is equal to 511 m^3/ha but with a large heterogeneity between fields. Fields located in tlie Fordwali Distributary command area records a higher (although not statistically significant) water application than fields located in the Azim Distributary command area. While the opposite occurs for water application during Stage C. Also, water application during Stage C is 21 percent lower than during Stage B, a trend also observed for each distributary.

Table 5. Irrigation water use and economic indicator? in sample areas (average values for each area).

Variable	All sample	Fordwah Distributary	Azim Distributary
Irrigation water use in Stage B (in m3 per acre)	511	520	490
Irrigation water use in Stage C (in m3 per acre)	402	384	446
Marginal Value Product in Stage B (in rupees/m3)	0.33	0.17	0.81
Marginal Value Product in Stage C (in rupees/m3)	2.33	2.67	1.61
Tubewell water price (in rupees/m3)	0.33	0.41	0.26

The comparison between water use for the two distributaries is interesting as tlic Fordwali Distributary is perennial and receives canal water year round, while the Azim Distributary is non-perennial and docs not receive canal water year round (apart for a few times during **the** rabi season, when the Azim Distributary is used as an escape by the irrigation manager). When canal water is not in high demand (i.e. Stage B), Fordwah Distributary farmers are able to take advantage of the dual access to canal and tubewell water, and use more water than Azim Distributary farmers that have to pay the full cost of irrigation water applied. However, as the pressure on water resources increases in Stage C, Fordwali Distributary farmers apply relatively less water; they have to rely more on tubewell water at a higher average price (as highlighted in Table 5), and thus limit their tubewell water use for economic reasons. a decision that is consistent with economic theory.

However, and although farmers seem to react **to** changes in scarcity and water prices, there is no guarantee that water is allocated efficiently in either command area. The comparison between the Marginal Value Product for water and tubewell water prices is required **lo** gain **a** better understanding on allocative efficiency. Looking at Table 5, it appears that the Marginal Value Product and tubewell price are very close for the overall sample for Stage B. I-lowever. tlie value of the Marginal Value Product is lower and higher than tubewell price for the Fordwah Distributary and Azim Distributary samples, respectively. Thus, if cost minimization behaviour is assumed for farmers, then water use in both distributaries is not consistent with their respective tubewell water price. This difference may suggest that the tubewell water price is not a very good indicator of the true opportunity cost of water.[10]

These results confirm to some extent what has been highlighted by the comparison between irrigation water **use.** During periods of moderate demand. Fordwali Distributary farmers receive a good canal water supply **and** their needs for tubewell water are minimal. They use water to tlie extent available and the result is that the marginal increase in yield from an incremental unit of water has little relationship with tubewell water price. Along tlie Azim Distributary, farmers use only tubewell water. The Marginal Value Product of water that is more than twice the value of tubewell water suggests that Azim Distributary farmers are rationed from the water supply point of view, and that tubewell water markets that have developed within the area are unable to relieve this constraint.

As mentioned earlier, crop water requirements are higher in Stage C when wheat is heading and flowering. Results presented in Table 5 emphasize the impact of increased water scarcity on the efficiency of irrigation water use. The Marginal Value Product of water for the overall sample. Fordwah Distributary sample and Azim Distributary samples are significantly higher than tubewell water price. This would indicate that in periods with high demand, tubewell water markets fail to remove the water constraint.

Interestingly, tlie values of Marginal Value Product of water suggest that Fordwali Distributary farmers are more constrained than Azim Distributary farmers. The unreliability and variability of canal water supply may explain why Fordwali farmers hesitate to use tubewell water due to higher tubewell pumping costs. Also, their lower tubewell water quality (compared to Azim Distributary farmers that are close to tlie river and benefit from the recharge of the river) may be an important factor that limits tubewell water use. In fact. larmers along this distributary may prefer waiting for an extra **week** in order to receive (unreliable but free of cost and of good quality) canal water supply. To understand tlie reasons explaining this asymmetric response, *it* thorough investigation of tlie functioning of, and constraints on. tubewell water markets is also required. **Such** an investigation, however, is beyond tlie scope of tlie present paper.

The comparison between the Marginal Value Product of water for Stage B and Stage C has an important implication for irrigation system management. **An** extra cubic meter of irrigation water applied during Stage C would lead to an average increase in wheat gross margin by 2.33 rupees, versus only 0.33 rupees for each extra unit of water applied during Stage **B.** The large difference between these two values stresses tlie need **to** improve irrigation water management during the Stage **C** period. Special attention should be given to this period, with expected **high** payoffs in terms of increased wheat production and gross income. **Also,** tlie results suggest that there is a

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[10] The existence of transaction costs may explain differences between tubewell water price and the opportunity cost of irrigation water. Transaction costs may be related to not gelling tubewell water when required, or **to** the use of poor quality tubewell water **that** may inhibit **farmers** from using this water.

potential for reallocation of water supplies between periods of time (from Stage B to Stage C, for example) that would benefit farmers and improve wheat production[11].

DISCUSSION

The results obtained so far have highlighted some of the elements of the complex relationship between irrigation water supply and agricultural production. The main findings that have been obtained so far are summarized below.

(i) Reduction in canal water supply variability is expected to have an important impact on farmer's decisions and lead to an increase in farm income. But results obtained from simulations with the remaining 10 models are required to better understand the expected magnitude and variability of increase in farm income. In the example included in the paper as an illustration, the farmer considered is a tubewell owner, with high control over water resources. His tubewell allows him to increase the area cropped and also is used as a buffer for canal water variability. Non-tubewell owners will not have the same level of control will be expected to react differently based on their existing water canal supply and access to tubewell water markets. However, non-tubewell owners are expected to have higher gains as a result of decreased canal water supply variability.

(ii) The analysis of the relationship between water and agricultural production stresses the need to investigate the existing large heterogeneity of farm strategies and constraints. It is important to understand this heterogeneity lor the development of irrigation sector policies. Although policy makers and donors may he more interested in global indicators and an aggregated impact on agricultural production, it is important to assess different farmers' reactions, and develop accompanying measures accordingly.

(iii) The preliminary results obtained regarding the analysis of the impact of canal water supply variability adds an important dimension to discussions on the equity issue. To restore equity in canal water supply along distributaries means increasing water supplies to some and reducing water supplies to others[12]. The results show that this reduction may be accepted by farmers, if accompanied by a reduction in canal water supply variability.

(iv) Although farmers have access to tubewell water (whether owned or purchased), they still have water constraints as highlighted by the analysis of the wheat production results.

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11 This could be achieved, for example, by developing extra storage capacity, whether at the Indus Basin level or at the farm/watercourse/local level.

12 Hart (1996) shows that remodelling of outlets would significantly improve equity in canal water supplies. Also, desilting of some reaches of a distributary may he required. In some cases, to restore equity requires an increase of canal water discharges at the distrihntary head

Constraints, however, do not relate necessarily to quantity of irrigation available. Other factors are to be considered; for example, the existing canal water variability that limits tubewell water use (insurance factor); the use of poor quality tubewell water (sustainability factor); high transaction costs in tubewell water markets (access and price factor); etc.

(v) The importance of the impact of water applications during Stage C **of** the wheat cycle on wheat yield is to be considered when addressing issues related to improvements in canal water supply performance. These improvements (along with the removal **of** some of the existing constraints **in** tubewell water markets) would lead to significant increases in wheat yield and gross income. The identification **of** such critical periods are important elements that should be considered by irrigation officials.

This last point, however, cannot be further developed, as competition between crops may also explain choices made by farmers to favour other crops versus wheat. The existing marginal value product of water may be the result of choices made by farmers between different crops (for example, favouring sugarcane output at the expense of wheat yield that is used for autoconsumption).

The two levels of analysis presented in this paper show that variability and timeliness of (canal) irrigation water supplies may be of more importance than the quantity (adequacy) of these supplies. Although the objective of tlie paper is to illustrate the potential of methodologies to address issues related to water supply and agricultural production, the importance of this preliminary conclusion (with expected impacts on potential interventions in tlie irrigation system) is to be stressed.

The field level analysis shows that there is a low potential for significant wheat yield increase if other factors such as the access to certified seeds, sowing date, or fertilizer applications (especially application of Di-Amino Phosphate) are not modified. In fact, sowing date may he defined as a water related factor as it is directly related to tlie availability of irrigation water supply during the months of November and December. With the importance of tlie sowing date variable[13], special attention is required to ensure appropriate canal water supplies during tlie sowing period[14].

The farm level analysis proposed in the present paper is relatively simple to implement. However, it requires ***a*** good understanding of current water supplies. Also, results of production functions for the main crops are required. **Also,** the quality of the results obtained from the initial stages (i.e. identification **of** farm groups with distinct strategies and constrainls) directly

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13 Missing one warabandi turn. that would delay sowing by one week after November 15, leads to a reduction **of** 112 kg/acre (or ***5*** percent ***of*** the maximum obtainable wheat yield).

14 Farmers rarely use tubewell water for the pre-sowing and first irrigation on most of the crops, due to costs and water quality aspects.

influences the quality and usefulness of tlie results obtained from simulations using the economic models. An important assumption made for developing micro-economic models relates to the income optimizing objectives of farmers. In some cases. however, farmers are clearly **not** income optimizing farmers. Specific constraints have hecn included in the LP models to take info account other farm objectives such as autoconsumption, risk-aversion, minimum income, etc.

The production function approach has led to very good results, thanks to the joint agronomic and economic approach and to the information collected through detailed monitoring of farming practices for sample fields. However, the analysis has been limited by tlic number of sample fields considered *(56* fields) that did not allow tlie inclusion of a larger number of variables in the regressions (for example, cross-variables).

The restitution to farmers that were undertaken in the field to present the results of the production function for wheat have been very valuable. **IIMI** researchers visited individual farmers to discuss results of the regression analysis. Using a map of the farm and simple visual devises to represent tlie cycle of the wheat crop and farm practices, discussions with farmers led to tlie validation of the results of the analysis. Also, the restitution was used to hctter understand farm constraints and simulate the impact of changes in canal water supply **on** farming practices. For some farmers, the results of the analysis were knowii. but good reasons could be advanced to explain why improvements are not implemented. For other farmers, less well informed and knowledgeable, the restitution showed their strong interest in research results ohtainecl so far.

CONCLUSIONS

With increasing costs of interventions to improve water supply performancc and high pressure on water resources, there is a need to allocate water resources and financial resources in an optimal way. In this context, economic analysis may provide useful insight in the relationship between irrigation water and agricultural production, and facilitate choices between interventions in tlie irrigation sector.

Research results on the relationship between water and agricultural production are rarely used for policy decisions in Pakistan. Agronomists develop water-yield relationships in research stations. However, they control all inputs, while farmers in the real world control few of their inputs (in terms of timely availability on markets, water supply unreliability and variability. etc). Thus, it is not clear whether research results have a potential use for farmers, and for understanding existing constraints **on** agricultural production.

Economists develop large farm surveys to analyse the relationship between irrigation and agricultural production and productivity. However, the analysis of the heterogeneity within the farm community is often too rigid to capture the existing variability[15]. Also, very few studies

[15] The use of **prc-defined** categories such as fixed landholding **size** classes or simple head versus tail analysis may **be required** for **quick** analysis. However, from a research point of view, pre-

are able to obtain good information on the actual irrigation water supplies received by farmers. Often, irrigation variables are summarized in an unsatisfactory proxy such as the number of irrigations, or the source of irrigation. Thus, the relationships developed do not properly integrate water supplies.

In some ways, more research under real conditions is required. Also. there is a need to renew some of the approaches and methodologies that have been in use lor several decades to tackle issues related to the relationship between water and agricultural production. Also. the sustainability issue is to be added to the analysis. For example, the impact of salinity and sodicity on crop yields (under farm conditions).

For IIMI, several follow-up activities have been planned. First, there is a need to finalize the preliminary results presented above, and complete the evaluation of the methodologies developed and tested. LP farm models will be developed for all 11 farm groups, and used to test the impact of different canal water supply scenarios on agricultural production and productivity at the farm level. Also, efforts have concentrated on the development of production function for cotton. following the same methodology as the one applied for wheat. Both the wheat and cotton experiences will help to evaluate the potential and limitations of the proposed approach.

Second, specific missing elements of the analytical framework presented in the second section of the paper will be investigated. Those will include the analysis of intra-farm water allocation (how to allocate and distribute irrigation water supplies to different fields, based on past practices and expected output for each field) and of its impact on agricultural production. The comparison between tubewell owners and non-tubewell. owners (between farmers with diflcrent levels of control over irrigation water resources) will be an important issue addrcsscd during the analysis.

Also, emphasis will be given to the link between farm level decisions and watercourse level water management. Watercourse level economic models will be developed by aggregating individual micro-economic models. The development of the watercourse level economic models will also include developing relationships between individual models (for example, links are lo be established between water sellers and water purchasers), and identifying watercourse level constraints (for example, for groundwater resources accessable to farmers of a given watercourse). These models will be used to analyse the impact of (re-)allocation of canal water or water trading (whether tubewell or canal water) on agricultural production and productivity.

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determined classes will hide the existing structure of the farm population. Then, it will be difficult to identify constraints that differ among farm groups, and to specify in a proper manner the relationship between water and agricultural production.

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PARTICIPATORY ON FARM DRAINAGE FOR IMPROVED WATER MANAGEMENT AND INCREASED AGRICULTURAL PRODUCTION [1]

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ABSTRACT

Increasing population and depleting land and water resources are demanding better management practices for making more beneficial use of scarce irrigation water as well to control waterlogging and salinity problems. In the absence of further development of water resources, efficient and purposeful management of available resources (land and water) is becoming more vital in present day's context in order to ensure agricultural production to meet the food, feed, fiber, and shelter requirements of the ever growing population and provision of raw material for agro-based industries. At the tertiary level of the irrigation system (at the farm level), improved on farm surface drainage' with the participation of farmers has been considered to be affective, beneficial, and more diagnostic in nature as it can quite efficiently remove excess surface water.

The paper aims at presenting the results of implementation of On Farm Drainage Pilot Project under "Second On-Farm Water Management Project. Dera Ghazi Khan" that has successfully been implemented on a gross area of about 1,500 hectares. The Pilot Project is enclosed between Mehrpur and Haji Wah minors and Shah Jamal-Khangarh Road in Muzafargarh district of the Punjab Piovince. Its positive impact started occurring within a period of 1/2 and 1 year, after construction of the on farm drains. It has also been observed that nearly 31 percent area, which was previously ponded, has been drained and has come under cultivation. The cropping intensity before construction of on farm drainage network was 96.4 percent which increased to about 122 percent, after one year of project completion. The paper also discusses the importance and establishment of On Farm Drainage sites under OECF/Japan assisted On Farm Water Management-Ill Project and stresses upon the need for community participation in operation, management and maintenance of drains for tertiary level drains in the country.

I. INTRODUCTION

Nature has blessed Pakistan with abundant land and adequate water resources. The diversity in agricultural resources, climate, people, and socio-economic conditions has given rise to varying farming systems. Agriculture can be broadly categorized into irrigated, rainfed, and dry land farming. Often, rainfall, soil, and other characteristics determine the ecological influence on various farming systems. In Pakistan, about ***85*** percent *of* the agricultural production comes from the Punjab and Sindh provinces

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which are mainly irrigated from the Indus Basin Irrigation System. Agriculture is the main foundation and the pivotal sector of the country's economy. It accounts for 24 percent of the GDP, employs 47.45 percent of total labour force and supports directly or indirectly about 70 percent of the population of the nation

The main challenge to be faced today by the agriculture sector of Pakistan's economy is to meet the demands of food, feed, fiber, and shelter of fastly increasing population which is growing at an average rate of about 3.0 percent per annum. Development of the agriculture sector is also vital for the supply of raw material to the agro-based industry of the country. The agriculture sector has to meet these challenges by competing with the depleting available resources of land and water.

II. LAND AND WATER RESOURCES OF PAKISTAN

Pakistan is spread over an area of 79.9 million hectares, with mountains in the north and west, a plain called Indus Basin comprising a major area of the Punjab and Sindh, and arid and semi arid tracts in the south and east. Out of the total cultivated area of 21.46 million hectares, 17.12 million hectares (79.78%) are irrigated and the rest 4.34 million hectares (20.22 %) are rainfed. The reported area of the country is 58.12 million hectares, of which 3.44 million hectares (6%) are under forests, 24.38 million hectares (42%) are unculturable, 8.84 million hectares (15%) are culturable waste and 21.46 million hectares (37%) are cultivated. Over the past 30 years, there has been a gradual increase in cultivable area, total cropped area, and area under forest. This increase has been mainly achieved due to the development of new water resources and irrigation facilities. Another 2.0 (approximately) million hectares are riverine and are cultivated by the moisture left by summer floods.

The surface irrigation system of Pakistan is the largest integrated conveyance network in the world, which is generally identified as the Indus Basin Irrigation System. It is fed by the waters of the Indus River and its tributaries. The salient features of the system are three major storage reservoirs; namely, Tarbela and Chashma on the River Indus, and Mangla on the River Jhelum; 19 barrages, 12 inter-river link canals and 43 independent irrigation canal commands. About 100,000 community watercourses of the Indus Basin convey irrigation water from the canals to the farmers' fields. Total length of the main canals alone is 58,500 km. Watercourses comprises another 1,621,000 km.

III. EMERGENCE OF WATERLOGGING AND SALINITY PROBLEMS IN INDUS BASIN IRRIGATION SYSTEM

Flood irrigation has been practiced in the Indus Plains comprising of irrigated tracts of the Punjab and Sindh since the earliest settlements along the rivers. The canal system which exists today was constructed in the middle of the nineteenth century under the British colonial administration. After creation of Pakistan, expansion of the irrigation system was continued. In 1949-50, India cut off the supplies of the three eastern rivers. This dispute was resolved in 1960 with signing of the Indus Basin Water Treaty. Under the agreement, link canals were constructed to transfer water from the western rivers to the eastern rivers besides construction of storage reservoirs at Mangla and Tarbela, along with the introduction of Salinity Control and Reclamation Projects (SCARPs).

Prior to the introduction of weir controlled irrigation, the groundwater in the Indus Plain was fairly deep. The seepage from the canal system and on farm irrigation added significantly to the normal recharge, resulting in the rise of groundwater till it began interfering with crop production. In the early 60's, it was estimated that about 100,000 acres of culturable land was being lost every year due to waterlogging and salinity, which meant almost one acre after every five minutes.

The causes of waterlogging are mainly attributed to: i) seepage from the rivers and irrigation channels; ii) flat slope of the surface resulting in poor natural drainage; iii) improper irrigation practices (e.g. over irrigation in some parts and under irrigation in others); iv) lack of adequate artificial drainage; v) contribution made by development efforts such as irrigation network, roads & rail links, replacement link canals, and other infra-structural developments in the flood plains which interrupt the surface runoff, resulting in the accumulation of ponded water on the soil surface during the monsoon, part of which contributes to deep percolation; and vi) deep percolation from rainfall and flood waters.

Combined with waterlogging, another menace is of land salinization. The salt-affected soils in the Indus Plains occur in specific physiographic positions and were formed as a result of a gradual redistribution of salts in the landscape extending over several thousand years. This 'primary salinity' was due to the original geological formation of the basin. Later on, as a result of salt accumulation, originating from evaporation of flood waters and groundwater, the salinity increased in the upper strata of the soil. The low-lying areas successively inundated by floods and the natural depressions where rain water was collected to an appreciable amount, became fertile as the salts were leached to the lower layers of the soil. Areas underlain by shallow watertables and on the slopes of high lands in the basin, however, became severely affected due to the accumulation of salts. This secondary soil salinity' can, therefore, be attributed to irrigation.

All waters, whether derived from springs, streams, rivers, or wells contain soluble salts. When irrigation water is applied to land, part of it evaporates and the remaining portion seeps down through the soil. In the absence of adequate irrigation and drainage, the salts accumulate in the root zone. If ample water is delivered to the land, the salts are leached down to the watertable. Thus, irrigation adversely affects the salinity status of soil and the quality of the groundwater.

Moreover, the rise of watertable (i.e. waterlogging) also aggravates the salinity of the soil. As the watertable approaches the surface, substantial surface evaporation takes place and appreciable amounts of salts move upward by 'capillary action' into the soil surface, if the leaching requirements are not met. Accordingly, as most of the salts accumulate on the soil surface, the concentration of salts in the groundwater changes, though slowly. Unless the salts are transported out of the system, the salt build-up goes on.

Since the introduction of irrigation, the Indus Basin has been acting as a salt sink (i.e. the salinization of soil and of groundwater has been continuously on the increase). If the disposal of salts remains inadequate, their concentration, both in the soil and groundwater, will soon Increase to an intolerable level.

According to the Agricultural Statistics of Pakistan (1993-94), about 0.6 million hectares are slightly saline, about 1.23 million are moderately saline, 0.98 million hectares are severely saline, out of the cultivated area. Whereas, 2.4 million hectares of uncultivated area is severely to very severely saline-sodic. It has been estimated that about 24 million[4] of the 33 million tons of salt which are brought into the Indus Basin annually are retained and recycled within it. i) 2.2 million tons are stored in the Desert Cholistan in evaporation ponds, which are highly permeable and threatening the Panjnad-Abbasia Canal Commands on the lower edge of the Upper Indus; ii) 2.6 million tons are stored in the country's largest inland freshwater lakes, Manchar and Hammal on the right bank of the Indus River, which are now threatened with extinction; iii) 0.7 million tons are trapped in the Peshawar Valley; iv) 18.5 million tons are stored in the aquifer through direct seepage from canals, watercourses, and drains; and v) the rest is disposed in to the Arabian Sea via the Lower Indus River itself. This means that salinity levels increase rapidly as extraction of irrigation supplies increase in the Lower Indus. In addition to distributing river supplied salt, additional salts are mobilized directly onto the surface and retained in fresh groundwater areas due to tubewell irrigation.

Back in history, the irrigation induced waterlogging and salinity problems were first observed on a limited scale in the 1920s in Rechna and Chaj Doabs. In 1961, it was estimated that 40,000 hectares of land was being lost due to high groundwater tables, and by this time a crash program was in the making. In 1958, the Water and Power Development Authority (WAPDA) was established. It developed a long term program for controlling the high water tables in the Indus system. This was done through the Salinity Control and Reclamation Projects (SCARPs). These SCARP projects applied a range of drainage measures with emphasis on deep tubewells, surface drains, and subsurface systems.

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[4] Annexure 1.5, Staff Appraisal Report, National Drainage Program (NDP) Project

IV IMPACTS OF WATERLOGGING AND SALINITY

The impact of salinity on agricultural productivity is severe. It has been mentioned in the Staff Appraisal Report (SAR) of National Drainage Program (NDP)[5] that a 25 percent reduction in the production of our major crops is attributed to salinity alone. In Sindh Province where the problem is much more severe, the impact may be closer to 40-60 percent in saline groundwater areas. The impact of waterlogging on yields just as startling. As the watertable approaches the surface up to **5** feet below, yields are of all major crops decline rapidly to almost zero. For example, at 0 to 0.8 feet depth to watertable, yields for cotton are 2 percent, 9 percent for sugarcane, and 21 percent for wheat. In addition, there are serious environmental and poverty impacts associated with waterlogging and salinity.

V EMERGENCE OF THE CONCEPT OF PARTICIPATORY ON FARM SURFACE DRAINAGE IN PAKISTAN

In the 1960s and early 1970s, strategy and investment in irrigation and drainage in Pakistan was mainly focused on three activities i.e. construction of major storages, barrages and link canals, control of increasing waterlogging and salinity through drainage (public tile and tubewell drainage projects), and expansion of water supplies by new storages, and public tubewell schemes. During the 1970s, the strategy was changed due to i) high cost of additional stored water; ii) the faltering performance of the surface irrigation system (especially inadequate maintenance leading to operational problems); and iii) sustainable problems with the public sector tubewell fields. The Revised Action Program (RAP) for Irrigated Agriculture of 1979, however, switched the emphasis of improving system efficiency through rehabilitation and upgrading, and to small-scale physical investments (private tubewells. watercourse improvements and soil reclamation). The new strategy so adopted focused on better utilization of existing infrastructure, especially at the watercourse level, the "savings" of surface water "losses" from channels, and improved management of water from the irrigation command level down to the farm, Furthermore, since the Revised Action Program for Irrigated Agriculture (RAP) it was estimated that saving water by increasing watercourse efficiency (i.e. reducing **"losses")** cost **about** a quarter that of developing new irrigation supplies[6]. On Farm Water Management activities were, therefore, adopted in the country on priority basis.

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[5] **Annexure 1.5, Staff Appraisal Report, National Drainage Program (NDP) Project**

4 [6] **Report' No. 15863-PAK, Pakistan Impact Evaluation Report June 28, 1996, Operations Evaluation Department, World Bank.**

For a long time, the construction and management of drainage systems in Pakistan has been the exclusive domain of the public sector. The role of government in this context is justified because these drains largely carry hazardous water (effluent) that is dangerous to both humans and animals. The public sector has, however, failed to ensure proper operation and maintenance of the drainage system due to the lack of physical and financial resources. There is, therefore, dire need that benefiting communities should be involved to participate and share their responsibility with the government agencies. Increasing population and depleting land and water resources are demanding better management practices for making more beneficial use of scarce irrigation water, as well as to control waterlogging and salinity problems. In the absence of further development of water resources, efficient and purposeful management of available resources (land and water) is becoming more vital in the present day context in order to ensure enough agricultural production to meet the food, feed, fiber, and shelter requirements of the ever growing population and provision of raw material for agro-based industries. At the tertiary level of the irrigation system (at the farm level), improved On Farm Surface Drainage (OFSD) with the participation of farmers has been considered to be affective, beneficial, and more diagnostic in nature as it can quite efficiently remove excess surface water in areas with emerging problems of waterlogging and salinity.

Keeping the importance of On Farm Surface Drainage in view with the involvement of farmers as being practiced in other On Farm Water Management programs, a pilot project for On Farm Drainage was launched under the Second On Farm Water Management Project, Dera Ghazi Khan. The experiences gained and results obtained after the implementation of the On Farm Drainage Pilot Project under the afore-mentioned OFWM project are presented below. This paper gives more emphasis on the concept of a participatory approach for managing surface drainage rather than engineering aspects. Moreover, the concept of on farm drainage being replicated in the establishment of On Farm Drainage sites under the Overseas Economic Community Fund (OECF)/Japan assisted On Farm Water Management-III Project is also discussed.

VI ON FARM DRAINAGE PILOT PROJECT UNDER SECOND ON FARM WATER MANAGEMENT PROJECT DERA GHAZI KHAN

The On Farm Drainage Pilot Project (OFDPP), as one of the components of the Asian Development Bank (ADB) assisted Second On Farm Water Management Project, Dera Ghazi Khan, is probably the first example in Pakistan where the on farm surface drainage (OFSD) system has been installed at the field level. The OFDPP as originally formulated was meant to investigate the feasibility of improved on farm surface drainage in the Dera Ghazi Khan (D.G. Khan) area. Accordingly, the OFDPP site, covering an area of about 1,500 hectares, falling in the commands of 15 watercourses along Kot Adu Main Drain, Khan Garh, Muzafargarh District was selected and the OFSD system was constructed during 1992-93 by the Water Management Wing of the

Agriculture Department, Punjab with the technical assistance of local as well as expatriate consultants (NESPAK and EUROCONSULT, Private Ltd.) and active involvement of the farmers.

1. Project Objectives

It was observed during visits to the project area that an excess surface water in the D.G. Khan area was generally experienced to be a problem in the seriously waterlogged and salinized areas only. Excess surface water often leads to extensive and prolonged surface ponding on waterlogged and saline land, as it can not infiltrate due to the lack of profile storage andlor poor soil structure. It was also observed during the survey that improved surface drainage could not' be the best remedy for waterlogged and salinized land as it might not be expected to ascertain a significant lowering of the watertable and or leaching of the excess salinity. This would generally require the introduction of improved groundwater (subsurface) drainage. Improved surface drainage on the other hand did not seem to be an urgent requirement for the non-waterlogged and non-saline lands in the D.G. Khan area. The little excess surface water which occasionally occurs on such land, generally caused only minimal damage.

Therefore, it was concluded that improved tertiarylon farm surface drainage would be suitable in areas with emerging waterlogging and salinity problems. Such areas occur in abundance in the D.G. Khan division.

In view of the findings of the survey, the scope of the project was drawn to accommodate areas with emerging waterlogging and salinity problems caused by recharge of excess surface water (from irrigation andlor rainfall) in the fields. Improved tertiarylon farm surface drainage was anticipated to prevent the further spreading and aggravation of said problems in these areas. It was further conceived that it might **also** provide some relief to the in between areas which are already partly waterlogged and salinized and, consequently, suffer from serious surface water ponding. The following objectives were, accordingly, set forth to address the need for on farm drainage:

i. Selection of sifes *with* emerging waterlogging and salinity problems;
ii. Organization *of* Drainage Beneficiary Groups *(DBG)* in each catchment area of the tertiary drain for participation of the beneficiaries in *the design,* construction and subsequent operation and *maintenance* of *the* drainage works: and
iii. Construction of a system of tertiary surface drains for improved surface drainage.

In addition to the above mentioned objectives, the project was envisaged to serve as a basis to test and establish suitable design criteria, construction methods, and economics for surface drainage works for future drainage projects.

2. Drainage Conditions in the Pilot Project Area

The drainage conditions in the pilot area can be differentiated into three zones as illustrated in Figure 1.

Zone-I	non drainage problems envisioned;
Zone-11	emerging waterlogging and *salinity* problems; and
Zone-III	existing waferlogging and salinity problems.

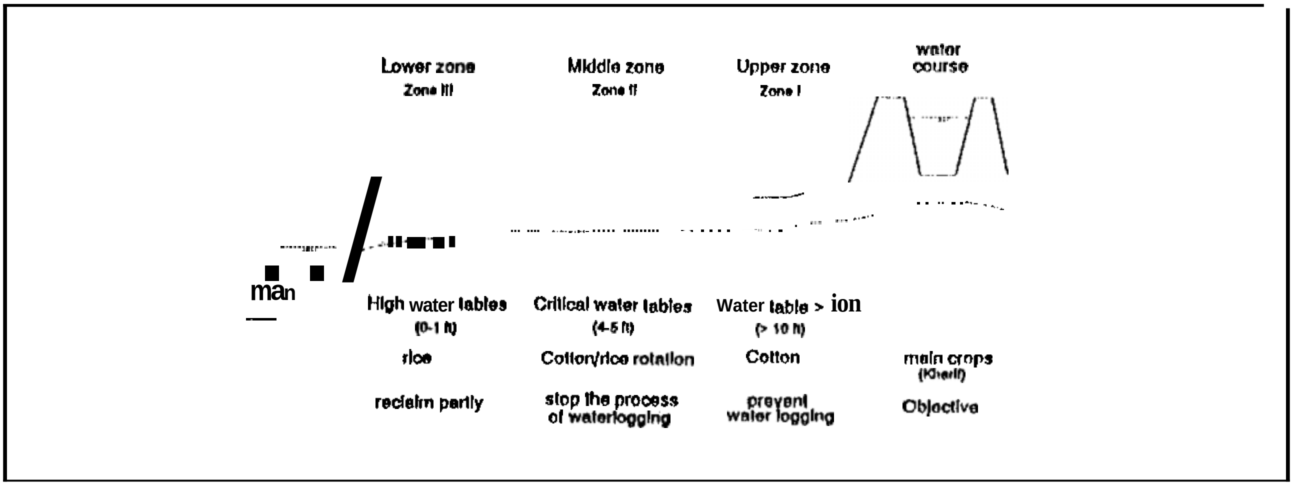

Figure-I. Drainage zones in the pilot project area

The pilot project aimed to prevent waterlogging and salinity in Wone-II and to a lesser extent in Zone-I. To reclaim Zone-III, it was considered that groundwater drainage would be required since surface drainage will bring only limited relief.

3. Project Location

The selected Khan Garh pilot has a gross surface area of 1,500 ha and is located in the Muzaffar Garh district, at a distance of approximately 30 km south-west of Muzaffar Garh city. The boundaries are formed by the Mehr Pur Minor in the west, the Haji Wah Minor in the east, while the road Khan Garh to Shah Jamal forms the northern boundary. The two minors are converging to the southern end **of** the project area. The Kot Adu Drain passes through the centre area (approximately north-south direction). The pilot area is thus divided into two parts, whereby the part at the east side is called Part-I and the part located on the west side, Part-II. The location of the project area with respect to other major cities of the Punjab Province is shown in Figure-2. The map **of** the pilot area Khan Garh is presented in Figure-3.

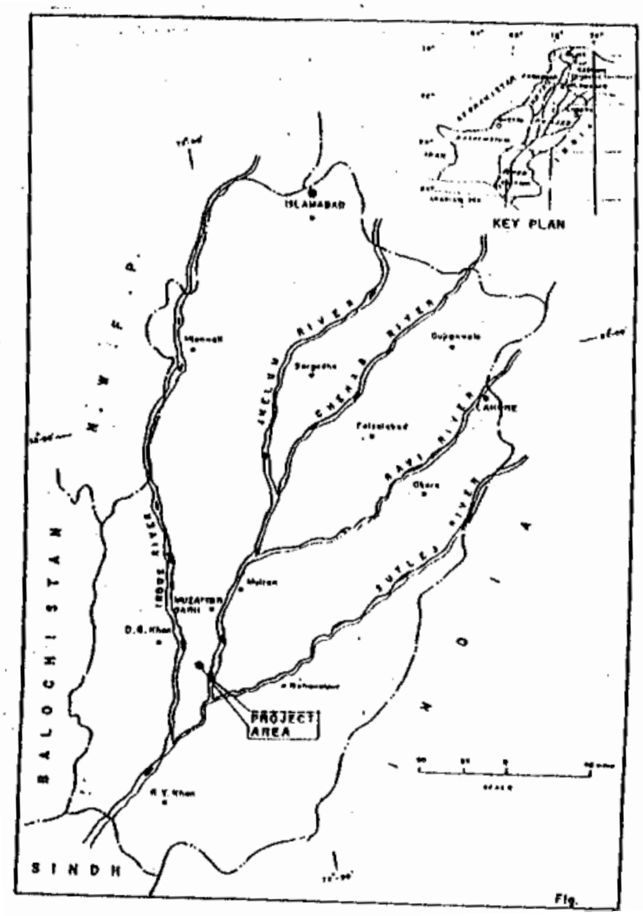

Figure- 2 Project location map.

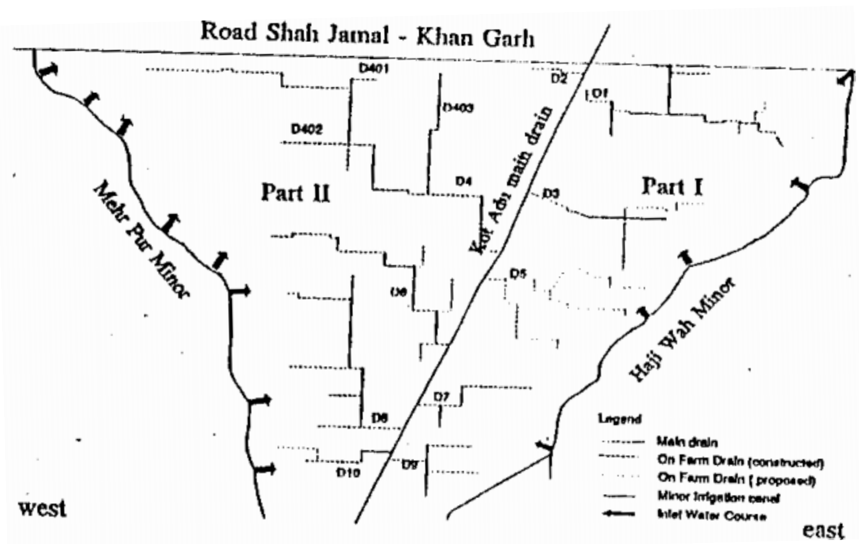

Figure-3 Map of the pilot project area, Khan Garh.

4. Topography

The topography of the pilot area is very flat. The land slope is only 5-10 cm per kilometer going from the two minor irrigation canals towards the Kot Adu Drain. Although the differences in elevation in the area are small, there are a number of depressions in between the watercourses where excess surface water can accumulate and stagnate. These depressions are in need of surface drainage.

5. **Soils**

Most of the soils of the project area are clayey and are suitable for the crops grown in the area especially sugar-cane, rice and wheat. With modern management, including mechanical cultivation, application of balanced fertilizers and growing of improved crop varieties, high or very high production can be realized on these lands.

6. Rainfall

The rainfall in the area totals some 230 mm per year on average, of which the major part falls during the kha'rif (July-September) season.

7. Groundwater

Along the Mehr Pur and Haji Wah minors, a number of tubewells are in use (both government and privately operated) which add to the irrigation supply. The groundwater is predominantly fresh in the upper layer, although conditions seem to vary and some tubewells are known to pump low quality water (saline), which can only be used for irrigation after mixing with surface irrigation water.

8. Agriculture

Farmers in the area grow a variety of crops. They have a preference for cotton during the kharif season (summer), being the best paying crop. When waterlogging and salinity becomes a problem, farmers generally switch to rice. First in rotation with cotton, but as the situation becomes worse, they switch to rice only. During the rabi season (winter), wheat is the main crop. Again rice is chosen when waterlogging becomes a problem. A cropping calendar for the area is presented in Figure-4.

Land ownership and tenancy in the pilot area appears to be fairly representative for the D.G. Khan region. Most of the farm holdings are smaller than 5 acres, but there are a number of large farmers with holdings up to 200 acres. The land holding pattern observed in the project area during interviews conducted by the *MIS* Waterman Consulting Engineers in their impact evaluation study is given in Table-I.

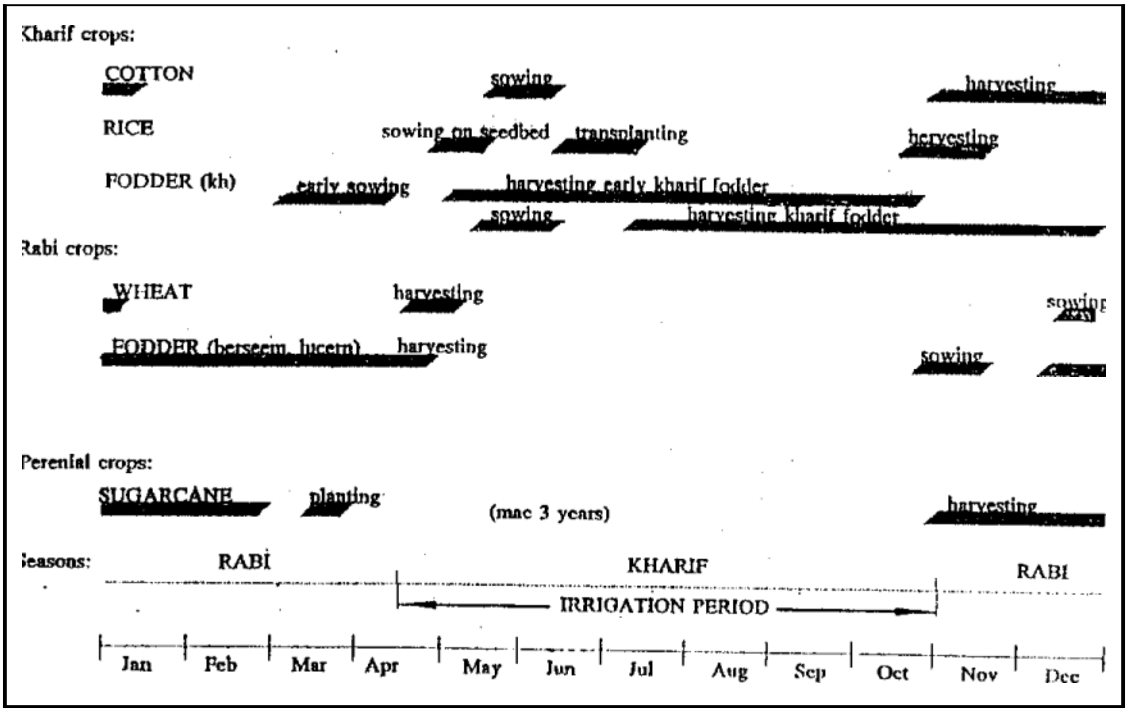

Figure-4. Cropping calendar for the pilot project area:

Table-I. Farm size (land holdings) of the farmers in the project area.

Land Holding	Respondents on Improved Watercourses		Respondents on Un-Improved Watercourses	
(Acres)	Number	Percentage	Number	Percentage
< = 5	32	11.1	24	19.5
6 - 10	55	14.1	26	21.1
11 - 15	a7	30.2	28	22.8
16 - 20	25	8.7	11	9.0
21 - 25	31	10.8	13	10.6
26 - 50	44	15.3	18	14.6
51 - 100	8	2.8	2	1.6
> 100	6	2.1	1	0.8
Total	288	100.0	123	100.0

Source: Impact Assessment of Second OFWM Project, Dera Ghazi Khan by Specialist Group Inc (Pvt.) Limited in association with Waterman Consulting Engineers.

9. Irrigation System

The irrigation water supply has its origin in the Indus Basin. From the Taunsa Barrage the water is diverted through the Muzaffar Garh Canal to the Haji Wah and Mehr Pur Minors. Then through the watercourses to the farmers fields. The pilot area is part of the Muzaffar Garh command system and is irrigated by the two minors (irrigation canals), the Mehr Pur and Haji Wha. Some additional irrigation water is diverted from the Mondka Minor that runs to the north of the pilot area.

During the kharif season, the actual discharges are many times larger than during the rabi season. During the rabi season, the available irrigation water is limited. **As** a result of water shortages during the rabi season, the canals in the pilot area have been designed for non-perennial flow. This means that in principle these canals are only operational during the months of April to October (kharif season). In actual practice many non-perennial canals receive water during the rabi season as well, although in reduced quantities. During periods of water shortage the canal systems are often operated in rotation.

10. Watercourses

In **Table-2,** the names, acreage and discharges of the watercourses in the pilot area are given. At **the** start of the pilot project, some of the watercourses were improved under the OFWM program. The remaining watercourse were also improved during the project period.

The command areas of the watercourses is not equal to the catchment areas of the tertiary surface drains designed **by** the pilot project. The drains are interfingering with the watercourses and the catchment area of the drain contains parts of several watercourses.

11. Drainage system

The existing drainage system for the pilot area has the following existing components:

i) Primary - Chenab River.
ii) Secondary - *Kot* Adu Drain.

In addition to this existing system, the system also needed tertiary and field level drains, which were introduced, **as** part of the OFDPP.

i)	Tertiary	*Tertiary* drains: *On* Farm Drainage system as *implemented by* OFDPP, *on the same* level as the watercourses.
ii)	Field level	In field drains *in the* farmer's plofs, were constructed *by* the farmers, as advised by *OFDPP.*

Name of Minor	Watercourse Unit	Area (acre)		Design discharge	
		GCA	CCA	(1/sec)	(cusec)
Haji Wah	43928/R	382	366	53	1.9
	48168/R	274	265	58	2.0
	52385/R	410	400	71	2.5
	55108/R	434	416	87	3.1
	58571/R	237	227	50	1.8
Mehr Pur	68720/L	193	172	48	1.7
	69500/L	560	536	133	4.7
	72695/L	105	100	24	0.9
	74179/L	160	154	52	1.8
	7572011	248	240	78	2.8
	76678/L	111	103	25	0.9
	1852/TL	179	170	41	1.5
Mondka	26700/TR	427	410	73	2.6
	26700/TF	498	451	80	2.9
Total		4218	4010	875	31.0

The Kot Adu Drain is the main disposal drain out of the pilot area. It has adequate capacity and is reasonably well maintained. The main shortcoming of the selected pilot area is the rather shallow depth of the Kot Adu Drain. The drain water level at some places is only just below the adjacent ground surface level. This is undoubtedly part of the reasons for the large scale waterlogging and salinity found in the lands in the southern part of the pilot area on both sides of the Kot Adu Drain.

The Irrigation Department during 1992 re-excavated sections of the Kot Adu Drain. Unfortunately, during the flood in 1993 the embankment of the Chenab River was breached to protect Muzaffar Garh City from flooding. This also flooded the pilot area and the Kot Adu Drain was again filled with sediment.

12. Beneficiary Involvement in the Pilot On Farm Surface Drainage Project

Farmers' involvement in all stages of implementation of the pilot project was seen as an important requirement to create a successful and sustainable project. The main objectives for farmers participation under the project were: i) to build Drainage Beneficiary Groups (DBG). ii) to have an effective contribution of the farmers in the execution of the works: and iii) to lay a basis for future maintenance of the tertiary drainage system.

On farm drainage was a completely new element for the farmers in the pilot area Experience with organizational set-ups was limited to the organization of Water Users Associations (WUA) for improvement of watercourses It was expected that the OFDPP would be confronted with a variety of problems and that a flexible approach would be needed The participation process followed under the project consisted of the following phases,

i. Entry phase;

ii. Organizafion phase;

iii. Design and planning phase,

iv. Construction phase; and

v. Operation and maintenance phase

12.1 Entry phase

During this phase, the farmers in the pilot area were informed about the project plans and the consequences. The possible impacts of the drainage facilities were explained to them.

12.2 Organization phase

The drains are generally located in between two watercourses. It was, therefore, proposed to establish a Drainage Beneficiary Group (DBG) instead of making use of the Water Users Associations (if existing) organized for each watercourse. A similar approach as to the forming of the WUA's was, however, followed. The DBG's worked together with the OFWM staff during the implementation of the project.

After the topographic survey of the area, the catchment areas of the tertiary drains were determined and a preliminary layout design of the drains was prepared. Subsequently, the groups of farmers located in the catchment area of each drain were listed and approached.

The Drainage Beneficiaries Groups were formed, whereby the number of members depend on the size of the catchment area of the drain and on the farm size. It can be seen from **Table-2** that in the project area, the size of each established DBG varied from 10 to 100 farmers. Afler establishing a DBG, a contract between the DBG and OFWM was signed by both parties.

12.3 Design and Planning Phase

During this phase, the design was made and the farmers were informed about the progress made. Many discussions on the subject of surface drainage were held and the concept of tertiary (on farm surface) drainage was explained in detail. Information included physical consequences (some farmers will lose some land); the need to maintain the system after construction; the contribution to the construction of the works; and the expected benefits (increase of area to be cultivated, yield increases etc.).

The DBGs formed an important role in these discussions, whereby some farmers, certainly those who have *to* sacrifice land for the benefit of the community. had to be convinced.

It became apparent during the discussions that the tail-end farmers of the watercourses adjacent to the main drains were, in general, much more interested and co-operative than the farmers located in the head reaches. The former played an important role in the successful implementation of the project.

A compromise between the best layout (in the lowest area) and the interest of the farmers (no loss of land, i.e. along plot boundaries) had to be made, while discussing the initial layout designs with the farmers. It was found that the initial layout design had to be verified with each individual farmer before the plan could be discussed in the DBG.

During the discussions with individual farmers, it was possible to obtain additional information on the area, problems, organization, etc. which could be used in the decisions for the final layout design. In this way, it was possible to obtain some clear commitments of some farmers, thereby creating a group of supporters which was very important in subsequent group discussions. The hydraulic designs were prepared after this stage.

Farmers in the lower parts *of* the pilot area were warned about the possible inflow of drainage water from the Kot Adu Drain. The risk which they felt was such a major issue in the discussions that the provision of an outfall structure with a gate had to be promised. Otherwise, the project would not have proceeded.

One farmer opposed the implementation of the project during the design phase. He refused to contribute land for the drains. Once construction started, this same farmer, however, requested to be included and to even extend the tertiary drain beyond the planned length.

In **Table-4,** the as built data of the tertiary drains are presented together with the number of farmers per tertiary drain and the number of farmers who contributed land for the drains.

Table-4. Tertiary drains and number of beneficiaries

Drain		Total		Beneficiaries	
Drain No.	Length (m)	Catchment area (ha)	Discharge (m3/s)	In catchment area	Contributed land for drains
Part-I					
D1	3132	171	0.154	76	45
D3	1095	88	0.088	45	8
D5	421	65	0.065	33	6
D7	1076	54	0.054	25	8
D9	1507	62	0.062	28	15
Part-II					
D2	517	31	0.031	27	6
D4	5957	331	0.232	104	37
D6	2548	165	0.148	68	27
D8	2838	186	0.158	41	18
D10	721	61	0.061	34	9
Total	19,812	1,214	1.053	481	179

ources: Final Evaluation Report - On Farm Drainage Pilot Project, Second On Farm Water **Management Project.** D.G. **Khan by Euconsult**.

12.4 Construction Phase

Depending on the participation of the farmers in the construction, which was recommended, regular meetings with contractors, farmers and OFWM staff were held to guarantee the progress and quality of the works. Initially, it was proposed to have part of the drains constructed by the farmers. Although this was not done, the idea is sound and should definitely be tried during the next pilot project. For this project, the authorities, however, thought it better to prove first whether a tertiary surface drainage system would work. Participation by the farmers in the construction of drains (funds and/or labour) in this pilot area was, therefore, not asked and the work was carried out by a contractor and paid for with project funds.

During the construction phase, it has been observed that although the plans have been discussed and approved during the design phase, with and by the farmers, **it** was not always possible to construct the system as planned. Some farmers changed their minds once the construction of the system started. Sometimes, difficulties occurred that had not been foreseen during the planning phase. Plans should, therefore, be flexible enough to make changes possible during construction. Flexibility is not always possible, or easy, when work is carried out by a contractor.

12.5 Operation and Maintenance Phase

Motivation of and guidance to the farmers by the OFWM staff was essential in case of the pilot project, although the operation and maintenance of the surface drainage works would be the full responsibility of the farmers. Monitoring of the adoption of the surface drainage system by the farmers would be important during the subsequent years of operation of the project. The construction of the tertiary drains was completed in mid 1993. The first monitoring results showed that most farmers were quite happy and satisfied with the system that has been constructed and say that they saw definite improvements in the pilot area. The farmers appeared to have a clear understanding of the use of the tertiary drains and realized the importance of cleaning the drains.

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13. CONCLUSIONS & RECOMMENDATIONS OF THE EVALUATION STUDIES OF THE PILOT PROJECT

Evaluating Agency	Acreage of acres covered by ponded water	
	Before Project	After project
Euroconsult	24%	0%
* Waterman Consulting Engineer	30%	1.77%

13.2 Groundwater Level

There is a distinct variation in groundwater levels over the year. Generally, the watertable at the end and the beginning *of* the year is at a peak, while in the dry months before the start of the monsoon and the peak irrigation season, the water tables will drop to **a** low. With regards to groundwater table fluctuations between before and after project, it **has** been observed that the water level only fell slightly during May, 1994 as compared to the data of May, 1992 (difference of 0.20 m). Water levels measured at the beginning of February and March 1992 have been compared to the levels during the same period in 1994. The 1994 levels are lower than the 1992 levels by 60 cm in February and 50 cm in March. Groundwater depths below the soil surface before and after the project implementation are shown in **Figure-5** and **Figure-6,** respectively.

13.3 Soil and Groundwater Salinity

It has been observed that the average EC at the head and middle sections of the drains has decreased appreciably from 0.87 dS/m to 0.58 ds/m while at the tail section, it increased from 0.87 dS/m to 1.4 dS/m[7] The tertiary drainage system has, therefore, effectively reduced the salinity of major portion of the command area falling in the head and middle sections of the drains. The increasing trend of salinity at the lower reaches is evidently because of salt movement with groundwater flow from upstream section towards main drain I-ligher groundwater salinity indicates downward movement of salts from the upper soil layer, but restricted groundwater drainage during the post construction period. The soils and groundwater salinity status , therefore. indicates **a** need for groundwater drainage as well.

13.4 Cropping Patterns and Cropping Intensities

The impact of the improved drainage conditions is demonstrated by the increased cropping intensities as *is* evident from **Table-6.** The promising result obtained by the improved surface drainage in the pilot area indicates the considerable benefit from the tertiary drains to the farms operations, notably increased cropping intensities.

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[7] Impact Assessment of Second On Farm Water Management Project, ***Dera*** Ghazi Khan **by** *MIS* Specialists Group Inc. (Pvt.) Limited in association with M/S Waterman Consulting Engineers.

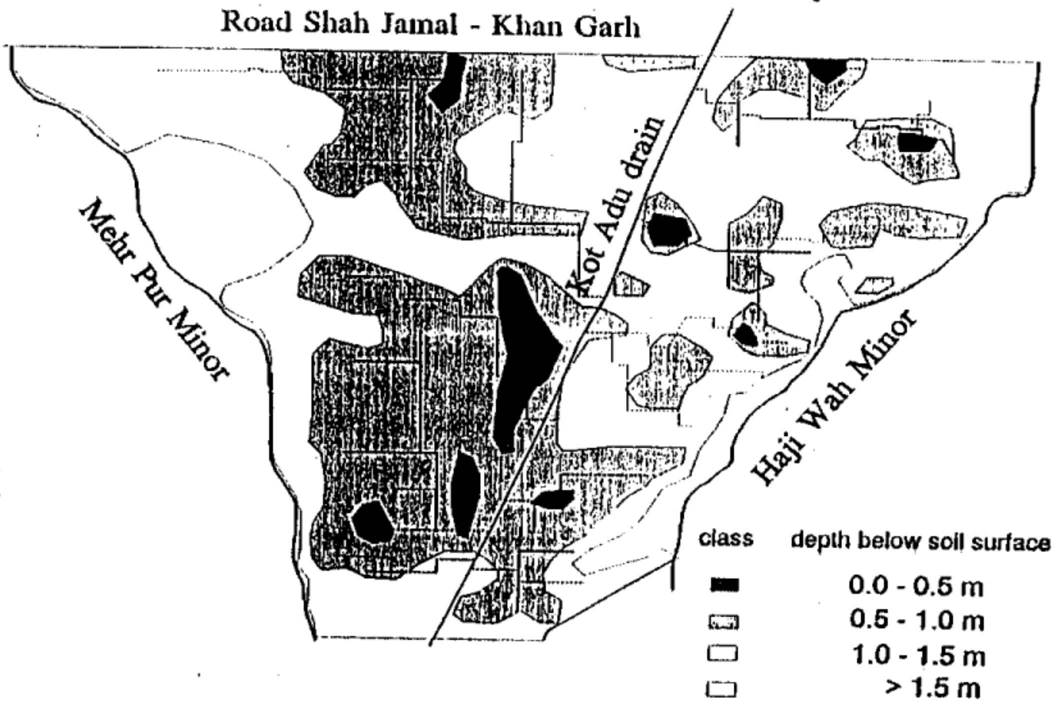

Figure-5 Groundwater depths below soil surface (1991-92), after monsoon).

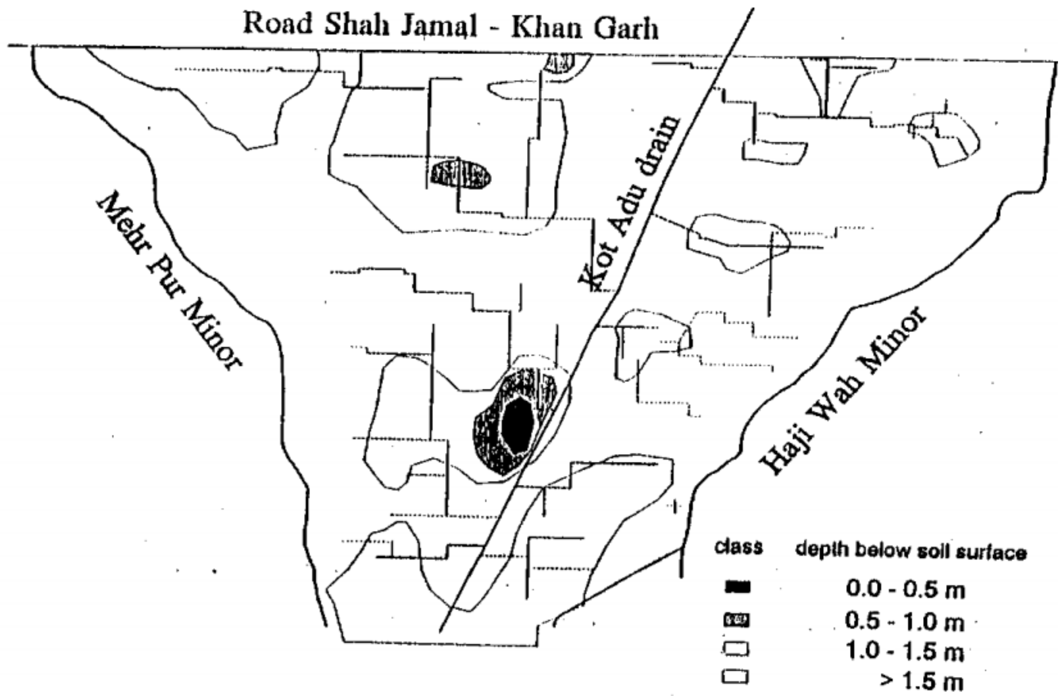

Figure-6 Groundwater depths below soil surface (1994, before monsoon).

Source: Final Evaluation Report - On Farm Drainage Pilot Project, Second On Farm Water Management Project, D.G. Khan by Euroconsult.

Table-6. Cropping Pattern and Intensities.

Crops	Pilot Proiect Area							
	Euroconsult				Waterman Consulting Engineers'			
	Before Project		After Project		Before Project		After Project	
	Area (ha)	occu-pancy (%)	Area (ha)	Occu-pancy (%)	Area (ha)	occu-pancy (%)	Area (ha)	occu-pancy (%)
Kharlf Crops								
cotton	357.0	22.0	563.0	34.7	40.09	23.56	57.06	32.88
Rice	92.5	5.7	97.0	6.0	14.17	8.16	13.15	7.58
Fodder	17.9	11.0	179.0	11.0	15.18	8.74	25.70	14.81
Jantor (Sesbania)	57.0	3.5	164.0	10.1	13.97	8.05	16.70	9.62
Sugarcane	6.5	0.4	6.5	0.4	0.90	0.52	1.09	0.62
Orchrd	16.3	1.0	16.3	1.0	0.18	0.10	0.08	***0.05***
Sub-Total	708.0	43 6	1026.0	63.2	84.5	48 68	113.22	65.57
Rabi Crops								
Wheat	714.0	46.0	816.9	50.3	73.00	42.05	92.51	53.30
Fodder	127.0	*7.6*	122.0	7.5	16.30	9.40	20.54	11.83
Sugarcane	***6.5***	0.4	6.5	**0.4**	0.90	0.52	1.09	0.62
Orchards	16.3	10	16.3	10	0.10	0.06	0.06	0.05
Sub-Total	864.0	53.2	961.0	59.2	90.30	52.02	114.23	65.8
Grand-Total	1527.0	96.4	1987.0	122.4	174.7	100.7	228.03	131.38

Sample Farmer = 34
Total holding = 173.5 ha

** The cropping intensityloccupancy percentage in the Pilot area is based on CCA+ 1624 ha as measured during the baseline survey

The slight difference in the findings of both studies as described in **Table-6** is due to sample size. The *M/S* Euroconsult had tried to cover the whole project area in contrast to taking sample watercourses as well done by the *M/S* Waterman Consulting Engineers. If the whole project area is considered, it is evident from **Table-6** that the cropping intensity has increased by 28% of the cultivable command area **(CCA)** (i.e. from 95% to 122%). The major increase is found in the cotton crop, were the increase in cropped area is 12%. In rabi season, the intensity of the wheat crop has increased by 65%. It may be expected that the cropping intensity will gradually increase even further than 122% with better drainage and more irrigation supplies. Moreover, changes in the cropping pattern are likely to occur (e.g. a reduction in areas cultivated with rice and fodder, and an increase of areas under wheat and other grains, cotton and sugarcane).

13.6 Farmers' Perceptions

Since the farmer is the ultimate beneficiary from the land and crop improvements resulting from the surface drainage system, the farmer's response was considered an important component of the impact evaluation exercise. As per the Final Evaluation Report of *M/S* Euroconsult, the first monitoring results showed that most farmers are quite happy and satisfied with the system that has been constructed and see definite improvements in the pilot area. The farmers appeared to have a clear understanding of about the use of the tertiary drains and realized the importance of cleaning the drains.

For the construction of the tertiary drains, ***9*** ha of land, which equals 0.06 percent of the area, has been made available free of charge by the farmers. Although the drains were constructed in the worst parts of the area on mostly abandoned lands, the farmers agreed to sacrifice part of their property for common benefit. This was one of the major achievements.

To check the farmer's response to the Surface Drainage System, MIS Waterman Consulting Engineers in their Impact Assessment of Second On Farm Water Management Project, Dera Ghazi Khan interviewed randomly selected samples of the beneficiaries. The following observations have been made during the interviews:

i. 37% of the respondents participated during the planning stage, and 57% during the construction phase *of* the projecf. Neither the farmers contributed *material* or financially, nor, was it requirement from *the government* to do so;

ii. about *51.4%* of *the* respondents participated in social matters, resolving conflicts and promoting cooperalion among *the* farmers as well as *with* the government staff. About 26% *of* the farmers participated as paid labour during *construction;*

iii. about 97% of the farmers concluded that the project is beneficial to them as far as utility and work quality of drainage facilities are concerned. The remaining 3% either had land holdings at higher elevation that did not need drainage, or they were not convinced of its utility for other reasons. Similarly, about 97% of the farmers considered the drainage project economical;

iv. all of the respondents without exception expressed their desire to replicate the surface drainage system in other areas where surface ponding exists;

v. about 97% of the respondents indicated that the constructed drainage system definitely reduced damage to crops caused by sustained surface ponding;

vi. about 43% graded the construction quality as good, 54% as satisfactory and about 3% as unsatisfactory. This was probably because of a lack of satisfaction in the contractor's progress, which was partly due to difficult field conditions hindering transportation of material, etc;

vii. when questioned about to recovering some of the costs of drainage and participation in operation and maintenance of the main as well as the tertiary drainage system, 23% of the farmers expressed their willingness to share the cost of the field drainage system similar to the cost sharing options for watercourse improvement. A majority of the farmers (77%) were reluctant to share costs, mainly due to their present poor financial conditions. As the surface drainage system operates and crop production improves, more farmers may be in a better financial position in the future to pay some of the costs;

viii regarding maintenance of the main drain, 94% expressed the need for deepening and cleaning the Kot Adu Drain;

ix. for operation and maintenance of tertiary drains, 20% of the farmers opted for cleaning by the farmers themselves, 43% by DBG without recovery, 9% by DBG with recovery, 17% by the government with recovery from the beneficiaries and only 9% by the government with no recovery. The majority expressed confidence about DBG, which shows the important role of the beneficiary groups in mobilizing farmers resources;

x. about 91% expressed that the loss of land under the surface drains was justified in terms of the increased cropped area, crop yields and socio-economic conditions of the farmers as a result of the surface drainage system;

xi. about 95% of the donating respondents donated land voluntarily for the surface drains. None of the farmers, out of the respondents, complained against any social or official pressure regarding land contribution. About 5 expressed ignorance of their independent decision on land donation as they were dependent on someone else; and

xii. one of the important questions asked *regarding* the feelings *of the* land donating farmers about the neighboring non-donating farmers indicated that 80% of the donating farmers showed no signs of negative *feeling* and considered ***it*** a cause for community development. The other 20% thought that the non-donating farmers should be charged ***for*** the development *to* compensate those who have donated land for the drainage system.

As this was a pilot project, and it was a new experience for the farmers to understand the need and advantages of the system, it was probably not appropriate to recover some of the costs, particularly from non-donating farmers. As the system proves to be useful for the farm lands, farmers are convinced of its anticipated benefits and the system has to operate on a permanent footing. Sotne cost sharing system must be developed to continue the technology for new development in the region on a sustained basis.

13.6 Costs

The cost of the on farm drainage project as implemented was approximately Rs. 500/acre (Rs.1200/ha)[8].

VII. ESTABLISHMENT OF ON FARM DRAINAGE SITES UNDER OECF/JAPAN ASSISTED OFWM-III PROJECT

The experiences gained and recommendations put forth during the implementation/completion of On Farm Drainage Pilot Project, D.G. Khan by OFWM and consultants, replication. of the on farm surface drainage concept under OECF/Japan assisted OFWM-III Project (revised) has been followed. A brief description of the establishment of On Farm Drainage sites under the OECF/Japan-assisted OFWM-III project is described below.

This project envisaged developing **25** On Farm Drainage sites in the entire project area of the OECF/Japan-assisted OFWM-III project. At present work on 12 sites is in progress at various stages of survey, design, agreement, tender documentation, tendering and construction As per tenders finalized for 5 sites, the unit cost of establishing drainage sites is Rs. 989/acre (Rs 2443/ha) as given in **Table-7.** The increase in the unit cost as compared to Rs. 500/acre (Rs. 1200/ha) incurred on On Farm Drainage Pilot Project, D.G. Khan is due to the depreciation of the Rupee, increase in the cost of construction material, etc. and due to other site specific reasons like topography, etc.

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[8] Final Evaluation Report, On Farm Drainage Pilot Project. Second On Farm Water Managemenl Project, Dera Ghazi Khan by *M/S* Euroconsult.

Table-7. **Costs** involved in development **of** on farm drainage sites **under** OECFIJapan-assisted **OFWM-III** Project.

On Farm Drainage Sites	Tehsil/ District	Area (ha)	Cost	Rs per ha	Rs per **Acre**
Sheikhu Chak	Kharian	1056	3581350	3391	1373
Bacanawala	Kharian	623	1430610	*2296*	930
Jandusahi	Deska	558	10917117	1957	792
Akbar Ghanoke	Kamoke	820	1916916	*2338*	946
Akanwala	Hafizabad	1416	3165089	*2235*	905
Average				2443	989

As per findings of the evaluation studies of the pilot On Farm Drainage Project, it is envisaged under this scheme that the beneficiaries would be required to pay about 50% of the costs to be incurred on the development of On Farm Surface Drainage systems. The volume of earth moving on these projects requires that they are undertaken by using contractors. This, to some extent, dictates the cost sharing arrangements. The cost sharing mechanism that is being followed under the OECF/Japan-assisted OFWM-III Project is as below:

i) ***fhe*** Drainage Beneficiary *Group (DBG)* will provide the land *for* the drains. The farmers, through *the* Drainage Beneficiary *Group (DBG) shall be* responsible for settling any claims for compensation from individuals who would lose land as a result *of* the construction of the drain:

ii) the contractor, at the projects expense, will excavate the material from the farm drain and place it beside the drain. The farmers will undertake the spreading of all the material excavated from the drain on adjacent fields or in low areas, to the satisfaction of the project and those farmers whose land is adjacent to the drain:

iii) the contractor, at the projects expense, would construct all structures required on the drain;

iv) the farmers will be responsible for excavating the field drains to connect their fields to the farm drainage network; and

v) the DBG would have to guarantee free and unrestricted access to the site for the contractor's machinery and employees.

It is believed that the successful model development during implementation of Participatory On Farm Drainage Management at Dera Ghazi Khan and its replication under the OECF/Japan-assisted OFWM-III Project with improvements will prove to be a foundation stone for institutionalizing the role of farmer's organizations for sharing responsibilities in operation, maintenance, and management of drainage systems in Pakistan.

VIII. CONCLUSIONS AND RECOMMENDATIONS

In the light of experiences gained during implementation of On Farm Drainage Pilot Project under ADB-assisted Second On Farm Water Management Project, Dera Ghazi Khan and those of the currently ongoing OECF/Japan-assisted OFWM-III Project, a few conclusions and recommendations have been drawn as given below:

i) On Farm Surface Drainage may be replicated and included as one of the components of future Irrigation, Drainage and On Farm Water Management Projects;

ii) legislation may be made for formal functioning of the Drainage Beneficiary Groups. Necessary modifications/amendments for this purpose may be incorporated into the existing Water Users Ordinance, 1981 under which the Water Users Associations are organized and registered;

iii) The role and responsibilities may clearly be defined for the participating agencies like the Drainage Beneficiary Groups in the private sector as well as that of the provincial Irrigation and Power Department and Agriculture Department (Water Management);

iv) a financial program of investments and recoveries similar to the watercourse improvement program may be developed, where the farmers are charged for part of the expenses by considering their economic status;

v) a promotional campaign highlighting the importance of "On Farm Surface Drainage" for environmentally sustainable agriculture in areas with emerging waterlogging and salinity may be launched, wherein farming communities may be approached to support and promote on the farm drainage concept and activities;

vi) a specialized training program for acquainting the OFWM staff, as well as the farming communities, on the subject of "On Farm Surface Drainage" for future and ongoing OFSD projects may be conducted;

vii) all of the Drainage Beneficiary Groups's (DBG) may be organized into a Drainage Federation (DF), to strengthen the operation and sustainability of these groups. A DBG can be too small to work optimally and collect contributions from the farmers for development works. The DF will have more influence on concerned government agencies on issues like cleaning of the main drainage system, as well as irrigation supplies. The DF can further play a role as an advisor to the participating farmers (for example, by giving advice on reclamation and soil improvement practices); and

viii) regular monitoring of the completed and on-going On Farm Surface Drainage projects may be made for proper documentation of the experiences gained, lessons learned and data base for designinglimplementing similar projects in the future.

PRESSURIZED IRRIGATION SYSTEMS FOR INCREASING AGRICULTURAL PRODUCTIVITY IN PAKISTAN

Shahid Ahmed', Muhammad *Yasin*[2], M. S. *Shafique*[3] *and* Muhammad *Akram*[4]

ABSTRACT

The main emphasis of the paper is on the productivity level which has to be enhanced to cope with the ever growing population in Pakistan. The population of the country is going to be doubled in twenty years. The food consumption will also be doubled during the same period. Hence, either crop yields or the cropped area will have to be doubled to cope with the future requirements. In the context of a fixed and short water supply system, the challenge of the enhanced productivity can only be met by improving productivity of lrrlgation water supplied. It means that we will have to use our limited water resources very optimally. During the initial crop growth period, water uptake by the plants is lower as compared to that at later stages. Such low requirements are quite difficult to be applied by flooding-the usual way adopted in Pakisfan. However, this purpose can be attained by use of a pressurized irrigation system. Moreover, adaption of pressurized irrigation practices has also been emphasised in the paper to manage the root zone salinity in the centers of doabs in Pakistan.

1. BACKGROUND

1.1. Agricultural Productions and Imports

The total wheat production of Pakistan during 1994-95 was around 17 million tonnes. About 2.3 million tonnes of wheat was imported to meet the country's food requirements (GOP 1995). The annual growth rate of population of over 3.0% further demands a similar increase in the import of wheat grain per annum. There is a net shortfall of edible oil in the country and its import costs about one billion US dollars during the year 1994-95. The government, although giving high priority for the cultivation of oilseeds in the country, but still the local production of edible oil is not a significant order. The country's imports of food items are continuously increasing at a rate which is hard to sustain as the exports of agricultural commodities, especially cotton, are adversely affected during the last five years due to curl-leaf-virus.

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1.2. Agricultural Productivity

The yield of rice, sugarcane and coarse grains are either stagnant or declining, whereas an annual increase of around 1.5% in wheat yield was observed over the last 20 years. The yields of wheat were **2.3** and **1.1** tonnes/ha for the irrigated and rainfed farming systems, respectively, during the year **1994-94 (GOP 1995).** About **83%** of the wheat cultivated area during **1994-95** was irrigated, which constituted about **91%** of the total wheat production. The existing yields of irrigated and rainfed wheat are almost half **of** the possible yields which can be achieved through improved management practices.

The agricultural productivity as viewed in this paper is "the system's net output of goods and services, commonly measured either as crop yields or net income per unit of input or resources". In Pakistan, the productivity must be viewed in a comprehensive manner considering the future challenge to increase cropping intensity, yield and income per unit of land, water and time. Therefore, the productivity index can be defined as Under:

$$I_p = I_{ci} * I_y * I_{wu}$$

I_p - Productivity index;
I_{ci} Cropping intensity index **as** a ratio of actual to targeted cropping intensity:
I_y - Yield index as a ratio of actual to targeted yield; and
I_{wu} - Water use index as a ratio of actual to targeted water use efficiency.

This index will provide a combined picture of agricultural productivity in time and space and one can view the options of how to enhance productivity considering the potential for extensive and intensive levels of development.

1.3. Future **Food** Requirements

Wheat is an important crop related to the country's food security. The wheat requirement for the year **1994-95** was about **19.3** million tonnes and with a 3% annual growth of population, the wheat requirement during the year **2014-2015** will be around 34 million tonnes, which is almost double the production for the year 1994-95. This means that either the crop yield or the cropped area must double in the next 20 years to cope with the future requirements. Otherwise, the country has to spend huge resources of foreign exchange for import of shortfalls. Similarly, the import of edible oil will double after 20 years if local production is not increased significantly.

Stage of Irrigation	Root Zone Depth (mm)	Available Water in Koot Zone (mm)			
		Coarse	Light	Medium	Fine
First Irrigation	360	29	50	60	72
Second Irrigation	570	45	80	95	114

The above figures indicate that for a pre-showing irrigation, a maximum water application of 10-15 mm should be kept for most *of* the soils. If the scheduling of first and second irrigations is done at 50% of the management allowed deficit (MAD), then the first irrigation for most practical purposes should range between 15-30 mm. Similarly, the second irrigation should range between 25-45 mm. However, it is not possible to apply irrigation of **less** than 75 mm. in medium and fine textured soils and less than 100 mm in light textured soils using the level basin or level border methods of surface irrigation. Therefore, a major part of the pre-showing, first and second irrigations is lost because of percolation below the root zone and excessive infiltration at the head end of the field. This loss also contributes towards a drainage surplus. Furthermore, there is a shortage of canal water supplies during the early and middle parts of the rabi season due to low river flows. Thus, a majority of farmers in the Punjab Province use tubewell water. The pressurized irrigation systems can provide an alternative for applying light irrigations of 10-45 mm. Weekly applications through a sprinkler irrigation system is also possible, which provides a better strategy for effective utilization of rainfall. Therefore, for practical purposes, the sprinkler irrigation application can be ranged between 10-25 mm (Bhatti et al. 1993).

2. PROBLEMS AND CONSTRAINTS

The problems and constraints related to productivity enhancement are as under:

- pricing of commodities;
- efficient use of limited freshwater resources (surface and groundwater);
- saline water upconing in the middle of doabs in the Indus Basin because of uncontrolled groundwater exploitation;

- management of salinelsodic soils and waters; and
- maintaining soil physical and chemical health.

3. RESEARCHABLE ISSUES

The researchable issues related to productivity enhancement of the irrigated farming systems are:

Fractional well technology helps to skim the shallow freshwater but, in most cases, the small discharges of such wells can not be efficiently applied using traditional surface irrigation methods. The researchable issue is to apply light and more uniform irrigations using efficient application methods.

Surface irrigation methods, especially for pre-showing or the first irrigation, is inefficient because the water requirement or soil moisture depletion is much lower than the minimum depth of water required to cover the field The issue is how to apply light and uniform pre-showing irrigations to reduce the time required for seedbed preparation and to plant crops as early as possible. The other issue is how the light first irrigation can help to reduce the contribution to a drainage surplus.

The following of land contributes towards salt buildup and therefore the issue is to increase cropping intensity so that more area is brought under wheat and oilseeds. This increase in cropping intensity has to come through efficient application of good quality water.

The root-zone salinitylsodicity and water table management are important elements for sustainability of the enhanced productivity. The issue is how to enhance the uniformity of leaching in salinelsodic soils where salinelsodic water is used for cropping. The management of sodicity in soils and waters is a major concern, if the irrigated areas are to be expanded to meet future agricultural and food requirements. especially. self-sufficiency in wheat and edible oil are needed in the irrigated area.

4. PRESENT STATE OF TECHNOLOGY DEVELOPMENT AND INDIGENIZATION

The Water Resources Research Institute (WRRI) of the National Agricultural Research Centre (NARC) in collaboration with the local pump industry (MECO Pvt. Ltd., Lahore), the plastic industry (GRIFFON Pipe Company, Lahore) and the irrigation company (Hydro-Tech Farms and engineering Services, Islamabad) developed and indigenized the technology for (Ahmed et al. 1993, and WRRI, 1996):

Hand-move raingun sprinkler irrigation systems for farms of 5-15 acres or more where farmers are interested in using these systems for conjunctive use (surface and pressurized irrigations) are now commercially available and can be procured on order from the MECO Pvt. Ltd., Lahore or M. Azam Khan and Company, Rawalpindi. These systems are now being provided to the barani farmers by ABAD and OFWM in Pothwar Plateau.

Trickle irrigation systems for fruit orchards using simple emitters, filters and fertilizer injectors, are now commercially available and can be procured on order from GRIFFON Pipe Company, Lahore. These systems are now being installed by various Programmes and farmers in arid lands of Balochistan, hot deserts, northern areas and barani lands.

- Semi-automatic reel-machine type sprinkler irrigation systems for nurseries, golf courses and specialized farms, which can be manufactured on order by M. Azam Khan and Company, Rawalpindi. The prototype of these machines have been tested by the WRRI-NARC and can be indigenized if a large order is available.

- Centre-pivot sprinkler irrigation systems for farms of over 100 acres and for areas where water is at premium and higher productivity is targeted. The one-span prototype has been tested by the WRRI-NARC, and Hydro-Tech Farms is now capable of producing production-scale units. A proposal for a joint venture of Pakistan and Saudi-Arabia based US Companies is now in the pipeline for phasewise introduction and local manufacturing of centre-pivot sprinkler irrigation systems.

The new and emerging technologies which are still in the initial phases of testing and introduction are:

- The Bahria Foundation of Pakistan and Sweetwater Farming Inc. USA entered into an agreement to bring the technology for a sulphurous generator to Pakistan. The **WRRI-NARC** and IIMI-Pakistan are the research institutions involved in the process of technology testing and experimentation. For this purpose, initially two units have been imported by Bahria-Sweetwater Farming Joint Venture and one unit has been installed in the tail-end of the Fordwah Distributary at Hasilpur, or at any other suitable location to amend sodic groundwater.

A handpump based trickle irrigation systems for community based fruit plantations in areas outside the Indus Basin, including women participation for growing of vegetables.

The **MONA** Reclamation Experimental Project, Bhalwal has conducted operational research for the testing and introduction of skimming wells *to* pump fresh groundwater at a discharge which is sustainable without mixing of brackish water with the freshwater layers. The technology is now available for use in conjunction with the pressurized irrigation systems. The researchable area is how to develop effective strategies for cost-effective introduction of the technology in areas where surface irrigation supplies are in shortage, especially at the tail-end farms.

5. SPRINKLER IRRIGATION FOR WHEAT

The WRRI-NARC has conducted experiments on supplemental irrigation of the wheat crop in the rainfed areas around Rawalpindi, Islamabad and Fatehjang. The 5 years of studies (1989-1995) indicated:

- The yield of barani wheat of 1.0 tonnes/ha increased upto 2.0 tonnes/ha with a pre-showing irrigation of 10-15 mm. The pre-showing irrigation helps to plant the crop at the desired or optimum planting date, whereas farmers delay their plantings for the occurrence of rainfall if carryover moisture is not sufficient. The pre-showing irrigation helps to apply fertilizer and efficient uptake by plants to achieve a desired crop stand.

- The yield of barani wheat of 1.0 tonneslha can be increased upto **4.0** tonnes/ha with additional 2-3 irrigations of 25 mm each at critical stages of water deficit. These irrigations also help to schedule nitrogen fertilizer applications into 2-3 splits instead of full application at planting time as being practiced by the barani farmers.

One collaborative experiment on sprinkler irrigation was conducted with an enlightened farmer in the dense sodic soils of the Indus Basin in the Narowal area. Instead of using surface irrigation for the first *two* irrigations, sprinklers were used to apply 10-15 mm of water to avoid ponding due to limited infiltration rates. The sprinkler irrigation helps, to achieve better crop emergence and tillering compared to surface applications, in addition to saving water . Afterwards, surface irrigations were applied. This mixed strategy of irrigation helped to increase wheat yields from 2 tonnes/ha to 3.5 tonneslha. The sprinkler irrigation is also promising in efficient use of canal water and helps to minimize the use of sodic groundwater. Furthermore, the mixes irrigation strategy is one of the workable option for enhancing productivity of wheat in the rice-wheat system.

6. FUTURE INITIATIVES

The MONA Reclamation Experimental Project (MREP), Water Resources Research Institute (WRRI) and International Irrigation Management Institute (IIMI) recently submitted a project for funding under the National Drainage Programme, WAPDA, entitled "Root-zone salinity management using fractional skimming wells with pressurized irrigation systems". The project has been approved and will be initiated shortly. The project is aimed at the management of root-zone salinity for those field conditions which are mainly associated with the centre and lower parts of doabs and other pockets of irrigated lands where similar conditions exist in the Indus Basin. There are locations where exploitation and application of groundwater by using traditional means is either not feasible, or there is a serious concern that the outgoing practices will render the thin-layered fresh groundwater unusable in the very near future. These affected zones like those in the central region of doabs form about 30% of the irrigated area of Pakistan (MONA, WRRI and IIMI 1996).

The results of this applied research will be utilized in the Phase-II preparation of the Fordwah Eastern Sadiqia Irrigation and Drainage Project. Also, the results should play a significant role in the next phase of the National Drainage Programme. In addition, this package of technology and management will become increasingly more valuable over time as an alternative to abandoning tubewells. Moreover, the proposed activities fit well in the two key research areas of IIMI: i) Design and Management of Irrigation Systems; and ii) Health and Environment. The proposed activities will also help WRRI-NARC to refine the pressurized irrigation systems and make them tnore cost-effective for the farming community in the irrigated areas, in addition to scheduling of conjunctive water use (MONA, WRRI, IIMI 1996).

The specific objectives of the project are to:

- identify and test a limited number of promising skimming well techniques in the shallow fresh-water aquifers which could control the saline water upconing phenomenon as a consequence of the groundwater pumping;
- encourage and support in-country manufacturers to develop low-cost pressurized irrigation systems adaptable within the local setting of Pakistan; and
- implement an irrigation scheduling programme aimed at root-zone salinity management with skimmed freshwater (in a relative sense) applied by low cost pressurized irrigation systems.

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IMPROVED SURFACE IRRIGATION PRACTICES

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ABSTRACT

This paper discusses improved Surface irrigafion pi-actices in two ways: (i) monitoring and evaluatioii of selecled practices being experimented; and (ii) future challenges for the improved practices at watercourse level. As these practices are the actions which are aimed at achieving set goals of the watercourse level subsystem, the authors attempt to provide: (i) results to show poleiitial for achieving set goals by adopting better irrigations practices; and (ii) discussion abouf issues related to many other irrigation pracfices.

Irrigation practices selected for monitoring and evaluation include: (i) surface irrigation scheduling; (ii) comparison of two wafer applicalion methods; (iii) use of "sweetwater" / sulfuric generator for quick reclamation of sodic /saline-sodic soils; and (iv) conjunctive use of surface arid groundwater by gravity and pressurized systems. Under the future cliallenges for improved irrigation practices, issues and options are presented.

1. INTRODUCTION

From canal-outlet to field level, the surface Irrigation practices at the farm and field level form a critical part of the farmers' irrigation management domain in Pakistan. These practices are defined as the ***instituted actions*** which are aimed at achieving set goals and objectives of the on-farm subsystem without causing adverse effects. These surface irrigation practices can be categorized as improved actions if the differences between the measured goals and set goals are within an acceptable range. Otherwise, low performance of the farm level irrigation practices may suggest that the system is simply being ***operated*** but not ***managed.***

In order to identify key irrigation practices for discussion, the physical irrigation system is divided into four subsystems: (i) water delivery; (ii) water application; (iii) water use; and (iv) water removal. Each subsystem or component of an irrigation system is influenced by many elements and factors in performing certain functions. However, the degree of such influence is linked to the irrigation practices opted at each level of an irrigation system. In this context, this paper provides: (i) the functions and major factors of each component with examples quoted from different arid and semi-

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arid irrigated areas; **(ii)** selected improved surface irrigation practices with corresponding findings; and **(iii)** future challenges which liave to be met for sustainable use of the improved practices.

1.1 *Water Delivery*

Lowdermilk et al. (1983) have described this component ***as to convey water from fhe water supply source by way of the main canal and distributary canals to a canal outlet*** (main physical subsystem), ***and from there through farm and field channels*** (watercourse or on-farm physical subsystem). The major function **of** this component is to deliver irrigation water in a sufficient quantity and quality to the field. This process of water delivery is based on the following four steps (Walker et al., 1995): (i) assessment of water demand; (ii) water allocation; (iii) water distribution; and (iv) implementation (of the water delivery plan). However, the actual practices may differ from one setting to another.

1.2 *Water Application*

The main function of this component is to distribute water with the designed ***I*** desired uniformity over the field to meet the crop-water requirements and satisfy leaching and erosion considerations. Major factors which influence the process of water application are as follows (Lowdermilk et al., 1983): (i) field geometry; (ii) water supply rate; (iii) slope and levelness; (iv) infiltration rate; (v) surface roughness; (vi) irrigation methods; and (vii) management.

Selection of the water application techniques is the main concern for the farm managers. Because of the old traditions and familiarity, social acceptability within the existing management abilities of the farmers, and the prevailing economic environment, different countries with almost similar climatic conditions opt for different water application methods and practices. However, it does affect the performance of the component in achieving its goals.

1.3 *Water Use*

This component aims at storing and supplying water to meet crop water requirements. In order to meet this function, the factors wliich influence the process for water use are as follows: (i) knowledge about the irrigation requirements; (ii) quantity and quality of irrigation water; (iii) soil type; and (iv) nutrient availability (Lowdermilk et al., 1983).

This is the one component which attracts a maximum of attention by many scientists in the irrigated agriculture of the developing world. In spite of this interest, the information generated by the scientists is not translated in a useable form that the farmers can benefit. General irrigation practices under this component are based on either the visual condition of a crop, and ***I*** or water availability determined using the feel method by the farmers.

1.4 Water Removal

The main purpose of this segment is to create and maintain conditions for optimum crop production by providing surface and /or subsurface drainage. Water removal, surface and /or subsurface, is an essential part of irrigation. But the drainage component for many of the irrigation projects has not been considered important enough to be included in the development plans at the design stages. With time, however, the groundwater levels in many cases have come up within one meter or so from the ground surface. This development has made drainage an unavoidable requirement.

Like subsurface drainage, surface drainage is also equally important. The latter is particularly essential for heavy clay textured soils A good example in this context is the irrigated schemes in Sudan. The central plains of the locality are formed by the swelling heavy clay soils which disperse and seal the soil pores after coming in contact with water, As a result, the water is mainly absorbed during the advance phase of irrigation, and thereafter, the infiltration rate becomes almost negligible. This causes a serious problem of surface waterlogging which is considered to be an important factor contributing to lower crop yields.

2. MONITORING AND EVALUATION OF IRRIGATION PRACTICES

This section presents a selected number of innovative irrigation practices which are either already being monitored or in the process of being set up in the field for pilot testing. These practices include: (i) surface irrigation scheduling; (ii) improved surface irrigation application methods; (iii) quick reclamation of sodic / saline-sodic soils with sweetwater generator; and (iv) conjunctive use of surface and ground water by gravity and pressurized system.

These innovations are intended to improve the performance of the existing irrigation practices. However, these changes in the traditional actions will demand adjustments and cautions. In this context, IIMI and its national[6] and international[7] collaborators are undertaking and monitoring these activities to document the strong and weak points of important irrigation practices under experimentation as described below:

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[6] For example, Center of Excellence in Water Resource Engineering, Lahore; Water Resource Research Institute; On Farm Water Management, Punjab; etc.

[7] AgrEvo, Pakistan; and Sweetwater Farming Inc., USA; etc.

2.1 Surface Irrigation Scheduling

Irrigation scheduling *is* commonly defined as determining when *to irrigate* and how much water *to* apply, or as deciding when *to start* and when to stop an irrigation *event* (Martin et al., 1990). This practice is successfully implemented with pressurized water application systems in many countries of the world. However, the same practice of when and how much to irrigate in the context of hydraulically complex surface irrigation systems is difficult to translate into when to *start* and when *to* stop irrigation. Therefore, an effective surface irrigation scheduling program must develop strategies for each field on the farm to decide how and how long to irrigate, coupled with when and how much to apply. This is essential because of the enormous variability of infiltration rate both spatially and temporally. Also, surface roughness, field geometry and net required irrigation depths are other parameters that change from event-to-event and season-to- season (Shafique and Skogerboe, 1987).

→When and how much to irrigate?

In order to decide when and how much to irrigate, four techniques are commonly used (Salazar, 1987): (i) modeling of crop-soil-climate-irrigation system through water balances; (ii) soil based measurements; (iii) plant based measurements; and (iv) lysimeters and evaporation devices. On an experimental basis, researchers in Pakistan have tested almost all of the stated techniques. However, these techniques are yet to be made more user-friendly to win farmers' acceptability.

For deciding when and how much *to* irrigate, IIMI and its partners plan to monitor the following techniques on farmers's fields: (i) soil based methods; and (ii) pan evaporation. While discussions with the Soil Survey of Pakistan are still at an early stage to make use of tensiometers for this purpose, IIMI has monitored two cotton seasons of irrigation scheduling by neutron probe at the Tareen Farm near Lodharan. This activity is undertaken jointly by an Australian Consultant and AgrEvo of Pakistan with, of course, active involvement of the owner of the farm, Mr. Jehangir Tareen.

The neutron probe is one of the soil-based methods for determining the moisture contents available in the soil at a particular time. This measurement is based on the degree to which high energy neutrons are thermalized in the soil by the hydrogen atoms in water. The rate at which thermal neutrons are detected is related to moisture contents available in the vicinity of the radioactive source. If one can afford to purchase such probe, the irrigation scheduling becomes less arduous when compared with the gravimetric soil sampling method.

During the last two years, the neutron probe technique has been effectively tested in deciding when and how much irrigation water to apply to different fields at the Tareen Farm. This practice has been based on two moisture curves: (i) full level; and (ii) refill level. With an access-tube lowered to 160 cm deep at the head-end of each

Irrigation Event	Date	Practiced Deficit (mm)	Actual Deficit (mm)	Actual Applied Irrigation (mm)
2	9/7	54	71	95
3	29/7	66	83	92
4	28/8	52	69	95
5	5/9	45	62	95
6	21/9	49	66	96

[8] personal communications with Mr. Asim Bajwa, field researcher of AgrEvo at Tareen Farm

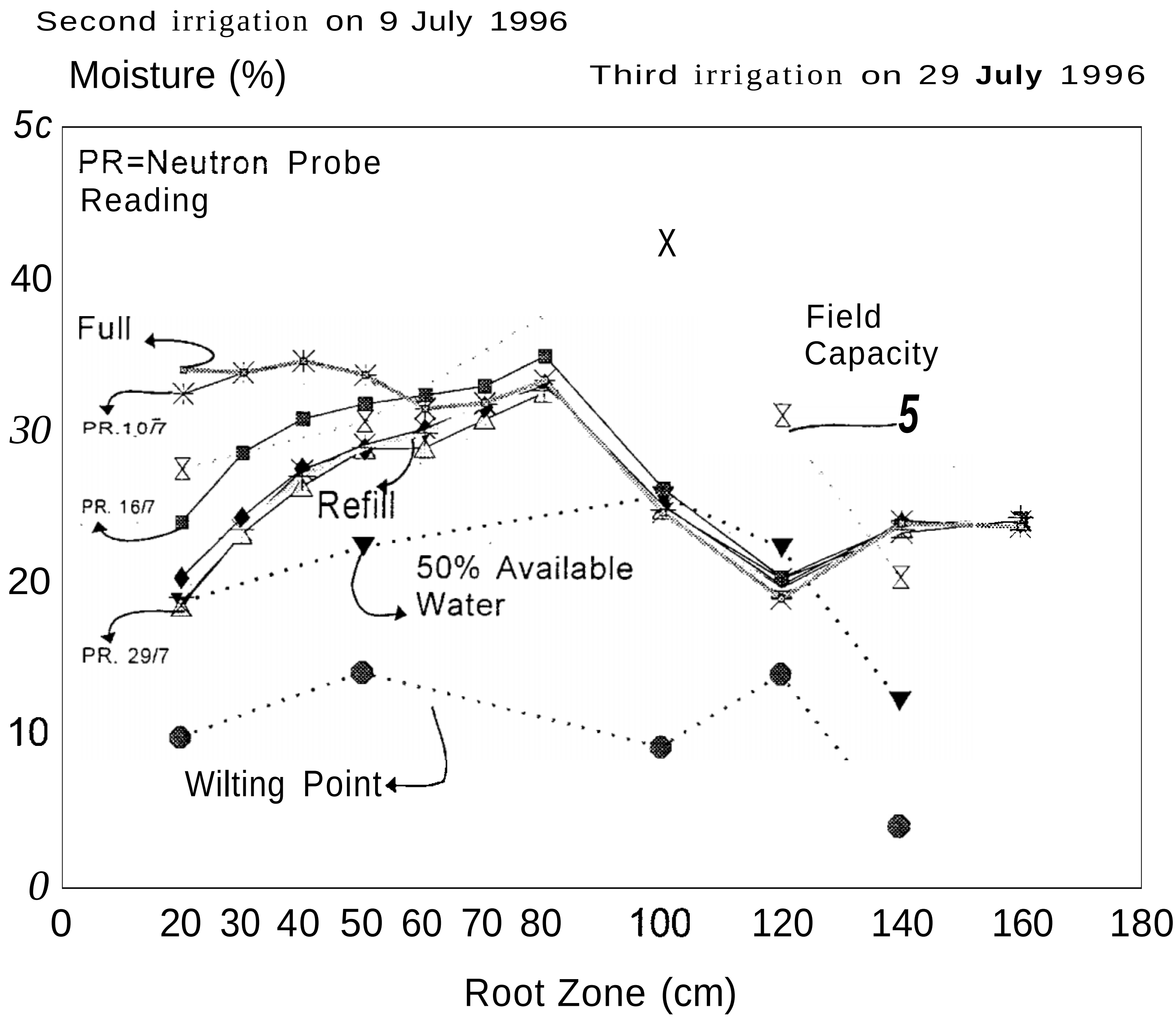

Figure 1. Monitoring of Plot S2-3 during 1996

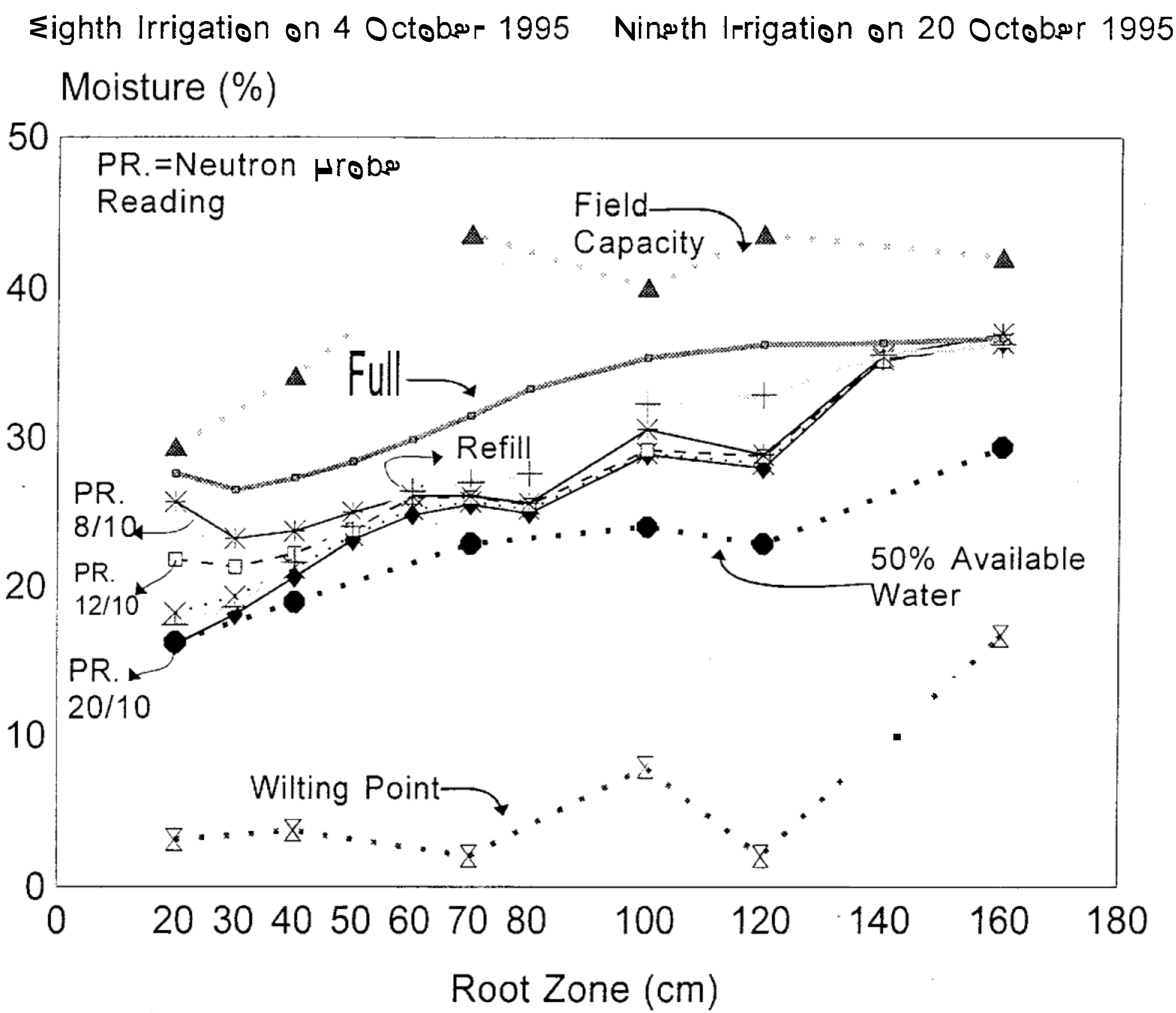

Figure 2. Monitoring of Plot S4-3 during 1995

hardly any water movement below 60-70 cm, whereas cotton roots can penetrate even more than twice this depth. The coefficient of variation from event-to-event for the profile below the effective moisture extraction zone (60-70 cm) mostly ranges from 0.0 to 0 04

-+How long *to* Irrigate?

The duration of an irrigation event for a given discharge at a certain time has to be determined, along with an awareness of the impact of certain physical processes, such as advance and infiltration behavior (due to spatial and temporal variability of soil parameters), soil surface roughness, field geometry and the crop water requirement on the irrigation process. These processes differ for subsequent irrigation events and between the seasons, both due to the change in soil compaction, crop and weeds development, cultural practices including intercropping, or climatological causes or changes.

To illustrate the advance and infiltration processes, corresponding graphs have been derived for subsequent irrigation events for a basin irrigation system (at the Tareen Farm). These advance graphs are derived, based on the two-point method as suggested by Walker & Skogerboe (1987) and Shafique and Skogerboe (1987). The advance function for basin irrigation systems is defined as follows:

$$A_x = p t_x^r$$

wherein: A_x=cumulative wetted area (m^2); t_x= advance time (min); p and r are fitting parameters.

The infiltration graphs are derived by the first reverse approach as presented in Shafique and Skogerboe (1987), which follows basic assumptions that "*the* subsurface water profile is linear and *the* average *infiltrated* depth *for the set* can be approximated as a *functions of* opportunity time at the mid-point *of the field*"(Shafique and Skogerboe, 1987; p.67). This concerns a first calibration of the empirical parameters of the modified Kostiakov equation:

$$Z = k\tau^a + f_o\tau$$

wherein: Z= cumulative infiltrated water depth (mm); τ = intake opportunity time (min); k=intake constant ($m^3/m/min^a$); a = exponent: and f_0 = final intake rate (mmlmin).

Data required for the analysis include:(a) amount of field water supply; (b) irrigation duration; (c) advance trajectory over time; and (d) recession over time. Figures 3 and 4 show the results of the advance and infiltration analysis, respectively. An increasing tendency is observed in the advance behavior and at the same time a decreasing tendency is observed for the infiltration behavior for the subsequent irrigation events. Differences from this observed tendency may occur, since the advance and infiltration are interrelated processes, which are subject to changes in the physical conditions as described earlier.

By irrigating a field for a certain time period, the main purpose is to meet the crop water requirement, which differs from event-to-event and depends on (i) the number of days between irrigation events; (ii) quantity of effective rainfall; (iii) 'actual evapotranspiration (ET,); and (iv) crop stage.

By applying a volume balance technique as suggested in Shafique and Skogerboe (1987), how long a field actually has to be irrigated compared to how long it was irrigated in order to meet the crop water requirement can be evaluated. Prior to this analysis for a particular event (a blocked surface system with a small slope, 1:1000), data have to be collected and analyzed on: (i) inflow rate; (ii) field geometry; (iii) irrigation duration; (iv) advance function; and (v) infiltration function. The shape factor (σ_z) for the sub-surface soil moisture profile is assumed to be 0.65. By calculating (i) the volume to be delivered; (ii) volume of surface water storage; and (iii) volume of water required, whether the time of cutoff is going to be less or more than the time of advance to cover the whole field area can be determined. The following formula is used:

$$t_{dif} = \frac{[V_{reqd} - (V_{surf})_{(t_a)_{x=L}}]}{Q}$$

wherein: t_{dif} = difference in time (min); V_{reqd}= required volume to be applied (m^3); $(V_{surf})_{(ta)\ x=L}$= volume of surface water storage corresponding to the time when the advance phase is completed (m^3); and Q = inflow rate (m^3/min).

Also,

$$t_{co} = (t_a)_{x=L} \pm t_{dif}$$

where: t_{co}=cutoff time (min); $(t_a)_{x=L}$ = advance time (min); and t_{dif} = difference in time (min)

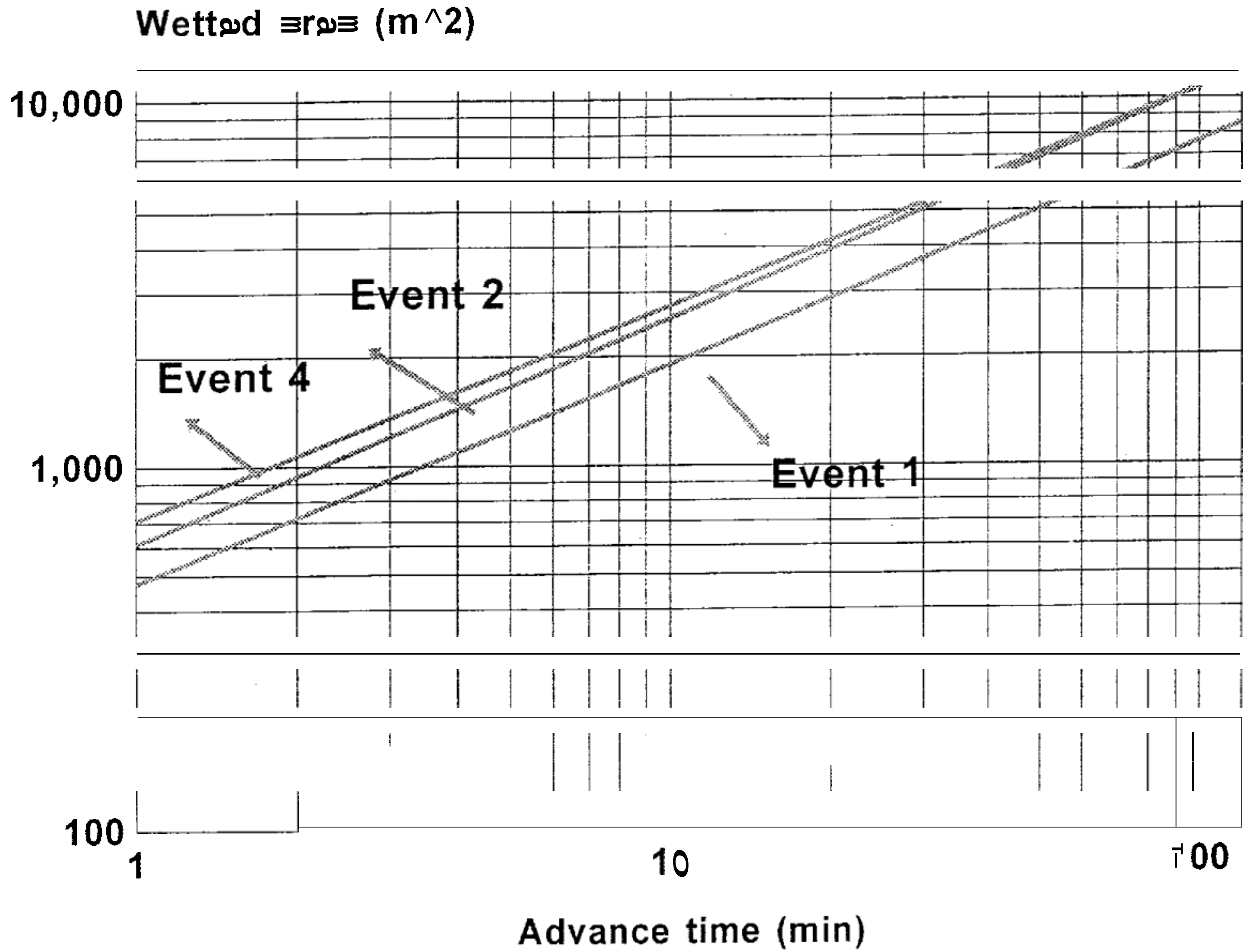

Figure 3: Advance Functions for a Basin Irrigation System.

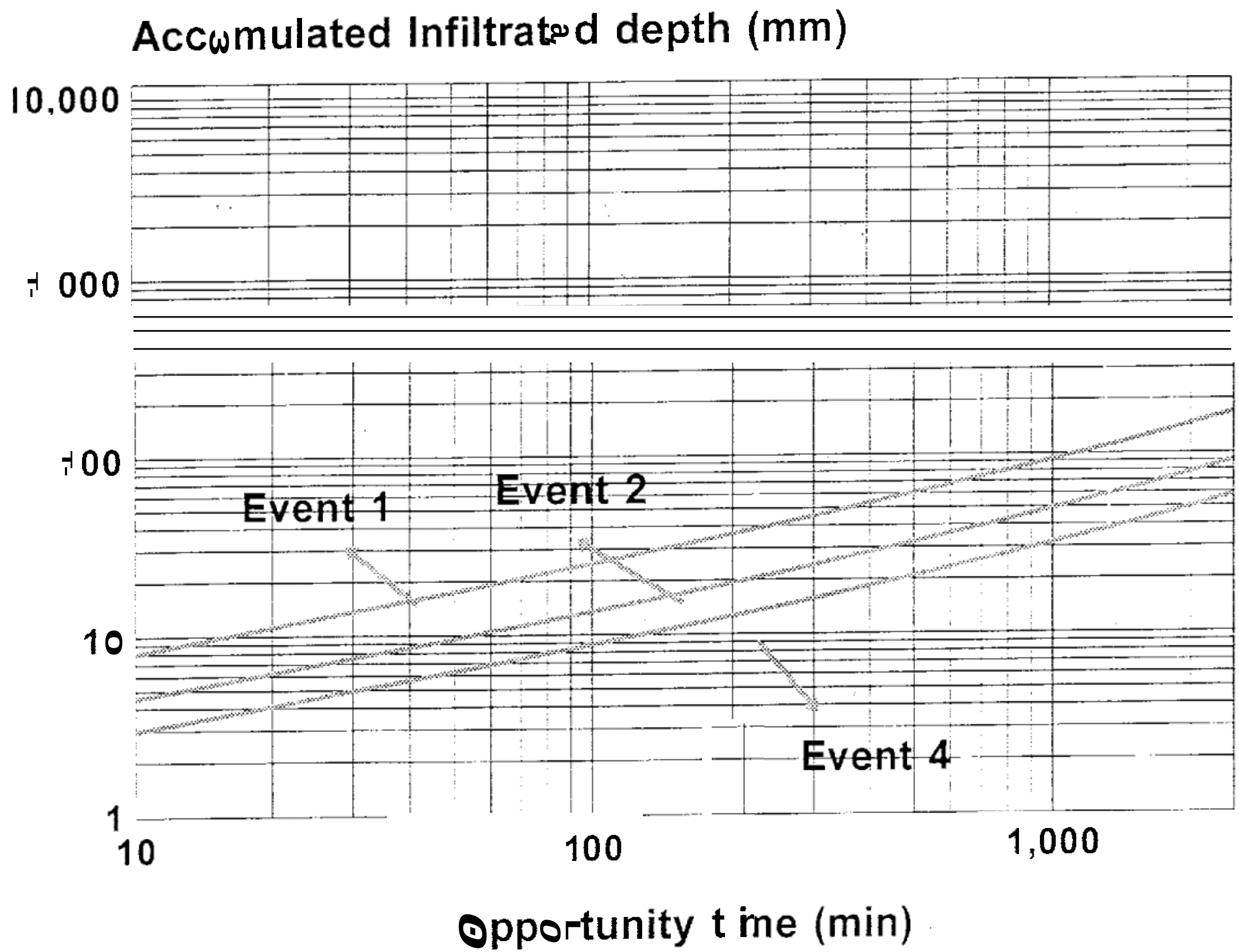

Figure 4: Infiltration Functions for a Basin Irrigation System.

Table 2 shows the results of this exercise. Observe that during the first and the second irrigation events, the irrigation duration was too long, respectively, by 94 and 17 minutes, whereas for the fourth irrigation event the irrigation was applied in too short of a time period by 44 minutes'. Based on these findings, the first and second irrigation events may lead to over-irrigation of the field and excessive water will percolate into the subsurface, whereas the fourth irrigation event may lead to under-irrigation according to the actual applied irrigation.

Table 2: Calculation of the cutoff time.

Cotton field	V_{inf} (m^3)	V_{in} (m^3)	V_{surf} (m^3)	V_{req} (m^3)	t_{dif} (min)	t_{co}(*calc*) (min)	t_{co}(*prac*) (min)
Event 1	145.3	907.5	762.2	499.3	- 37	78	172
Event 2	59.81	681.3	621.5	532.6	- 12	55	72
Event 4	38.60	388.5	349.9	499.3	21	86	42

- tco(calc) = calculated cu f time; tco(

. practiced soil moisture deficit for respectively events 1,2, and 4 are: 60 mrn. 64 mm and 60 mm.

Ongoing field observations showed that the general practice of a farmer is that the water supply to the field is cutoff when the advancing water front reaches the end of the field, without completely taking into consideration the changes in the above stated physical processes. However, field observations also showed that most of the farmer do not have sufficient access to information or means in order to gain insight into the relevant factors (available discharge, soil moisture deficit, advance behavior) for determining how long to irrigate. Basically, the farmer has experience in judging when to irrigate based on the crop conditions (leaves) and the soil condition (dryness), but it is not clear to them how long they should actually irrigate in order to meet the crop water requirement. These issues have to be further addressed in a detailed manner in order to provide the farmers with practical guidelines on how long to irrigate within the given constraints.

[9] For a conservative estimate, if the calculated t_{co} is less than $t_{a(x=L)}$, then $t_{co} = t_{a(x=L)}$

→How to irrigate (a future concern)?

Besides obtaining knowledge on when, how much and how long to irrigate, a link has to be established with how to manage the irrigation water (i.e. how the farmer has to operate the irrigation system at the farm). Insights into the above stated physical processes are crucial in order to practice good management of the irrigation water at the field level, along with an understanding of how to respond to the physical processes in terms of adjusting the design variables (unit flow rate, field or furrow geometry, and cutoff time) of a system has to be created.

In order to obtain insights into the management possibilities for different irrigation systems, mathematical models can facilitate this process. These models simulate the surface and subsurface irrigation process and assess, at the same time, the irrigation performance at the field level in terms of application efficiency, storage efficiency and distribution uniformity. Once a set of infiltration functions is calibrated for a whole season, and the crop water requirement is known for each irrigation event, these models can be used for prediction purposes. Basically, with these models, it is possible to develop a functional relationship between the design variables of an irrigation system. Furthermore, optimization techniques could be developed to determine ideal design and operational parameters.

IIMI's aim is, firstly, studying an existing model (SIRMOD[10]) and practically test its applicability for the existing systems in Pakistan. In a later stage, the target is to develop our own mathematical model for basin, as well as bed & furrow, irrigation methods. The main objectives are: (i) to develop operational and management strategies in conformity with the farmers who are using the traditional irrigation methods as well as for improved irrigation methods: and (ii) to transform the results into practical guidelines for the farmers on how to irrigate in order to obtain a more efficient use of the irrigation water and to increase crop production, taking into account environmental constraints.

A last note should be made on the inter-action between water delivery and irrigation scheduling as presented above. The farmers receive their share of water through a ***warabandi*** schedule, which implies that access to canal water is restricted to a certain time period per week. Additionally, research has shown that the canal

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[10] Surface Irrigation Model developed at Utah State University, U.S.A

water supply is considered to be variable in its amount and unreliable in its supply, Most of the farmers overcome this constraint by the use of tubewell water; however, this is often of lower quality. At this stage, it can be debated whether this insecurity of water availability and reliability has an impact on farmers' actual irrigation practices or not. However, the aim is to find solutions in how to facilitate the farmers in optimizing their use of irrigation water within the given constraints.

2.2 Improved Surface Irrigation Methods

This section describes the monitoring of improved surface irrigation methods. These methods include: (i) bed & furrows; and (ii) flat basins. The main purpose of the monitoring of two methods was to see if a change from basin to a bed & furrow system can enhance water control by the farmer in order to apply light irrigations and to maximize the number of bunded fields irrigated during each warabandi.

In this context, quantitative data were collected at the Tareen Farm during two cotton seasons, Kharif 1995 and Kharif 1996. At this farm, the fields are laser leveled and these are divided into plots of one hectare size. The bed & furrows are made with a special bed & furrow shaper which was designed and fabricated by a progressive farmer, Haji M. Arshad, from Khanpur. In case of flat basins, the earthening-up practice after the first or second irrigation event, converts them into a sort of shallow furrows. However, during irrigations the entire plot is covered with water just like a basin. In contrast; bed & furrow system does not have water flowing over the beds.

Two types of data were collected during two years: (i) total depth of irrigation water applied to each plot; and (ii) corresponding cotton yields. The main purpose of the exercise was to show the enhanced capability of farmers to apply light and frequent irrigations by switching from a basin to a bed & furrow system. This is particularly important for cases where the infiltration rate is quite low. The Tareen Farm did show such a phenomenon as the average surface intake rate during the first 4 hours was only about 1.4 cm/hr. A very low range of the temporal coefficient of variation (0.0 to 0.04) for the soil profile below 20-30 cm indicates even serious intake problems at the farm. Under these farm conditions, the enhanced capability has helped to increase the water use efficiency (Table 3).

Interestingly, during 1995, the average depth per irrigation for basins is 185 mm as compared with the case of bed & furrows where the average comes to 82 mm. However, this average has further dropped to 110 and 50 mm for basin and bed & furrow system, respectively, during 1996. Moreover, less use of water and increased yield per unit of area clearly favors the bed & furrow method for irrigating a cotton crop. Moreover, cotton fields monitored during 1996 by the officials of AgrEvo reveal that the virus attack in the case of bed & furrows was less severe (44-52%) as compared with basins (65-68 %).

Table 3. Monitored irrigations and cotton yields at the Tareen Farm near Lodharan.

Plot No.	Year	Irrigations	Water Depth Applied (mm)	Yield Kg/ha	Water Use Efficiency Kg/m^3
S4-2 (Bed & Furrows)	1995	6	532	2800	0.53
S4-3	1995	8	595	3291	0.55
S4-5 (Basin)	1995	4	750	2965	0.40
S4-6 (Basin)	1995	5	905	3133	0.35
S2-1 (Bed & Furrows)	1996	11	550	2076 (1st pick)	0.38
S2-2 (Bed & Furrows)	1996	12	630	2471 (1st Pick)	0.39
S2-3 (Basin)	1996	5	600	1383 (1st Pick)	0.25
S2-4 (Basin)	1996	7	700	1878 (1st Pick)	0.25

A survey was also conducted in another cotton growing area of Punjab *to* document the water savings achieved by switching from basins to a bed & furrow system. This qualitative assessment is based on the interviews of 13 out of 19 farmers who bought bed & furrow shapers from Khanpur. Two farmers said that there was no saving of water due to the bed & furrows as their un-leveled fields were irrigated like basins. The other 11 farmers said that their switch to a new system had saved them 30 *to* 50 percent of their water. As the cotton season is not yet over, no information about yields was obtained.

2.3 Quick Reclamation of Sodic / Saline-sodic Soils with Sweetwater Generator

In collaboration with Sweetwater Farming Inc., Utah; the Bahria Foundation and the Water Resource Research Institute, IIMI has tested a device, Sweetwater Generator, to amend sodic / saline-sodic water at the Malik Ghulam Hussain Farm near Hasilpur (Punjab). This event took place during October 1996.

This Farm is located at the tail of Fordwah distributary and seldom receives canal supplies (partial supplies around 50 % of the time only). Under the existing conditions, the owner of the farm is forced to use tubewell water, which is classified as unfit for irrigation because of the following chemical analysis: (i) total dissolved salts are more than 1800 ppm; (ii) Sodium Adsorption Ratio (SAR) is 13; and (iii) Residual Sodium Carbonate (RSC) is found to be around 8. Although the farm land is of lighter texture, sandy / sandy loam, the repeated use of bad quality tubewell water has resulted in sodium build-up. A soil analysis conducted by the Soil Survey of Pakistan shows that the Exchangeable Sodium Percentage (ESP) of the upper layer is 18 (SAR being 15.5) and EC is about 2 (sodic soil). The productivity of the farm has plunged to such a level that the farmer has almost gone bankrupt.

The Sweetwater Generator is used to burn sulphur for sulphur dioxide (SO_2) and this gas is mixed with water to get first sulphurous acid (H_2SO_3) and then sulfuric acid (H_2SO_4). This liquid of low pH value (2.4-2.9) is mixed with the low quality tubewell supply. In the case of Malik's farm, the pH value of the tubewell water was 8.1 on the test day, 18 October 1996. The pH of the liquid generated by the apparatus was found to be 2.9. After mixing with the tubewell supply, the pH became 6.9. Next, this treated water was applied to the field adjacent to a location from where samples were taken for the above stated chemical analysis.

Based on the SARs of the soil extracts, before and after the application of the treated water, Figure 5 shows a drastic reduction in sodium build-up in the soil. However, this reduction is more on the head-end as compared with middle and tail ends. On an average, the SAR for the entire field after the first irrigation is found to be around 5. A couple of more irrigations with treated water, while flushing with canal water when available, should help to reclaim the field fully.

IIMI in collaboration with the Sweetwater Farming Company intends to continue this reclamation support for one year at Malik's farm. During this period, a block of about 8 ha will be selected and during next two irrigation seasons, all of the important changes in response to the treated water applications will be monitored. There is also an expressed interest from the Company to demonstrate the use of the sweetwater generator for an entire command of Fordwah Distributary.

2.4 Conjunctive Use of Surface and Ground Water (Treated & Untreated) by Gravity and Pressurized Systems.

This is new study which is being undertaken by IIMI in Hasilpur in collaboration with national and international partners. At this stage, only the needed hardware is being installed. Once the basic arrangements are completed, IIMI's research staff located in Hasilpur will start collecting data to document the process and changes expected by the introduction of a package based on the conjunctive use of water from different sources and water application methods. This innovative irrigation practice aims to manage salinity in the root zone and achieve higher water use efficiencies.

In collaboration with the Punjab On-farm Water Management, Water Resource Research Institute, and Sweetwater Farming Company / Bahria Foundation, IIMI intends to have all required facilities in place by the end of the current year. The initial findings of the study will be available by the middle of next year.

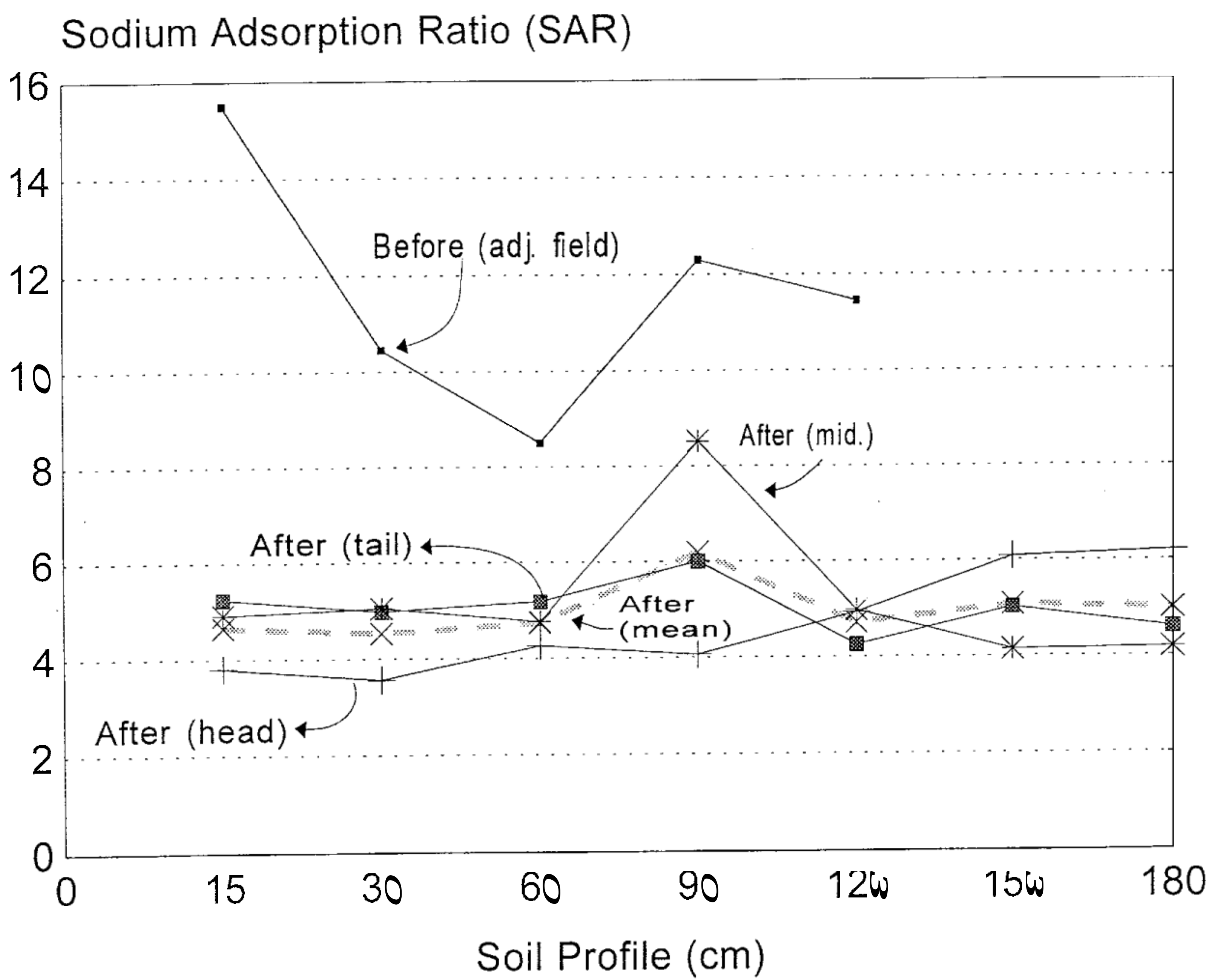

Figure 5. Change in SAR by using a sweetwater generator.

3. FUTURE CHALLENGES

3.1 Global / Effective vs. Local Efficiencies

Most of the irrigation improvement programs have been designed to improve generally low local irrigation efficiencies (E_i)[11] at the level of farms / fields. Such improvements are important for individual irrigators as they would like to be helped in managing their respective available water supplies in an efficient manner.

The concept is a useful tool for irrigation design and irrigation management (Keller & Keller, 1995). However, the concept of local irrigation efficiency does not help in understanding the status of irrigation water use at a larger scale as it ignores the contribution of return flows in its calculations. The irrigation water runoff and deep percolation are losses from individual fields, but may not be losses at a higher hydrological unit level . It is possible to divert surface runoff for reuse. Similarly, the deep percolation contributes to the underground aquifer and the groundwater can either be pumped for direct use, or it gradually moves back to the rivers and streams for downstream diversions (Heermann et al., 1995)

In order to account for the reuse of the return flows, a concept of global or effective irrigation efficiency (E_e)[12] is introduced by some irrigation management experts such as Dr. Jack Keller[13] and Dr. David Seckler[14]. As the new concept also

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11. Local Irrigation Efficiency (E_i) :

$$E_i = \frac{U_{ci}}{(1 - LR)\, V_D}$$

Where U_{ci} is the irrigation water consumed by crops, LR is the leaching requirement and V_D is the irrigation water delivered (Equation given by Keller & Keller. 1995)

12. Effective Irrigation Efficiency (E_e):

$$E_e = \frac{U_{ci}}{(1-LR_I)\, V_I - (1-LR_O)\, V_O}$$

where subscripts i 8 O denote inflow and outflow respectively for the terms already explained (Equation proposed by Keller 8 Keller. 1995)

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incorporates the reuse of the return flows, it is more suitable for formulating water allocation and transfer policies (Keller & Keller, 1995).

A major concern expressed about the proposed base for the freshwater resource planning and allocation decisions is the degradation of the return flows by the pickup of salts and other pollutants such as sewage water, industrial wastes, etc. Keller and Keller (1995) have included leaching requirements in the definition of E_e (Eq. 2) to control soil salinity, but the environmental and health concerns have yet to be addressed. Moreover, it would be very difficult and expensive to apply and ensure the degree *of* salinity control as suggested.

In a system which is government-managed, deep percolation and runoff from one supply component is a gain for the other when the underlying condition is not a salt sink. However, at a point when the irrigation supplies are turned over to a privately managed unit, the flows in any form going beyond the unit boundaries are a loss to the stakeholders of the unit. Deep percolation to the underlying aquifer with useable water quality can be recaptured, but it involves pumping costs for some who can afford, and a loss to others who cannot, or do not, do so.

Another hidden assumption (opinion of the authors) in the new concept is that the water distribution is executed as planned within a broader hydrological unit such as a river basin. Also, it alludes to conditions in which the resulting return flows will be distributed on an adequate, dependable and equitable basis for their reuse by the farmers. In other words, a selected system is operated as planned and hence the water resources planning and allocation decisions can safely be based on average values of a broader hydrological unit. However, all such conditions may, or may not, exist.

Therefore, a ***challenge*** for the researchers and the managers of the irrigated subsystem is *to* use both concepts with caution for design, irrigation management, water resource planning and water allocation within commands, regions and national boundaries. They need to give serious consideration to the old concept of water conservation at the field level as proclaimed by the scholars in favor of improving local irrigation efficiencies. At the same time, it seems appropriate to deal with concerns
4 raised about the productivity and cost of the reuse of water, as well as inequity due to water quality of the drainage water, when planning and allocation is based on using the effective or global efficiencies.

3.2 *Commercialization* of *Watercourse Improvement Programs*

Since the late seventies, extensive watercourse improvement programs are being implemented with huge public investments. Although the activities were initiated under the banner of either on-farm water management, like the one in Pakistan or irrigation improvement projects, such as in Egypt, the main thrust remained confined to the civil works related to the tertiary subsystems.

Perhaps in the beginning it was a proper strategy to put more emphasis on the ***hardware*** improvements as a main vehicle to create awareness and interest in the ***soffware componenf*** of the on-farm water management. In the case of Pakistan, for example, after following the hardware-oriented approach for the last two decades or so, the concerned entities now need to change. Any further delay in this context may endanger the survival of the on-farm water management program itself.

There is a ***challenge*** for the researchers and the managers in the irrigated sector to help their respective agencies to move out of the ***'hardware business*** to provide more time and resources to mend the ***software*** side for the sustainability of the programs.

Many countries, sooner than later, will find it extremely difficult to keep funding the civil works under the watercourse improvement programs forever. One way to reduce the financial burden would be to switch from the opted ***supply mode*** to an appropriate ***demand mode*** which may even improve the effectiveness of the physical improvements.

From one locality to another, the proposed switch may require different strategies to make the watercourse improvement programs sustainable. One option could be to find ways and means to commercialize these programs. For example, there is a good possibility to test the idea in Pakistan because of the following reasons: (i) the physical improvement program for watercourses has reached a mature stage; (ii) there seems to be a good demand created for the improvements; (iii) about a dozen private commercial outfits are already manufacturing and selling pre-cast lining and control structures to the farmers and to the relevant government agencies; and (iv) the financial sustainability for the continuation of the activity in the current mode is a major concern. Perhaps, by channeling the existing subsidies with a phase-out plan, the stated enterprises may help to make the watercourse improvement program a demand-driven commercial activity.

3.3 Commercialization of Precision Land Levelling Programs

Keeping the land level is a major concern for the farmers. It is a basic need at the field level to avoid over or under irrigation due to the micro ground surface undulations. Even without any outside support, this happens to be a routine activity undertaken by the farmers within the confines of their known skills and facilities. Such an irrigation facilitating practice points to a built-in demand for land leveling on a regular basis.

In view of the demand, many irrigated countries like Pakistan and Egypt initiated land leveling programs. However, these efforts did not achieve a desired degree of success. For example, in Pakistan, in spite of the provision of incentives such as sound facilities, skills and subsidies, the precision land leveling programs in the public sector had a hard time to sell themselves. Reasons for the **"cool *reception*"** given by the farmers to a subsidized facility, for which they have a felt need, are difficult to pinpoint. But these reasons can only be speculated as follows: (i) the time-interval required for land leveling was too long to be adjusted within a short period available between two crops; (ii) complaints about the quality of the job undertaken; (iii) lack of incentives, both positive and negative, to accomplish quality work; (iv) not enough effort directed to adapt the precision land leveling technology for small land holdings; (v) the activity was also conducted to reshape fields without giving due consideration to the boundaries as per revenue records; and (vi) hardly any effort was made to make the service cost-effective and within the financial reach of the small farmers.

In the case of Pakistan, there is no need to create a demand for land leveling; it already exists as a regular on-farm practice. However, a real **challenge** for the researchers and the field managers is to **cap** the demand effectively. Perhaps there will be a need to have two packages of this service; one for small farmers and the other for large farmers. For small farmers, it may help if only practical technical services about ***cuts and* fills** are provided to enhance the accuracy of the traditional land leveling practice, On the other hand, the large land holders may require quick and quality service with appropriate means, like access to laser technology for land leveling.

Based on past experience, it seems that the **official** approach adopted for land leveling has to be adjusted; it may help to commercialize the operation. The relevant agencies and donors can play a pivotal role by promoting this idea in order to make it happen, In the beginning, the local government agencies could provide subsidies, technical assistance and training to a number of private groups to initiate the process.

However, the support should be withdrawn in stages as the private groups are strengthened enough to take up !he challenge on their own.

In Pakistan, it is encouraging to know that the private sector, about a half dozen companies, has already been actively involved in inanufacturing the land leveling equipment such as scrapers and planers. More recently, two private firms have started producing laser equipment to facilitate land leveling operations. When the stated capacity is coupled with the availability of hundreds of private tractor and machinery owners who sell their services for other field operations regularly, the proposed commercialization of the land leveling operations becomes an accomplishable *target.*

3.4 Necessitating Flow Measuring by the Farmers

There are no two opinions about the necessity of flow measurements; it is a basic requirement for irrigation water management. For improving the water delivery. application, use and disposal subsystems, the available quantity of water must be known.

However, in many irrigated countries, most of the above stated operations at different levels of the main system are conducted based on experience and adjusted based on complaints and influence only. At the field level, it is also the experience of different individuals which determines the way irrigation water is utilized.

But the management of irrigation operations without the measurement of flows can not be generalized for each and every case: there are a number of exceptions too. For example, the farmers in the Lower Severe Valley in the USA have installed their own flow measuring devices to counter-verify the flows measured by their own elected irrigation company near the delivery points.

However, the above quoted case is such that the flow measurement is unavoidable as the farmers' shares are based on volumes. Other factors such as large holding sizes, commercial orientation, and education level of the farmers make flow measurements a normal activity. In spite of the other factors, the main fact remains that there should be a built-in necessity for flow measurements. So, the ***challenge*** for the researchers and field managers is to come up with innovative ways and means to create such conditions which make flow measurement a necessary and feasible practice

3.5 Applied Research in Irrigation

Over the past two decades or so, a tremendous amount of basic research in the field of irrigation has been conducted. Amazing mathematical tools have been reported which can facilitate the planning of operation and maintenance activities in the main irrigation system. At the field level, the research findings are extremely helpful in managing the surface and ground water supply, as well as the application, use and disposal components of the on-farm subsystem. Even in the case of surface irrigation methods, it is now possible to estimate the resulting irrigation efficiencies within the existing conditions, or to create conditions for achieving an acceptable level of irrigation performance at the field level.

However, progress towards the application of the irrigation research findings is not very encouraging. Generally, the research community is not found very eager to test the basic research findings for their field applicability. The lack of interest is not surprising as the applied research does not earn the same credit when compared with the basic research. As a result of the stated apathy, the findings of the basic research do not get translated for the benefit of the end-users.

Agencies like the International Irrigation Management Institute (IIMI) are undertaking applied research. For example, IIMI in Sri Lanka and Pakistan is field testing a set of decision support systems (DSS) for planning and operation of two main canal systems. IIMI in Pakistan also plans to apply mathematical tools to improve irrigation practices at the field level.

In spite of the limited but serious initiative taken by IIMI and others to improve on-farm irrigation practices, there is lot more to do. A ***challenge*** awaits for the researchers to conduct applied research at the field level in the areas which may address issues like those listed below:

a) Application of mathematical models to predict or estimate adjustments needed to improve on-farm irrigation practices;

b) Testing of management innovations to control excessive deep percolation at the time of soaking and a couple of early irrigation events:

c) Methodology for surface irrigation scheduling which should also provide information about the time required to irrigate a field with the right quantity, at the right time, within a given set of field conditions (Shafique and Skogerboe, 1987);

d) Preparation of guidelines for the conjunctive use of surface water, groundwater and drainage water at the field level;

e) Development of appropriate irrigation technology which may include the following ideas: (i) for the brackish groundwater zones with an upper thin layer being of relatively acceptable quality, use of fractional skimming wells or application of multi-strainer shallow wells; (ii) trying of low pressure irrigation application methods; and (iii) testing of new irrigation water measuring techniques for pressurized flow (tubewells) and flat gradient open channel flow at the farm level;

f) Application of on-farm surface and subsurface drainage; and

g) Institutional arrangements required for improved irrigation water use below the canal outlets.

3.6 Irrigation Advisory Service (IAS)

Practical and user-friendly on-farm irrigation water management techniques can be developed, but their field adoption will require appropriate disseminating arrangements. Such a need will be met essentially by providing irrigation advisory services at the farm level.

For example, an irrigation advisory service is being established in Egypt within selected commands of the irrigation improvement projects. However, the scope and capacity of the institutional arrangement is limited; it is mainly confined to organizing farmers at the tertiary level and provide assistance in managing the finances of these groups. However, there is a common concern in the Ministry of Public Works and Water Resources (MPWWR) about the future role and perhaps justifications after the completion of civil works related to single point water-lifting arrangements at the tertiary canal level. It is feared that if the role of the service is not reviewed, this unit may become dysfunctional as has happened with the water users' associations in Pakistan after the completion of watercourse improvements.

Another concern relates to the location of such an irrigation advisory unit, One ***easy*** solution is to let the government provide the service. However, it is a costly option for a public sector to shoulder, while the lack of cooperation between relevant agencies makes the choice difficult to make. Moreover, when a decision is made to pick one agency, others refuse to cooperate. For example, IAS in Egypt is located in the MPWWR and the existing lack of cooperation between the MPWWR and the Ministry of Agriculture and Land Reclamation (MOALR) does not help the effectiveness and usefulness of the service.

Possibly, such a service could be located with a neutral outfit, or non-governmental organizations (NGOs). However, such groups in the choice area are almost non-existent in most of the irrigated countries. Perhaps, the idea could be tried to gauge the level of interest in the NGOs' domain.

Another option in the context of Pakistan is to make use of the agricultural input ***vendors*** to take up the assignment as a bonus to attract customers. However, in this case, public agencies will have to provide training, materials and support (incentives) to institutionalize the service. As these dealers are located everywhere in the country, the mechanism provides an excellent cost-effective network to test the implementation of the model. Of course, it is going to be a real ***challenge*** for the researchers and public sector to devise an effective irrigation advisory service.

3.7 Sustainable Farmers' Participation

Farmers' participation in the operation and maintenance of the on-farm irrigation subsystem is crucial. Obviously, this requires a group action which is conventionally secured by organizing farmers on a formal or informal basis.

Informal group action is for a specific purpose, which is usually built around a felt need by the farmers themselves. Examples in this context are the regular cleaning of watercourses and the fixing *of* irrigation schedules (warabandi) by the farmers in India and Pakistan, Such an informal collective arrangement still works and ensures farmers' participation on a sustainable basis.

In general, farmers have also been 'organized on a formal basis to secure ***farmers' support*** for implementing certain on-farm activities. As it is obvious from the water users' associations organized in Pakistan and Egypt, these groups were ***designed*** to provide only ***support*** to a public agency in implementing a specific improvement activity; there appears to be no real intention to ensure farmers' participation by incorporating their clear role in planning, design, construction and management of an improvement activity. Consequently, with the completion of an improvement activity, like watercourse lining. the need for farmers' support faded and so did the need to keep the water users' associations functional. This might be one important reason for having dysfunctional water users' associations in Pakistan.

Although the water users' associations in Egypt were also intended to seek support from the farmers to improve tertiary channels (mesqas), the built-in single-point pumping requirement in the mesqa improvement is keeping the groups functional. Perhaps, it is this day-to-day operational interdependence which may keep the farmers' organizations working. Likewise, initial positive reports about the sustained functioning of tubewell committees established under a community-well program might have been helped by a similar operational interdependence. In both cases, the farmers have an active role in the operation and maintenance of the water lifting systems.

In order to achieve positive impact by improving irrigation practices below the canal outlet, farmers have to act together. A few individual actions in this context may not suffice. However, it is a ***challenge*** for social scientists and community organizers to suggest models which create conditions and an environment suitable for seeking sustainable farmers' participation and collective actions.

3.8 Accountability

The irrigation system in Pakistan is designed to deliver a constant amount of water to the end users. But the fact is that the water delivered is not constant and often it is much less than the designed / authorized amounts. For example, a distributary at the lower-end of the Gugera canal system deiivered 50 % and 70 % of the designed supply during Rabi and Kharif seasons from 1989 to 1991, respectively (Latif, 1995). Under the present conditions, no one is held accountable for not delivering the authorized supplies to the users.

3.9 Addressing Environmental and Health Concerns

That irrigation development has created environmental and health problems has long been acknowledged. These concerns are listed as follows: (i) waterlogging and salinization; (ii) disposal of the drainage effluent; (iii) water quality concerns due to the disposal/mixing of sewage and industrial waste in the irrigation and drainage systems and irrigation return flows; and (iii) diseases such as malaria, river blindness and bilharzia.

For the most part, the above stated concerns stem from the low irrigation efficiencies and inappropriate irrigation practices at the farm level. Therefore, the future **challenge** for the researchers and the managers of the irrigated sector is to improve irrigation efficiencies by introducing appropriate irrigation practices at the farm level.

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