OPTIMIZING WATER USE
THROUGH ALTERNATIVE TECHNOLOGIES
AND CROPPING PATTERNS

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Abstract

Irrigated agriculture provides 90% of the total wheat production of the country and almost 100% of cotton, sugarcane, rice, fruits and vegetables mainly within the Indus basin command area. Irrigation also plays a vital role in the industrialization process of Pakistan with the production of cash crops and dairy cattle. The irrigated area has increased from 9.1 million hectares in 1947 to about 18 million hectares in 1998. The doubling in irrigated area in 50 years is a major factor in increasing agricultural productions in the country. Coupled with increases in cropping intensity of 60% in 1947 to 120% in 1998 provided a 4 fold increase in production compared to 1947. The increase in productivity due to Green Revolution was primarily due to the improved seed, use of chemical fertilizers and increased water supply. The increase in productivity of major cereal crops like wheat, rice and maize was almost 100% in the last 50 years. This increase in productivity was due to the Green Revolution and improved agricultural water management including the precision land leveling and efficient irrigation methods. The border and furrow irrigation provide more efficient options compared to basin irrigation. Because precision land leveling under 0% slope is costly as an initial cost and rather it is much more difficult to maintain the level within the existing availability of the tillage machinery. Local manufacturing of sprinkler and drip irrigation systems' components helped to reduce the cost and easy availability of spare parts. With a population of 132 million today, that is expected to reach 171 million by the year 2010, the demand for food products is expected to continue to grow. The problems associated with irrigation system are the main cause for low productivity in agriculture because of water scarcity, in-efficiency, inequity and sustainability issues. There have been advances in improving cropping patterns by adding high value horticultural crops. The area under these crops has increased significantly during the last 50 years. The paper highlighted the achievements made during the last 50 years while addressing these issues. The major unresolved issues were identified which still require technological development, managerial and institutional reforms and mechanisms to attain sustainability of irrigated agriculture. There is a need to initiate comprehensive planning and integrated development and management of irrigated agriculture in the country. The information of predicted crop water requirements, rainfall probability and forecasting of extreme events like droughts and floods should be printed daily in the newspapers or forecasted on radio and television to meet seasonal and weekly requirements of the farmers.

1. Introduction

The importance of the agriculture sector in the economy of Pakistan can be viewed from the factor that it contributes 25% to the gross domestic product of the country and provides job opportunities for 55% of the labor force. It also accounts for 80% of the total export earnings of the country (GOP 1998a). Within the agriculture sector, irrigation plays a predominant role as it provides 90% of the total wheat production of the country and almost 100% of cotton, sugarcane, rice, fruits and vegetables mainly within 16.4 million hectares of the Indus basin. Also, the irrigated agriculture plays a major role in the industrialization process of Pakistan with the production of cash crops (cotton, sugarcane, citrus, mango) and dairy cattle.

During the 60s and 70s, the country benefited from technological development of the Green Revolution through improvements in self-reliance of agriculture and food products due to significant increases in cropping intensities and crop yields. Later during the 80s, the agricultural water management programs in the country also contributed
towards increase in agricultural productivity and productions. In the last 50 years, the productivity was almost doubled mainly due to the Green Revolution and the improved agricultural water management. This was very much true for the cereal crops like wheat, rice and Kharif maize where yields were doubled (GOP 1998b).

The irrigated area has increased from 9.1 million hectares in 1947 to about 18 million hectares in 1998 (GOP 1998b). This doubling in irrigated area in 50 years is a major factor in increasing agricultural productivity and productions. Coupled with increase in cropping intensity of 60% in 1947 to 120% in 1998 provided a 4 fold increase in production compared to 1947 level of productivity. This four-fold increase was mainly due to increase in water availability from both surface and groundwater sources. This is a sufficient indicator that water contributed more than the Green Revolution for enhancing production and productivity of the irrigated agriculture in the country.

By the end of 80s, several signals suggested that the period of agricultural output growth was over, with the productivity per unit of land of the main crops becoming stagnant or even following a decreasing trend (GOP 1998b; World Bank 1994; Bandaragoda and Firdousi 1992).

With a population estimated at more than 132 million inhabitants today, which is expected to reach 171 million by the year 2010, the demand for food products is expected to continue to grow. Thus, unless there are significant improvements in agricultural productivity and total production at least in the same order of magnitude as those recorded during the Green Revolution period. The imbalance between supply and demand of basic agricultural goods is expected to increase in the future which will threaten the self-reliance objective of Pakistan.

The problems associated with irrigation system and availability of non-water inputs are the main cause for low productivity of the Indus basin. Although, the benefits of irrigation per unit area are fully recognized under the arid environment of Pakistan, as little would grow without irrigation. Yet the irrigation sector has become increasingly the target of criticisms and considered as the main cause for productivity problems in agriculture because of water scarcity, in-efficiency, in-equity and sustainability issues. The challenges confronted by the irrigated agriculture are:

- surface water resources are inadequate to meet the requirement of agricultural water use;
- canal water distribution is not equitable due to increased competition for scarce freshwater resources and associated problems with the age-old Warabandi system – a system of time equity;
- water allocation to different canal commands is based on design rules but requires adjustments because of recent groundwater exploitation in terms of quantity and quality;
- measurement of canal flows, communication and processing requires to build irrigation operational management information considering the country and site-specific requirement;
- inefficient water use at the farm level in terms of land, water, labor and time;
- lack of indigenization and effective demonstrations for alternative irrigation technologies and profitable cropping patterns; and
- viability of land and water resources and high prices of energy for pumping
water are the major threats for sustainability of irrigated agriculture.

The paper is based on review of past achievements in irrigated agriculture during the 20th century and outlines the major issues, which have to be targeted in the 21st century. Therefore, this paper is an effort to provide basis for building vision for 2010.

2. Achievements

A review of achievements in agricultural water use during the 20th century was conducted considering seven major thrust areas: a) water availability; b) alternative water use technologies; c) control of salinity and waterlogging; d) rising cost of water; e) alternative cropping patterns; f) optimizing productivity and returns; and g) self sufficiency. The effort made in this paper is just a beginning and has to be further strengthened by adding additional information. Because such an effort requires much more time to reach to a point leading towards identification of real-issues which have to be addressed in the next century.

2.1. Water Availability

2.1.1. Surface Water

The main source of water is the Indus basin irrigation system, one of the largest and oldest contiguous systems in the world. It consists of the river Indus, its eastern tributaries of the Jhelum, Chenab, Ravi, and Sutlej, and the northern and western tributaries of the Kabul, Swat, Haro, and Soan. The use of Indus waters is governed by two major political agreements, the Indus Water Treaty 1960, between India and Pakistan, and more recently the Water Apportionment Accord 1991, between the four provinces of Pakistan.

The system fed by glacier and snowmelt and rainfall primarily outside the Indus plains, records average annual flows of about 171 billion m$^3$ (WSIPS 1990). However, the flows exhibit considerable variation, both annually and seasonally. The annual flows range between 231 billion m$^3$ in 1959-60 and 124 billion m$^3$ in 1974-75, and the average Kharif flow of 142 billion m$^3$ is over five times the average Rabi flow of 27 billion m$^3$ (Ahmad 1989; Mohtadullah et al. 1990).

The Indus system includes three main artificial reservoirs at Mangla, Tarbela, and Chashma with original total live storage capacity of 19 billion m$^3$, which has reduced to 16 million m$^3$ in 1998.

2.1.2. Groundwater

Although the existence of groundwater does not increase total water availability, it is an important mechanism for delivering water to farmer under a flexible system of operation – on demand. A vast aquifer of variable quality exists under the Indus plain, recharged by natural precipitation and river flows and becoming increasingly saline the farther it is from recharge sources. It is harnessed through tubewells, open wells, and Karezes. There are around 484,000 tubewells in the country, pumping about 48 billion m$^3$ (GOP 1998b).

Thus, of the total annual recharge of approximately of 60 billion m$^3$, less than 4 billion m$^3$ of unutilized recharge is available to contribute to rising water-table mainly in
areas of saline groundwater that is not drawn down by tubewells.

2.1.3. Water Availability Picture

Based on 52 years (1936-88) of historic data the average inflow of western rivers amounted to 171 billion m$^3$ (WSIPS 1990). The Water Apportionment Accord assumes a total allocable supply of 141 billion m$^3$, which is 12 billion m$^3$ higher than existing canal withdrawals. This increase is based on the assumption that the outflow into the delta can be reduced from its current average level of 25-31 billion m$^3$ to about 12 billion m$^3$. However, the precise magnitude of the necessary outflow has been left open for the time being, subject to further research and analysis. Detailed studies are to be commissioned on the needs of the delta in general and the coastal mangroves in particular. At the moment, the only available study on the subject is by Meynell (1991), which shows that the system needs may be greater rather than smaller than the assumed benchmark of 12 billion m$^3$. Another unpublished study recently conducted by the NDC indicates that water needs of mangroves are much less than expected as major parts of the plantations are along the coastal areas instead of the delta region. This controversy has to be resolved by initiating joint studies by consultants, research institutions and the line departments.

The low irrigation efficiency of the Indus basin of only 34 percent means that 66% of water diverted to the canal system is not available for crop consumptive requirement (Ahmad 1990). Canal water supplies are highly inequitable, variable and unreliable (Bhutta and Vander Velde 1992; Kuper and Kijne 1993; Ahmad 1993a; Vander Velde 1990). The operational performance of the public tubewells is poor, which results into utilization rates and discharges lower than the designed level (Malik and Strosser 1994). Poor maintenance, lack of implementation of operational rules and inappropriate information system are the major reasons reflecting the poor performance of the irrigation system. In addition to this, the local preference by operators that increase downstream variability, and interference by notables in the operation of the irrigation system, or lack of interest by the department staff in improved operational management are reasons explaining the poor performance of the irrigation system. These factors contribute in widening the inequity between head and tail reaches.

Ahmad and Khan (1990) presented results of watercourse conveyance efficiency of 84, 65 and 54% at the head, middle and tail, respectively for long watercourses of SCARP areas. This is a good indicator of inequity in water availability at the farm level and thus demands to review the concept of Warabandi, which is based on time equity instead of volume equity. The situation becomes worst for the tail-end reaches of the canal, distributary and watercourse. In-equity also exists at the secondary canal (Tareen et al. 1996).

2.2. Water Use Technologies

2.2.1. Irrigation Efficiency

Irrigation efficiency in this paper is referred to the ratio of the volume of water
required for a specific beneficial use as compared to the volume of water delivered for this purpose. This is commonly interpreted as the volume of water stored in the soil for evapotranspiration compared to the volume of water delivered for this purpose, but may be defined and used in different ways (Jensen et al. 1990). The recent concept of global efficiency put forward by IIMI is not adopted in this paper because of serious concerns of its application under site-specific limitations (rights, quantity and quality). This school of thought yet has to prove practical application of this definition.

2.2.1. Canal Conveyance Losses

The Indus basin irrigation system constitutes main canals, branch canals, distributary canals, minor canals and watercourses. There have been a number of studies conducted in the past to estimate conveyance losses of earthen canals. The review of over a dozen studies conducted by various institutions revealed that conveyance losses in main canals and branches varied between 15-30% (Ahmad 1993b). The earlier studies conducted by Kenedy, Benton, Higham, Blench and Khangar indicated losses on the lower range of 15-20%, whereas studies conducted by various consultants indicated losses in the range of 20-30% (Harza 1963; IACA 1966; LIP 1966). The later studies conducted primarily by the WAPDA indicated an average annual canal losses of 23, 12 and 20% for the canal commands of the Punjab, NWFP and Sindh provinces, respectively. On basin-wide, these losses are around 21% (WSIPS 1990; Siddique, et al. 1993; IWASRI 1993; Shahid et al. 1996).

2.2.2. Watercourse Conveyance Losses

The conveyance loss measurement studies for the tertiary system namely watercourse were initiated during earlier periods of system development by Kenedy, Benton and Blench which were 27-29% (Hunting Technical Services 1965). The systematic work on watercourse operational loss measurement was initiated jointly by the Colorado State University and the WAPDA (Ashraf et al. 1977). On the basis of two systematic studies of 40 and 61 watercourses, the actual watercourse operational losses were 47 and 45%, respectively. Which were higher than earlier studies and especially from the 10% loss reported by the Punjab Irrigation Department based on seepage losses in watercourse sections constructed at the research institute instead of farmers’ watercourses. The actual conveyance loss includes all the operational losses along with the seepage loss (PARC-FAO 1982; WAPDA 1979; Ashraf et al. 1977). In these studies, the watercourses were selected under perennial and non-perennial canal commands covering all the four provinces.

Ahmad and Khan (1990) developed an approach based on the Warabandi schedules where they have used the loss rate function developed by Trout and Kemper (1980). The average watercourse losses were around 32% over the watercourse length during a particular rotation schedule. The average watercourse losses were 16, 35 and 46% at the head, middle and tail end reaches, respectively. The study revealed that watercourse losses as presented by WAPDA (1979) and Ashraf et al. (1977) represent the total watercourse length especially the tail-end reaches, which are higher than the average water losses in relation to the Warabandi schedule.

2.2.3. Field Application Losses

The field application losses measured under 40 watercourses and 61 watercourses
studies were 50 and 30% under both the perennial and non-perennial systems, respectively. The acceptable figure on basin-wide is 25% as most of farmers are practicing deficit irrigation (PARC-FAO 1982; WAPDA 1979). The recent studies conducted in the Chabba distributary of Lower Jhelum canal indicated field application losses of 30%. This is a confirmation of the previous results (Cheena and Piracha 1993).

The application losses indicated that the application efficiency at the field level is around 75%. This is mainly due to the unveled fields and un-scheduled irrigation without considering the surface irrigation hydraulics. Although, precision land leveling support is being provided to the farmers even using the laser leveling machinery which is the state-of-the-art, because farmers’ are facing difficulty to maintain the levelness within the available tillage machinery. The concept of precision land leveling needs rethinking.

2.2.4. Surface Irrigation Methods to Improve Application Efficiency

**Basin and Border Irrigation:** In Pakistan basin irrigation is practiced in fields which are not precisely leveled and thus application and uniformity efficiency is low (Ali et al. 1993). The precision land leveling started under the On-Farm Water Management Program helped to improve application of water but this practice could not be linked with selection of appropriate irrigation method. Border irrigation is more efficient than basin and requires little or no precise leveling. Stream size, width of border, length of border and infiltration is the parameters while designing the irrigation method. The larger stream size of 2-3 lps per meter performed better than 1 lps per meter. The application efficiency of level borders is higher than level basins (Ali et al. 1993; Piracha et al. 1989).

The level borders provide an opportunity to adjust the width of the field considering the available stream size. Normally farmers are not willing to adjust the length of the field. Therefore, in the design of the irrigation system unit discharge is considered in relation to the available stream size to select the width of the border. The leveling requirement of borders is less than the level basins as slope in the direction of flow can be an added advantage to reduce the advance time.

**Furrow Irrigation and Bed Planting:** The planting of cotton on broadbeds with row to row spacing of 75 cm resulted in 30-35% increase in yield compared to flat planting. This increase in yield was also accompanied with savings in water of 28%, 40-45% and 40-45% under furrow, alternate furrow and furrow-bed irrigation compared to basin irrigation (PARC-FAO 1982). These results were further verified by PARC, IIMI, LIM and UAF under a number of studies conducted during the 90s (Berkhout 1997; Javaid and Khoso 1991; Rafiq and Qureshi 1991; Javaid et al. 1988).

The Kahlown et al. (1998) presented results of improved methods of irrigation for cotton under varying water-table depths. Savings in water applied using furrow-bed method compared to basin irrigation were 61, 60 and 59 percent at water-table depths of 0-1, 1-2 and 2-3 m, respectively. For wheat crop, the maximum water saving of 68 percent was achieved with 120 cm bed at a water-table depth of 0-1 m. The furrow-bed system is most suitable for all conditions of water-table depths. It also helps to reduce leaching of nitrates and thus increase the fertilizer use efficiency.

The furrow irrigation not only provides saving in water but also reduce the requirement of leveling which is a pre-requisite in basin irrigation. Therefore, one of the
efficient alternative surface irrigation systems is furrow-bed to save irrigation water and to provide environment conducive for crop growth especially during the monsoon season. The furrows also help to drain excess rainwater. The standing water coupled with high temperature affect the summer crops adversely.

The cost of planting in bed is higher than flat planting in basin. Thus, there is a need to initiate studies on permanent furrow-bed system compared to temporary system in conjunction with nature farming to enhance macro/micro-organisms in soils.

### 2.2.5. Pressurized Irrigation Methods to Improve Application Efficiency

The pressurized irrigation systems are defined as systems, which require pressure of more than one atmosphere to apply water. These systems require pressure ranging from 20-100 psi and include whole range of sprinkler and trickle irrigation systems or associated adaptations.

**Sprinkler Irrigation:** Sprinkler irrigation is feasible in Pakistan. The potential introduction requires indigenization of the system and local manufacturing to reduce the cost. The WRRI-NARC selected two rain gun sprinkler models, which are now being manufactured in collaboration with the local industry. The high-pressure pumps are produced locally. These can be coupled with locally produced electric and diesel prime movers (Ahmad et al. 1993). The UV stabilized and black carbon polyethylene pipes are produced locally for conveyance of pressurized water. These pipes are normally less than 50% of the cost of galvanized iron and can be used on surface or under buried conditions. The local pump industry is now producing the complete system at a cost of around Rs. 10,000 per acre for systems not less than 5 acres.

Field experiments on supplemental irrigation in Barani lands on wheat crop using sprinkler irrigation indicated that crop can be planted on time by applying a minor irrigation of only 10 mm as Rauni. The application of Rauni and plantation of wheat in early November doubled the yield of wheat compared to Barani plantation. The Rauni irrigation increases the crop stand in addition to early planting. Further irrigation to wheat during dry spells can increase the yield to 3 fold. The Barani yields are around 1.0 tonne/ha in an average year (Ahmad et al. 1999).

Center-pivot sprinkler irrigation system is the most efficient system for irrigation, fertigation and chemigation of crops especially where the size of the farm is not less than 100 acres. The technologies for one-span center-pivot sprinkler irrigation system has been indigenized in collaboration with the private sector, the M/S Hydrotech Farms and Engineering Services (WRRI 1996). Now the local production of first 100 acres unit in Pakistan is being manufactured in collaboration with the Ministry of Science and Technology.

**Trickle Irrigation:** The WRRI-NARC further worked with the plastic industry to indigenize the trickle irrigation systems in Pakistan. The system components including emitters, connections, filters, laterals, manifolds, mainline and fertilizer injectors are all locally produced and the cost is around Rs. 12,000 per acre excluding the pumping system (Moshabbir et al. 1993; Ahmad 1999). The cost per acre is given based on 1999 price levels.

**Salinity Management:** In the context of a fixed and short water supply system of the Indus
basin, the challenge of the enhanced productivity can only be met by improving productivity of irrigation water supplied. It means we have to use our limited water resource optimally. During the initial crop growth period, water uptake by the plants is lower as compared to that at the later stages. Such low requirements are quite difficult to be applied by flooding the usual way adopted in Pakistan. However, this purpose can be attained by use of a pressurized irrigation system. Moreover, adoption of pressurized irrigation practices can help to manage root-zone salinity especially in sodic soils (Ahmad et al. 1996; Ahmad 1999).

The management of groundwater salinity is also needed as the larger discharge tubewells are redistributing the salts in the groundwater profile. In most parts of the basin, shallow freshwater is underlain by the poor quality groundwater. Therefore, skimming wells are needed to pump the freshwater without disturbing the poor quality groundwater. The low discharge skimming wells require systems like sprinkler and drip irrigation to apply small amount of water efficiently and effectively.

### 2.2.6. Crop Water Requirement

Consumptive use of water, or evapotranspiration ($E_t$) is one of the most basic components of the hydrological cycle. Consumptive use, which includes evaporation of water from land and water surfaces and transpiration by vegetation, continues to be of foremost importance in water resources planning and management and in irrigation development. As the water retained in plant tissues is minor relative to the amount used in $E_t$, both the terms are used for same meaning (Jensen et al. 1990).

Consumptive use of water information is necessary in planning and operation of water resource projects. Consumptive use is involved in problems of water supply, both surface and groundwater; water management; and in the economics of multiple-purpose water projects for irrigation, power, water transportation, flood control, municipal and industrial water uses; and wastewater reuse systems. In Pakistan, this information is now crucial for resolving issues related to water apportionment, allocations, development of new storage and disputes related to regional and environmental issues.

Various workers in Pakistan have done considerable work on consumptive use of water for crops. Most of the work done during early periods (1947-72) on estimation of consumptive use of water of crops is either based on estimations made in lysimeters or from calculations using empirical coefficients developed from climatological data. The work on estimation of consumptive use of water by crops in the field based on soil moisture depletion was initiated during mid 70s, when PARC initiated a national program on "Consumptive use of water for major crops under optimum management conditions".

In a lysimeter study, Hussain (1970) calculated the water requirements of crops in West Pakistan. He found that the consumptive use of wheat was 339 mm. He further reported that the consumptive use for wheat (indigenous) and wheat (Maxi-Pak) was 339 and 522 mm, respectively. The water requirement of the short statured wheat varieties is higher than the local varieties.

Systematic work on consumptive use of water in relation to moisture stress was initiated by PARC during 1975 which continued for over 10 years in six major agro-climatic regions of Pakistan. The studies were based on field experimentation using four moisture levels (management allowed deficit) and two fertilizers level with an objective to evaluate
yield of crops as a function of soil moisture stress. Gravimetric moisture measurements were used for scheduling of irrigation and to study dynamics of soil moisture. Jensen-Haise equation and pan evaporation data were used to estimate reference crop evapotranspiration and crop coefficients were estimated on 10 daily basis.

The information generated is very much beneficial for design and operation of irrigation schemes and managing irrigation at the farm level.

PARC (1982) reported results of consumptive use of water, moisture stress-yield functions and crop coefficients for wheat, maize, cotton, sugarcane and soybeans for six agro-climatic regions of Pakistan for experiments conducted under field conditions, where water-table was below 6 meters.

PARC (1993) further reported results of consumptive use of water, moisture stress-yield functions and crop coefficients for 12 crops grown in various agro-climatic zones of Pakistan. The results of 17 crops grown under various agro-climatic zones are now available for planning and design of irrigation schemes in the country.

The moisture stress-yield functions indicated that most of the grain crops like wheat, maize, sorghum and millets can be irrigated at 75% depletion of available soil moisture without loosing any significant yield. Thus management allowed deficit for these crops should range between 50-75%. Cotton crop behaved differently where further stress did not affect the yield rather it helped to maintain the yield. In addition first irrigation should be scheduled 40-45 days after planting. Another management strategy is to terminate irrigation at least 30 days before harvest so that dry conditions favor opening of bolls to have uniform harvest. The use of rainwater should be linked to achieve effective leaching of salts from the profile.

Irrigation scheduling models have been developed in the country based on the field data and can be used for fixed-rotation system of irrigation in the country (Ahmad 1985a; Ahmad 1985b; Ahmad and Heerman 1992; ICID 1992). The irrigation scheduling answers two basic questions of: a) when to irrigate; and b) how much to apply. The scheduled irrigation helps to save water and increase yields of crops.

The irrigation scheduling methods can be used to predict irrigation water requirements for various agro-climatic zones of Pakistan. The simplified information can be printed daily in the newspapers or forecasted on radio and television. The Meteorological Department can provide the rainfall probability information to meet seasonal and weekly requirements of farmers. In addition to this, farmers are also interested to have information on the extreme events – droughts and floods.

2.3. Sustainability of the Indus Basin: Combating Waterlogging and Salinity

The Salinity Control and Reclamation Projects (SCARP) were initiated during the 60s. The SCARP approach was successful in the fresh groundwater zone to lower the water table and increase the cropping intensity. Whereas in the brackish groundwater zone the use of poor quality groundwater resulted in secondary salinization or sodification process. The farmers were the driving forces to convince the Irrigation and Power Departments to close down the tubewells pumping hazardous quality groundwater. The recent increase in energy prices forced the Irrigation and Power Departments to develop transition projects to
transfer the public tubewells to the farmers. The farmers refused to take over these deep tubewells even at no cost to them, as they are not willing to pay the higher energy cost. Therefore, the government decided to provide subsidy to farmers or farmers’ groups to install community shallow tubewells with diesel prime movers.

The use of tile drainage was initiated during the 80s. The tile drainage was very successful in areas having natural gradient for the disposal of effluent like the MARDAN SCARP. Otherwise, energy requirement for pumping and disposal of brackish groundwater effluent is high. However, in the fresh groundwater zone, the water can be recycled for irrigation purposes. The maintenance cost of these systems is also higher as communities are not yet willing to take over the responsibility of pumping the effluent for disposal.

During the 80s, research projects were initiated to use biological approaches for reclamation and/or management of salt affected lands (Malik and Mohammad 1972; Sandhu and Malik 1975; Qureshi et al. 1982; Ahmad and Pietro 1985; Malik et al. 1986; Sandhu et al. 1988; Aro et al. 1988; IWASRI, UNDP and PARC 1990). However, these efforts were mainly restricted to the use of Kallar grass and plantation of eucalyptus and atriplex species to manage the salt affected lands. These techniques are therefore suitable for areas where traditional agriculture or cultivation of crops is not possible. Furthermore, these efforts were restricted at research level or small-scale demonstrations. Therefore, there is a need to test and evaluate the techno-economics of these approaches on pilot area basis similar to that of the SCARP approach.

Although investments in drainage have been significant in Pakistan during the last two decades, waterlogging still affects large tracts of land, with more than 22% of the total gross command area of the Indus basin irrigation system having water-table within 1.5 meters (World Bank 1994). Salinity and sodicity also constrain farmers and affect agricultural production. These problems are further exacerbated by the use of poor quality groundwater (Kijne and Kuper 1995). In fresh groundwater areas, excessive pumping by private tubewells leads to mining of the aquifer (NESPAK 1991).

It is necessary to state that some of these problems are not new in the irrigation sector of Pakistan. Dry tails, poor maintenance, users’ interference, waterlogging and salinity, have always been part of the history of irrigation in Pakistan. For example, as early as in 1895 measures were implemented to control waterlogging (Kuper 1997). However, the negative impact of these problems could then be compensated at the macro level by the construction of new irrigation systems that constituted the major public interventions in the irrigation sector for a very long period.

The sustainable approach for managing salinity and waterlogging is the common sense approach, where sustainability of the Indus basin has to be ensured for further enhancement of productivity to meet the country’s needs of food and fiber. However, the concept of forest plantations, forages/pastures and aquaculture has to be integrated with the traditional agriculture to achieve sustainability on long term basis. The aquaculture has to be seen to reduce the drainage surplus, whereas forest plants and pastures have to be seen in the context of fallowing of land to reduce salinization in the arid environment. The country can not afford to diffuse the problem in the discussion of engineering or biological or social approaches instead a balance approach is required – the middle approach.

2.4. Sustainability of the Indus Basin: Institutional and Financial Aspects
In the 80s, there was a considerable recognition of the inadequacy of the purely supply-based engineering biased interventions for tackling the problems faced by the irrigation and agriculture sectors. New approaches were proposed that included institutional components. Examples of such approaches include: the On-Farm Water Management Projects that promote the development of Water Users’ Associations at the watercourse level (Colorado State University 1976); the SCARP Transition projects that aim at reducing public involvement in the groundwater sector by closing down or transferring public tubewells to the water users (World Bank 1988); or the Command Water Management Program that promoted water users’ involvement in the maintenance of the irrigation system up to the distributary head (World Bank 1996). Also under the pressure of donors, there have been discussions on the need to increase water charges to decrease the gap between revenues from the irrigation sector and operation and maintenance costs. Although conditional loans for several projects, the political decision to increase water charges has been postponed. Only recently some of the provinces have decided to increase water charges.

However, despite the apparent change in philosophy that guided interventions in the irrigation sector, only the engineering and agronomic components of these new approaches were successfully implemented. A typical example is the On-Farm Water Management Projects in the provinces, where watercourse improvement and agronomic interventions (the engineering and agronomic components) have been implemented in large number of watercourses while few Water Users’ Associations (the institutional component) have been developed in a sustainable manner. Reasons explaining this lack of success may be related to inadequate approaches for local conditions; the absence of addressing real needs for Water Users’ Associations within the watercourse command area; the lack of local support and appropriateness of changes brought by outsider; the meager qualified human resources (i.e. technical staff from agriculture department with little training in mobilization and water management extension) allocated to the implementation of these projects; and the incentives for implementation staff closely tied to construction progress rather than to institutional progress and development impact (World Bank 1996). The opinion of the World Bank is partially correct because the problem is mainly with the project design instead of the implementation. The project targets are focussed on physical outputs, whereas very little resources were kept for social mobilization and institutional reforms until OFWM-III project. Even in the OFWM-IV project, the role of social and institutional component is assigned to consultants. In the past, the consultants teams of OFWM use to have background in institutional aspects but they could not create impact on the implementation of the project. What needed is the reorientation of the Field Teams and supervisory staff through integration of institutional, management and physical components.

More recently, in recognition to the current problems in the irrigation sector and under pressure from international lending agencies, drastic changes in irrigation sector policies have been proposed (World Bank 1994). These changes, in line with the worldwide recognition of the economic value of water, included the privatization of the irrigation sector and development of water markets in order to achieve financial autonomy of the sector and economic efficiency. Several rounds of discussions were held between the major stakeholders of irrigation system in Pakistan, i.e. government departments at the provincial and federal levels, farmer organizations, politicians and donors to discuss the proposed and highly controversial changes. The different stakeholders eventually agreed on the need to decentralize, instead of privatize irrigation system management and to promote a participatory management mode. In short, the final proposal opted for an increasing
involvement of water users and the development of financially autonomous irrigation authorities at the Provincial level and Area Water Boards at the canal command level.

The Provincial Irrigation and Drainage Authority Acts also provided the control of the distributary level command to the Farmers Organizations (Fos), who will be responsible for the operation and management of the system. These Fos should be given the financial autonomy and administrative responsibility to ensure sustainability of the farmers’ institutions. It is an essential element of the transfer process because in the past the Water Users’ Associations organized under the OFWM projects could not sustain due to lack of financial and administrative support.

Although, there has been a political decision to proceed with these changes, however, a very little is known regarding the details of the proposed changes and of their implementation, and their expected impact on water supply, agricultural production and sustainability of the resource base. The approach selected for implementation includes the development of selected canal command areas as pilot projects that are expected to provide information on constraints and limitations of proposed changes and lead to a successful implementation for other irrigation canal commands. It is important to note that pilot projects will impact on large areas of no less than 300,000 hectares, thus on a large number of farmers that may eventually pay for an ill-designed project or unsuitable options (Strosser 1997).

The sustainability of irrigated agriculture would depend on the effective implementation of institutional reforms especially the Farmers’ Organizations at the distributary level and assigned financial autonomy of these organizations. In addition, these organizations have to be linked with input delivery channels and markets so that productivity of agriculture is enhanced and organizations have a continued role for their sustainability. The line departments have to be reoriented to change their role from authority to service.

2.5. Alternative Cropping Patterns

The agricultural environments in the country provide diverse agro-ecological advantages with two distinct cropping seasons, the Kharif and the Rabi. The Kharif season represents the period from May to September, whereas the Rabi season represents the period from October to April. The ecological diversity can be viewed from the length of the wheat-growing season, which varies from 120 days in the south to 280 days in the northern mountains. This ecological diversity also provides an opportunity to raise off-season crops in different parts of the country, especially the vegetables.

There are five distinct cropping patterns prevailing in the country. These include: a) coarse grain-wheat; b) maize-wheat; c) rice-wheat; d) cotton-wheat; and d) sugarcane. These patterns further have mixtures of other crops like fruits, vegetables and pulses in the Kharif and Rabi seasons. These cropping patterns are based on spatial information of district crop databases and analysis using Geographic Information System.

The profitability of traditional irrigated and rainfed agriculture is now questionable because of the high input costs compared to the commodity prices and productivity. Therefore, the need arise to diversify the cropping pattern by introducing high value short duration commodities having export potential due to the comparative advantages in the
international market. Such commodities include herbs, condiments, flowers, berries, fruits and vegetables. The introduction of such commodities would depend on the market pull and the government policy for export of value added products.

The sustainability of rice and cotton based cropping patterns is a serious question because of stagnant or declining productivity due to biophysical complexities in the Indus basin. The use of chemical fertilizers and pesticides has also affected the health of soil and resulted in groundwater contamination. The efforts made in the last 40 years to promote chemical fertilizers could not have the desired impacts on agricultural productivity. Because still 1/3rd of the farmers are either not using any fertilizer or quantities which could not have any significant effect on productivity. Therefore, there is a need that the comparative advantages of some of the pockets where farmers are still using organic composts could be realized. These pockets exist among the resource-poor farmers of the Indus basin, Balochistan province, Barani areas and Rod-Kohi system. These farmers must be motivated with the provision of nature farming technology to raise organic fruits and vegetables for export purposes. Even there is a market for organic cotton in the developed countries.

It is interesting to note that many farmers in Balochistan and Northern Areas are still growing organic fruits and vegetables but they could not have the awareness to sell their product as high value organic produce. It is also an added benefit of the organic produce that the keeping quality is much higher than the chemical produce. Furthermore, this would also require a monitoring and regulatory system to ensure the production of chemical free produce. The government agencies have to provide a certification and at the same time to ensure the quality of the marketable product.

To introduce the high value and diversified cropping patterns, there is a need to introduce agriculture as a subject in school level education to keep the rural youth involved in future agriculture. Furthermore, vocational schools have to be initiated at the rural levels to provide practical training to farmers without literacy. Such a green movement is the need of the time. In fact such trades have to be developed where farmers can join evening classes in the existing schools.

2.6. Optimizing Productivity and Returns

The concept of maximizing yields per unit area needs rethinking because net return per unit of investment is the requirement of the farmer. The most limiting factor faced by the farmers is the low investment capacity and lack of credit facility at interest rates affordable to the farmer. Therefore, the concept of optimizing productivity has to be introduced in a four dimensional way covering the productivity in terms of land, water, labor and time. This concept can be named as resource use efficiency. However, the ultimate aim is the net returns per unit land, water, labor and time.

The concept of optimizing productivity and returns should also be seen in the context of the farmers’ investment capacity levels. The farmers’ investment capacity is not the same as there are resource-rich and resource-poor farmers in almost every farming system prevailing in the country. It is therefore recommended that the farmers’ investment capacity levels be considered in three categories as low, medium and high. This will also help to tighten the agenda for researchers to reorient their research to address the needs of the
clients – the farmers.

The present day research and extension approaches do not address the needs of the farmers. For example, the soil scientists and agronomist always recommend the optimal or maximum dose of fertilizer to achieve higher yield. Efforts were never made to translate the fertilizer recommendations into rupee terms, so that farmer can have balance fertilizer use within available financial resources. Similarly, the water management specialists always talk about optimal water requirements without considering the irrigation system constraints or the quality concerns of the groundwater. The weekly availability of water in the Indus basin have to be seen in the context of irrigation scheduling in a multiple of 7 days (7, 14, 21, 28 or 35 days intervals). Thus the approach of research and extension has to be reviewed considering the constraints of prevailing farming systems in the country – Indus basin, rainfed, Rod-Kohi, riverain, etc. This would demand unlearning of the research and extension scientists/engineers, and reorienting their activities to address the changing needs of the farmers.

The profitability of the irrigated agriculture especially in the tubewell command areas is a serious issue and requires government interventions. The rural youths are also migrating to the para-urban or urban areas due to lack of sufficient incentives in farming and drudgery associated with the existing farming systems. Even the basic amenities of life are not available in rural areas. Therefore, it is essential to make farming a profitable enterprise through ensuring minimum support price but let the free market determine the real price of the marketable products.

2.7. Self-sufficiency

Self-sufficiency in agricultural yields is an out dated concept, because agriculture has to be seen in the context of an economic enterprise context. Instead the concept of self-reliance is more relevant to the needs of the country. The purpose should be to reduce the import bill through increase in exports considering the comparative advantages of the country. However, the concept of self-sufficiency is desirable in the context of food security. The country certainly demands food security considering the need of the common man. However, it has to be seen in the context of global trade and market forces.

There is a great potential to achieve self-sufficiency in food crops by increasing and maintaining at least 25% increase in yields along with an annual increase to meet the needs of the growing population of around 2.6% per annum. However, in the context of 2010, the production of agricultural commodities has to be increased by 54% from that of 1998. This is a difficult target and concerted efforts are required to address the real issues in agriculture.

3. Issues

The Indus Basin Irrigation System today is the result of one century of supply-based policies. Surface water is supplied to more than 16.4 million hectares or 120,000 watercourses through an extensive network of main canals and secondary canals or distributaries. The system of Warabandi and crop-based water charges is still in use, although discrepancies exist between official rules and rules in practice, for example the development of localized canal and/or tubewell water markets. The 1980s, however, have brought major changes that have stressed the inadequacy of the supply-oriented and
engineering-driven interventions for projects implemented so far. The equity, efficiency and sustainability are the other issues affecting the productivity in the Indus basin. In this context, following issues are particularly important.

3.1. Water Scarcity

The first issue that relates to changes in water scarcity those has taken place within the irrigation system. It is not clear that the *Warabandi* system initially imposed by the British administration played a role as the demand for irrigation water was rather minimal. During the last decade, however, the pressure on water has drastically increased, with more competition for quantity and quality of irrigation water within the irrigation sector, but also from other sectors of the economy. The thrust areas related to water scarcity issues are:

- As a result of changes in the macro-economic environment, farmers have increased their cropping intensities from the original design figures of 50-70% to an average of 120% per year for the Indus Basin (John Mellor Associates 1994). This has led to an increasing pressure on the surface water resources (cheap freshwater), translated into a significant interference of water users into the operation of the irrigation system (Rinaudo et al. 1997).
- As a result of inadequate canal water supplies, but also as a response to changes in the macro-economic environment, farmers have installed a large number of private tubewells to tap groundwater resources (Malik and Strosser 1994). However, current pumping rates have already led to mining of the aquifer in several canal command areas with good groundwater quality (NESPAK 1991). In areas with poor quality groundwater, farmers still have installed tubewells and pumping leads to problems of secondary salinization and sodification (Kijne and Kuper 1995).
- More recently, water needs by other sectors of the economy, such as industries and municipalities, are becoming more significant, although the overall quantity used by these sectors remain marginal as compared to water use by the irrigation sector, i.e. less than 5% of total water resources (World Bank 1994). Competition over water resources between sectors has been limited to specific areas close to large cities and industrial complexes. The main issues presently at stake include competition on groundwater use (quantity), and problems of effluents and pollution of irrigation water (quality).
- There has been a recent recognition of the in-stream needs of the Indus River. Minimum discharges from the Indus to the sea are required to limit intrusion of seawater into the coastal area. However, little is known about the minimum flows required and how this would compete for surface water resources with the irrigation sector.
- Finally, the competition for surface water resources has intensified between the four provinces, and mainly between the Sindh and the Punjab provinces. After long negotiations, the Indus River System Authority (IRSA) was created in 1992 to implement the water apportionment accord that specifies surface water allocation to provinces. However, confrontations between the Sindh and the Punjab provinces regarding these allocations still arise periodically, mainly during periods of high water demand. The consensus on storage needs has yet to be attained among the provinces.

3.2. Efficiency
The second issue is linked with conveyance losses in canals and watercourses and application losses in the field. These losses further aggravate the problem of water scarcity and result into problems of waterlogging and salinity. It also affects the volume-equity in availability of water due to time-equity Warabandi system. The aspects related to efficiency are:

- As a result of deferred maintenance, lack of discipline and political/feudal interference the overall operational management of the canal irrigation system is affected to a level where accurate measurements are hardly taken and used in canal operational management.
- Cost-effective canal and watercourse lining techniques are not yet available even small-scale experiments were conducted by various agencies during last 50 years. The quality of contract works is also poor.
- The On-Farm Water Management (OFWM) Programs although considered quite successful but 30% lining of watercourses would be of limited advantage towards water savings. Cost-effective lining techniques although developed by various agencies could not be adopted by the OFWM Programs as they are still following 9” brick lining.
- Basin irrigation on unleveled fields is inefficient. The furrow-bed irrigation recently introduced in the cotton-wheat area has a potential for efficient surface irrigation if issues of high cost of bed-shaper cum planter and weeds control are addressed. The cost of temporary beds is higher than flat plantations, therefore, it requires studies on the adaptation of permanent bed system.
- The locally produced sprinkler and drip irrigation systems are still costly and outside the reach of common farmers until they are linked with specific objectives of Rauni irrigation and to have specialized benefits through frost control and cooling.
- Center-pivot sprinkler irrigation system is very much suitable for areas where water is at premium, if these systems are locally manufactured. The large farmers are interested in energy efficient systems, which are automated and require much less labor for irrigation.
- The high electricity prices have forced farmers to shift to diesel prime movers for pumping of water. The efficiency of Chinese single-cylinder diesel engines is low because of low combustion efficiency, low coolant temperature and higher engine speeds. The centrifugal pumps are also not energy efficient compared to direct displacement pumps. Therefore, renewable energy sources can't be used because of high initial cost until weights balancing direct displacement pumps are locally produced. Therefore, water and energy efficiency in tubewell irrigation is going to be a major issue in the next century.

3.3. Equity

The water losses during conveyance and time-equity system imposed for quota of water resulted into inequity in water availability. The deferred maintenance, political interference and lack of improved canal operational management further aggravate the problem. The aspects related to equity are:

- The concept of Warabandi is based on quota and due to huge conveyance losses it adds into inequity in water availability at the tail end reaches. The concept
needs to be modified to include conveyance loss function in the Warabandi formulae.

- The availability of information to the water users regarding canal flows and diversions at Moghas is a major limitation in arranging an organized community action to resolve the equity issues.

3.4. Sustainability

The issue of sustainability of irrigated agriculture demands rethinking about the existing approaches of irrigation especially the drainage as Pakistan is a vertical country and disposal of effluent to the sea is not a sustainable proposition. The aspects related to sustainability are:

- The fallowing of land results into accumulation of salts in the upper soil surface and therefore crop based farming system is not sustainable. Diversification of farming system through integration with forestry and pastures, aquaculture and livestock would add sustainability to the Indus basin irrigated agriculture. Such farming systems need to be evaluated.
- Flood irrigation in situation of water scarcity and more dependance on marginal quality groundwater will further aggravate the issue of salt build-up.

The other issue is linked with the level of financial resources available for the irrigation sector. Financial resources for the development of the irrigation sector are scarcer today than 20 years ago, both in absolute and relative terms. Several reasons explain this situation.

- Similarly to the general trend observed in the Sub-continent (Rosegrant and Svendsen 1993), the development costs of irrigation projects per unit area today are significantly higher in absolute terms, as low-cost high-potential areas have already been developed. As a consequence, significant improvements in agricultural benefits will be required if acceptable economic returns are to be realized.
- In the context of structural adjustment programs and under pressure from international lending agencies, there is a political will to reduce subsidies to the irrigation sector. Financial autonomy has become an important policy objective in Pakistan. The recent SCARP Transition Projects illustrate this concern. In order to eliminate the financial burden related to the high operation and maintenance costs of public tubewells, these projects aim at closing down public tubewells, selling them to farmers or group of farmers, or providing subsidies for the installation of private tubewells by individual farmers.
- The level of financial public resources available for the irrigation sector has drastically decreased in relative terms. This results from the disengagement of donors traditionally involved in the irrigation sector (the end of the US-Aid period in 1991 as a result of the Pressler amendment). The increasing importance of the total debt servicing of the country, is another element that limits the availability of financial public resources. Also, the competition from other sector of the economy has increased: higher economic rates of return are in fact expected from investments in industrial and infrastructure development as compared to investments in the irrigation sector.
With the increasing scarcity of water and financial resources, inefficiency, inequity and high energy prices, it is clear that highly expensive supply-based approaches become less viable. This has been reinforced by the increasing recognition of the failure of past projects that did not yield the expected benefits that were visualized, and could not solve problems in the irrigation sector.

4. Vision for 2010

4.1. Challenges

The research and development community is facing three challenges. The first challenge faced by irrigated agriculture is to raise production and productivity in favoured environments. Secondly, the challenge is to enhance production and productivity in less favoured environments like Balochistan valley agriculture, Rod-Kohi, Barani lands, riverine areas, etc. The third challenge faced by the country is that in the process of productivity enhancement the resources have to be upgraded rather degradation.

The population by the end of 2010 will be around 171 million based on medium projections. The increase of 30% in population would require at least same level of increase in food and fiber production to meet the country’s requirement. Coupled with country’s objective of increasing export and reducing import bill, it is more realistic to achieve a level of 50% increase in agricultural production.

The targeted 50% increase in agricultural production would demand 40-50% increase in water availability. This additional water will come solely through savings of existing losses and introduction of the high efficiency irrigation systems with cropping patterns, which are water efficient.

4.2. Scenario and Drivers

The selected scenario for the vision 2010 is to increase agricultural contribution to the GDP from Rs. 150 billion to Rs. 231 billion which corresponds to 54% increase in real-term. This would demand to increase agricultural production by at least 50% with more emphasis towards milk, meat, vegetables and fruits production to provide balance nutrition to the population and diversify the exports.

The drivers who will affect the selected scenario are: a) population; b) economic growth; c) technological progress; d) social process; e) environmental concerns; f) awareness and education; and g) management levels.

5. Recommendations

The unresolved issues were identified which need to be addressed in the 21st century. However, it is not appropriate to build recommendations for water use technologies and cropping patterns without considering the irrigated agriculture as a whole. Therefore, some of the tentative recommendations are as under:
The country’s future growth rate in agriculture should be fixed higher than the population growth rate to provide exportable surplus to the country for self-reliance and to support foreign exchange earnings. This means that annual growth rate in agriculture should be over 5% to reduce the burden of imports in the foreseeable future. This would also be required to improve the livelihood of the rural communities along with the improvements in their family nutrition.

Comprehensive planning of water sector coupled with integrated development and management of irrigated agriculture is essential to achieve self-reliance in agricultural production and sustainability of the natural resource base.

Efficiency of conveyance of water must be seen in the context of groundwater quality, as any loss of water in the brackish groundwater zone is not retrievable in quality terms. Therefore, canal and watercourse lining programs should be given priority in the brackish groundwater zone.

Research on developing low-cost and effective liners for lining of canals, watercourses and earthen ponds should be strengthened.

Conjunctive use of rainwater, runoff, surface and groundwater must be encouraged to address issues of multiple water use (irrigation, stockwater, and domestic water) in rural areas especially outside the Indus basin.

The sustainability of irrigated agriculture is a serious question, because drainage can not be considered as a sustainable solution due to the distance from the sea and the arid environment. The best option available is the integration of crops and cropping patterns with livestock, farm forestry, pastures and aquaculture. The forestry and pastures would help to reduce the salt build up in fallow lands, whereas aquaculture would help to manage high water table.

Layout of farm irrigation system is needed to design level basin, level/graded borders and furrow irrigation to suit the needs of cropping pattern, soils and streamsize available in various canal commands (perennial/non-perennial). The on-going OFWM projects in the provinces should provide such a support to the farmers and rural youth.

Cropping patterns have to be designed considering the water availability, soil type, profitability of production system, farmers’ preferences and market conditions. The crops like rice and sugarcane which require much more water compared to other crops must be evaluated considering the water use efficiency in terms of net return per unit of water.

Local development of sprinkler and drip irrigation systems including the development of automated center-pivot sprinkler irrigation systems for large farms should be encouraged.

Local development of water and energy efficient pumping systems should be encouraged to improve profitability of tubewell irrigated agriculture.

Research on productivity and sustainability should be initiated to address the issues of water scarcity and inequity.

Pilot projects in all the major canal commands should be initiated to address issues of canal operational management, institutional reforms, productivity and sustainability.

Farmers organizations at the distributary canal level should be given authority and financial autonomy. The Agriculture Extension department must reposition their activities to make these more responsive to the needs of Farmers' Organizations.

The On-Farm Water Management Programs in the provinces should be reoriented to address both the issues of surface and groundwater for agriculture.
and other uses in rural areas. Therefore, in future their mandate should be revised and the name may be changed to “Agricultural and Rural Water Management”. They have to reorient their technical backstop support system to make it more responsive to the needs of Farmers' Organizations and the country's farming systems (irrigated, Barani, Rod-kohi, deserts, coastal areas, etc.).

- The information of predicted irrigation water requirements for various agro-climatic zones of Pakistan should be printed daily in the newspapers or forecasted on radio and television, along with the information on rainfall probability to meet seasonal and weekly requirements of farmers and information on the extreme events – droughts and floods.

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