# IRRIGATION AND WATER MANAGEMENT IN THE INDUS BASIN OF PAKISTAN: A COUNTRY REPORT

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## 1. Irrigated Agriculture in Pakistan

### 1.1. Agricultural Environment

The land, water, vegetation and human are important resources related to agriculture. The development of water resources is more complex and cost-intensive compared to land and vegetation resources. The development of water resources is also important because of semi-arid and arid climate of Pakistan. The agricultural production is mainly dependent on climate and other agricultural resources. Pakistan's agriculture represents a complex and climatically diversed system with rainfall of less than 100 mm to about 1500 mm in the foot hills and mountains. The human element is also one of the most important component of the agricultural production system which is normally neglected in traditional systems. The diverse socio-economic conditions also pose restritictions for the adoption of technology if it is not site specific.

The farmers per se are not interested in irrigation and water management practices because their main interest is to increase net return at the farm level within available resources and their management skills. Therefore, need arises to translate irrigation and water management practices into improved plant production techniques. Only then farmers will adapt such practices. Furthermore, there is a need to test these practices for sustainability to have healthy balance between resource utilization and management. The sustainability also includes economic, ecological and social systems.

A summary of some of the major problems and constraints related to Pakistan's irrigated agriculture is as under:

- Uncertain river flows and erratic rainfall distribution;
- Shortage of water and storage reservoirs;
- Water delivery losses in irrigation system;
- Waterlogging and salinity;
- Poor quality of groundwater;
- Poor drainage facilities;
- Low water use efficiency at the farm level;
- Soil erosion through water and wind;
- Watershed degradation and siltation problems in water reservoirs, rivers and irrigation channels;
- Low crop yields and cropping intensity;
- Shortage of food, fibre, milk, meat, etc.;
- Sustainability problems in marginal lands;
- Lack of soil organic matter and low soil fertility;
- Lack of appropriate information about technology transfer; and
- Lack of effective role of farmers in agricultural research, education and extension.

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The Pakistan Agricultural Research Council divided the country area into 10 broad agro-ecological regions considering physiography as basis of characterization (PARC 1980). The broad agro-ecological regions are presented in Figure 1.

The ecology and resources in these regions vary considerably. The main limitation for development of agriculture in these regions is mainly water shortage because of arid climate and insufficient rainfall in most part of the country. The development of agriculture is therefore dependent mainly on the development of water resources which is much more capital intensive than any other development. The sedimentation in rivers and channels, erosion of soil, waterlogging, salinity, desertification and over-grazing are the examples of leaky agricultural systems. This requires an ecological approach than factory approach.

### 1.2. Land Classification and Irrigated Agriculture

The cultivated area is classified as canal command, tubewell command, sailaba and Barani (Table 1). The total culturable area is around 23.25 million hectares (mha), whereas, 11.78 mha are under forage and forests. This makes 35.03 mha suitable for agriculture and forestry. The rest of 44.63 mha is not suitable for agriculture and forestry within existing framework except for rough grazing in certain places. The development of this area requires systematic development of water resources which is one of the major limitation for the development of agriculture or forestry.

Salinity is one of the major problem in the irrigated areas of the Indus basin. According to WAPDA, 1981 surveys, about 26 and 39% area of the Indus basin is affected by surface and profile salinity, respectively. There is a decrease in the salinity in the Indus basin due to SCARP activities. During last 20 years about 6% area of the Indus basin affected by surface and profile salinity was reclaimed (Tables 2 & 3).

The salinity is further divided based on type of salts, present in the soil. The classification of salt affected soils indicates that 24% of area of the Indus basin is affected by salinity and sodicity, whereas, only 3% area is non-saline and sodic. About 11% of the area is saline (Table 4).

The waterlogging is another problem affecting the irrigated agriculture in the Indus basin. Within 100 years of the development of the Indus basin irrigation system, the water-table has risen from 40 m to within 3 m on about 42% of the area of the Indus basin (Tables 5 & 6). The situation is worst in sindh province where water-table is within range of 3 m on about 57% irrigated area of the province. The high water-table creates problem of oxygen deficiency, salt build-up in the soil profile and poor workability with soil (WAPDA 1986).

The high water-table although creates problems for crop production but at the same time in the fresh groundwater zone it provides facility for sub-irrigation. The fresh groundwater in other areas also provides a source of water for irrigation through pumping. At present about 30% of the total irrigation water supplies are met out of groundwater. The high watertable is a problem in areas where groundwater is of poor quality. This situation becomes worst due to flat gradient in the Indus basin which pose a restriction on the natural drainage. The combination of brackish groundwater and soil salinity makes the situation more complex which requires huge investments for reclamation purposes.

## 2. Irrigation and Water Management in Pakistan

## 2.1. Mean Annual Rainfall

The mean annual rainfall varies from less than 100 mm in the Sind to more than 1500 mm in the foothills and northern mountains. About 60% of this rainfall comes during the monsoon period (July to September). Much of the summer rains also not available for crop production because of rapid runoff due to torrential showers. At other occasions, rain may be so light that the precipitation evaporates before the water can penetrate into the root zone. However, the contribution of rain to crops in the irrigated areas of Indus basin is estimated about 16.5 billion cubic meter (bcm). These estimates are obtained by using effective precipitation data from a region and multiplying them by cultivated area (Punjab 9.9, Sind 3.3, NWFP 2.3, and Balochistan 1.0 bcm). The Barani areas are completely dependent on rainfall for agricultural production and in medium towards high rainfall areas about 50-60% of annual rainfall is lost through runoff. The mean annual rainfall of selected stations is presented in Table 7.

## 2.2. Indus Basin Rivers System

The Indus basin rivers system is the world's largest contiguous irrigation system. Rivers serving the Indus plains are the Indus and its tributaries the Kabal, the Jehlum, the Chenab, the Ravi and the Satlej. According to the Indus Water Treaty 1960, Pakistan is entitled to the full use of the Western Rivers comprising the Indus, the Jehlum and the Chenab, while the supplies of the Eastern Rivers the Ravi, the Satlej and the Beas are reserved for India. These rivers have a low flow season from November to February and start rising in spring and early summer with melting of snow in Himalayas and rise further with the onset of monsoon in June to attain peak flows in July and August.

Based on the Indus Basin Water Treaty, five barrages and one siphon-cum-barrage were induced in the Indus basin project alongwith other works like Mangla dam, series of new major inter-river link canals, remodelling of existing two barrages, and the feasibility study for the Tarbella dam.

The five barrages and Mailsi siphon have a total length of nearly 5.6 km and an aggregate discharge capacity of 125,000 $m^3$ $Sec^{-1}$ with the new and existing canals off-taking from these barrages and aggregate capacity of 3398 $m^3$ $Sec^{-1}$ (Framji et al. 1982).

## 2.3. River Flows, Surface Storage and Siltation

The ratio of the minimum and maximum average monthly flows comes to about one to ten. During the 39 years period from 1937 to 1975 the figures of yearly river water supplies are given in Table 8.

These figures are for the rim stations of Kalabagh on the Indus, Mangla on the Jehlum, and Marala on the Chenab River.

Although there is significant variation in volume of flow from year to year, the Indus River system has a high degree of natural regulation, generally attributable to a large improvement of snow and glacier melt. Natural regulation ratios measured as the ratio of minimum annual flow to average annual flow are the Indus, 63%, the Jehlum, 68%, the Chenab, 70%, and total system, 73%. As a thumb rule it is seldom economical to attempt to raise the regulation ratio of a river to more than 70% by use of reservoirs (Framji et al. 1982).

The high natural regulation ratios of the Indus River, and the absence of large reservoir sites, indicate that there is little practical livelihood of use of surface reservoirs to carry over water from high flow to low flow years, and excessive flood flows will continue to go to the sea. However, reservoir storage for transfer of water from the summer high flow season to the winter low flows season will continue to be essential element in water management. The details of surface storage available in the Indus basin system are presented in Table 9 (Framji et al. 1982).

Siltation in the reservoirs is the major problem to maintain the live storage capacity as per designed specification due to the degradation in the watershed areas. The high level of annual loss of capacity due to siltation requires systematic watershed management activity in the upstream areas (Table 10).

### 2.4. Salient Features of Irrigation Channels

The Indus basin system in pakistan is composed of more than 63,213 kms of channels which covers a total of 19.36 million hectares of culturable command area.

The irrigation water is diverted to watercourse at the canal outlet (mogha which serves a command area of 60 to 260 hectares). The watercourse is a miniature irrigation project. There are about 107,000 watercourses in the country. This includes: 55,000 in Punjab; 40,000 in Sind, 10,000 in NWFP; and 2,000 in Balochistan. The length of a watercourse ranges from fraction of a kilometer to 4 kilometers. The discharge varies between 28-120 litres per second. There are about 50-100 farmers according to size of land holding, availability of water, etc.

### 2.5. Surface Water Supplies and Losses

The total annual mean discharge in the Indus river system is in the order of 167 billion cubic meters (bcm). About 136 bcm are diverted into the canal system in an average year and the rest flow into Arabian sea. Moreover, after every second year 167 bcm are not available in the river system and drop every fourth year below 160 bcm and every sixth year below 150 bcm. These are important physical properties if the water use reaches the later quantities. The water losses in the canal system are in the order of about 25% which reduces the water availability to 102 bcm at the watercourse head (Ahmad 1991).

### 2.6. Groundwater Supplies

The Indus basin represents an extensive groundwater aquifer covering a gross area of 16.20 million hectares. Before the development of canal irrigation system, the water-table was well below the surface and the aquifer was in the state of hydrological equilibrium. The recharge to aquifer from rivers and rainfall was balanced by outflow. When canal irrigation system was introduced, percolation to the aquifer was greatly increased in the irrigated areas of the Indus basin. At present, the recharge is three or four fold from that of the natural state with the result that the water-table has risen within 4 meters or less of the surface over almost half of the irrigated area (Ahmad 1990).

Although there are disadvantages in having a high groundwater table, it is presently being used for irrigation by approximately 3,50,000 private tubewells with an average capacity of 30 lps and over 15000 public tubewells of designed capacity of 60-120 lps. The pumpage from tubewells is approximately 56 bcm which provides 30% of the total irrigation water exclusively to 2.81 million hectares in addition to supplementary canal fed areas.

### 2.7. Watercourse Losses

Significant research work has been done in the Indus basin to compute delivery losses in the watercourses. The earlier estimates are mainly based on watercourses which were either constructed in the research institutes or well maintained by the farmers. The field research studies cover the operational water losses on the farmers watercourses. At present, an average water loss of 40% in the earthen watercourses is considered as an accepted value (Table 11).

### 2.8. Water Budget

The water budget of Indus basin irrigation system is presented in Figure 2. The water available at the watercourse head is about 158 bcm after having groundwater pumpage of 56 bcm. Assuming watercourse losses of about 40%, this leaves only 95 bcm available at the field nakka. The application efficiency is around 75% which leaves 72 bcm available for crop consumptive use requirements. After adding effective rainfall contribution of 17 bcm in an average year, the total net water available for crop consumptive use requirements is in the order of 89 bcm (Ahmad 1991).

### 2.9. Irrigation Water Requirements and Anticipated Savings

The crop water requirement for net crop needs have been computed for Pakistan considering the 1982 cropping intensity of around 105% in the irrigated areas of Pakistan (Ahmad 1982). Assuming cropping intensity of 110%, the net water requirement comes to around 89 bcm which is same as the net availability. This means that water available in the Indus basin is sufficient to achieve 110% cropping intensity within the present irrigation practices. The water savings in the Indus basin of 16 bcm are possible through reducing the delivery and application losses (Ahmad et al. 1987).

To maintain healthy salt and water balance, it is important to increase the groundwater pumpage. Additional pumping of 38 bcm is needed to maintain the hydrological equilibrium in the Indus Basin.

## 3. On-Farm Water Management Programme

Realizing the huge conveyance and application losses in the irrigation system at the farm level and being low-cost technology for saving losses and developing water resources, the Government of Pakistan launched a five year pilot project called On-Farm Water Management (OFWM) in 1976-77 with the assistance of USAID.

Following the success of the pilot project, a regular OFWM programme was initiated in all the irrigated areas of Pakistan in 1981, with the assistance of the World Bank. The Phase-I and Phase-II of the OFWM project were completed in 1985 and 1991, respectively, whereas, the Phase-III is under implementation since May, 1992 which is expected to be completed by 1995. Besides World Bank assisted OFWM projects, there are other major

OFWM projects assisted by OECF-Japan and ADB. In addition to above major projects, there are a number of other irrigation and agriculture projects in the country having OFWM as a compulsory component. Inspite of these OFWM projects, rate of progress has been slow (1600 watercourses per annum) and at this rate almost 50 years will be required to renovate all the watercourses (107,000). To renovate all the watercourses in the shortest possible time (15 years) as proposed in the 8th Five Year Plan is possible if adequate monetary resources are available with GOP or cost recovery of Civil Works may be increased from farmers.

### 3.1. Components of Ongoing OFWM Programmes

The main components of ongoing OFWM-III programme are:

- watercourse rehabilitation and improvement with partial lining and control structures;
- precision land levelling for improved level basin/ border irrigation;
- demonstration centre for crop water use and farmers training;
- water storage tanks, water lifting devices and micro- irrigation;
- cooperative command tubewells for water supply;
- on-farm drainage;
- rehabilitation of runoff farming system.

### 3.2. Cost Recovery

In order to make the OFWM a self sustainable programme, the government of Pakistan introduced recovery of a part of construction material under OFWM projects. To begin with, it was introduced in provinces of Punjab and Sindh during OFWM-I @ 20% and 25%, respectively. The rate of recovery was increased for 25% and 30% for Punjab and Sindh provinces, respectively, during OFWM-II and was also introduced in NWFP and Balochistan @ 10% and 25%, respectively. Thirty % recovery has been proposed for the OFWM-III.

### 3.3. Impact of OFWM Programme

Monitoring and evaluation of the OFWM projects revealed that irrigation efficiency was increased through watercourse improvement and precision land levelling. The major findings are:

- Water losses were saved to the extent of 27% for the overall system.
- There is a shift in the cropping pattern from low to high delta crops.
- The annual cropping intensity has increased by 5.8% due to more available water.
- Crop yields have increased (wheat 6.3%, rice 14.9%, maize 14.9%, and sugarcane 23.6%).
- Precision land levelling reduced 42% saline areas and about 2% additional area was gained in Punjab and 5% in Sindh.
- There is a saving of 25% in duration of irrigation.

## 4. Water and Productivity

Pakistan is primarily an arid country, where about 92% area is categorized as semi-arid to arid. Therefore agricultural productions are mainly dependent on irrigation. Furthermore, the spatial and temporal variability in rainfall affects the productivity of rainfed agriculture and rangelands.

The poverty outside the Indus basin to some extent is related to water or based on water. The good examples are Barani lands, Rod-Kohi areas, *Sailaba*, *Khuskaba*, deserts and coastal areas. The domestic and stockwater needs in these areas are primarily met from rain water harvested and stored in earthen ponds. The human and animals drink muddy water which is a cause of disease epidemics. The diseases common in these areas are dysentery, renal diseases, worms infestations, etc. Simple sand filters can be used to reduce the sediment load in water, whereas biological activity can be taken care through boiling. The health of animals and human beings is a primary requirement for enhancing the agricultural productivity in the fragile environments.

Agricultural productions in areas outside the Indus basin are dependent on incident rainfall, runoff or stored water in reservoirs. Supplemental or life-saving irrigation is needed to improve productivity. Productivity in these areas must be seen in relation to per unit of water, i.e. Kg of marketable product per unit of water. The marketable product includes grain and straw/stalk. Because livestock is one of the dominant production system of these areas.

For livestock production system, fodders, forages and feeds are the basic requirement for small and large ruminants. The aspect which is normally neglected is the water for animals. Therefore, in fragile environments sometime livestock travel 10-30 Km daily in search of water which resulted into weight loss of animals. Thus important aspect is development of stock-water through rain water harvesting, storage in earthen ponds, seepage and evaporation control.

In the Indus basin, productivity is presently measured in terms of per unit of area, i.e. cropping intensity. The cropping intensity is defined as the number of crops grown annually per unit area. Maximum cropping intensity of 200% is normally assumed for the irrigated areas. Low cropping intensity is basically because of water shortage at crop planting and during the crop growing period. The small farmers especially those who grow vegetables are producing even three crops annually. Therefore, the need arise to view productivity interms of resource use instead of merely cropping intensity. Thus productivity must be viewed interms of per unit water, per unit land and per unit time. This concept may be termed as "resource use intensity", and can be computed using the following relationship.

$$I_{ru} = I_c * I_{wu} * I_t * 100$$

where

- $I_{ru}$ - resource use intensity in percent;
- $I_c$ - cropping intensity as ratio of actual to maximum possible;
- $I_{wu}$ - water use intensity as ratio of actual to maximum possible water use efficiency;
- $I_t$ - productivity per unit time as ratio of actual net income to maximum possible net income.

## 5. Future Challenges

### 5.1. Future Water Development

There is not much possibility of development of water resources in Pakistan. During the 1990-2000, it is possible to maintain an annual growth rate of 1.74%. This will reduce to 1.56 and 0.62% in the next two decades. This puts a physical limitation in the development of agriculture in the Indus basin. Even considerable resources will be required to maintain this projected annual growth rate.

## 5.2. A New Frontier

During the 1960s and the 1970s the international agricultural research and development community faced the challenge of increasing the production of food to meet the needs of a rapidly increasing world population. Donors, development experts, and agricultural research institutions emphasized quantitative increases in food production. The ensuing strategy focused for the most part on raising the yields of a few critical crops, in general under high-input, intensive farming systems on the more productive lands. The challenge was to avoid a Malthusian crisis which loomed on the horizon.

Nearly three decades later, to quote a recent Ford Foundation report, "the world's production of food staples has reached an all time high, more than enough, if it were evenly distributed, to provide everyone with an adequate diet". Despite this considerable achievement, yields and productivity levels throughout the developing countries, under both the best and worst resource conditions, remain far below their economic and technical potential. Food production technologies and practices developed under experimental conditions have proved difficult to transfer to the farmers' fields under even the best of conditions. Equally as important, rapid population growth in Pakistan has resulted in the degradation of the natural resource base, while at the same time there is a growing concern by environmental and other groups with the damage to the environment from more extensive use of modern inputs and from other features of high-input technology.

More specifically, due to continued population growth and the frequent lack of employment opportunities in rural areas, large population have migrated to more marginal lands, forests, hillsides, barani areas, or to areas of open access such as river basins, and to already overcrowded urban areas. The resource base in many rural areas is approaching, and in many cases has already declined, beyond the number of people it can sustain. When that occurs, negative externalities, where in the actions of individual farmers or resource users impose costs on other individuals, begin to threaten even the more favoured areas. And the amount of land left to develop, or on which new migrants can settle, continues to decline or is available only at increasing cost.

In addition, many of these marginal or disadvantaged areas and their populations remain beyond the reach of much of contemporary agricultural research. This is partly because research continues to focus on more favoured areas and partly because there is limited institutional capacity to address the plethora of problems pertaining to development of these areas.

## 5.3. Challenges

Three new challenges are now before the development agencies as increasingly important issues. The first is to safeguard and to sustain past increases in food production in line with the needs of an ever-increasing population. This requires that more attention be given to sustaining the current resource base. The second challenge is to contribute to improved productivity of cropping and resource systems in less-favoured environments. And the third is to develop effectively production technologies that raise productivity, but do not pollute the environment or create other negative externalities in the process.

These challenges have many facets. Productivity gains achieved in the past must be sustained through the continued development and adoption of high yielding varieties with increased resistance to diseases and pests. Farming systems must be developed that sustain productivity over time and which sustain and increase the associated income streams that redowned from this increased productivity. Constraints to long term productivity of both under-exploited and overexploited resources must be identified and alleviated. And resource-use strategies that are both economically and ecologically prudent must be developed and adapted to a wide range of socio-economic and physical environments.

### 5.4. Integrated and Comprehensive Strategy

To meet these challenges, an integrated and more comprehensive strategy needs to be developed, one that focuses on more efficient use of existing resources, through better management. There are significant differences between the kind of research and development that must be carried out under this strategy and that which has been pursued over the past three decades. The new strategy requires a "whole system" approach rather than a more limited focus on the system components. Research and development necessarily needs to be multidisciplinary in nature, since both socio-economic and technical issues need to be considered. Research needs to be more adaptive than strategic, and for that reason must be carried out in operating systems whether they be land, water, barani or watershed systems, in addition to research carried out on experiment stations. And, associated with the last issue, research must be carried out in collaboration with the agencies or institutions that manage these systems, and therefore must have strong institution-building component.

Three target areas have been identified: a) highly productive areas that have already been developed but operate at a level significantly below their potential, or above a level that is sustainable; b) marginal areas (in terms of agricultural production) which are now under threat of resource exhaustion and depletion; c) modern agricultural practices which lead to pollution or to destruction of the resource base. Irrigation systems, farming areas plagued by livestock or human diseases, and delta areas exemplify the first type. Marginal land areas, barani lands, hillsides, and forests, many of which border highly productive areas, exemplify the second type. And the pollution of ground and surface waters with chemicals, the leaching of soils, and the loss of effectiveness of pesticides exemplify the third type.

### 5.5. Approaches to Resource Sustainability

A number of common features characterize the programmes and activities of the national and provincial agricultural research centres. First, they are national or provincial in character, with mandates to stimulate, coordinate, and collaborate in research efforts. Second, their research is multidisciplinary in nature and involves the characterization of socio-economic environments. Third, their research is aimed at sustaining and diversifying rural production systems, with the objective of safeguarding and enhancing past gains in food production. Fourth, because of the site specificity of the adaptive research and a desire to link with and strengthen provincial programmes, they place great emphasis on collaboration. Finally, and perhaps most importantly, the national centres are relatively small, flexible, mobile, and thus efficient both in terms of their productive capacity and in their ability to reach their effective target areas.

Figure 3 provides a means of highlighting the similarity in approaches to resource sustainability taken by the various centres. Point 'A' represents a resource before exploitation, Point 'C', a resource that has been overexploited.

**In the case of soils**, consider a recently cleared area of forest. Immediately after clearing, forest soils are relatively fertile, but often quite fragile, and thus quickly follow a path of near or total depletion (AB) under cropping pressure. Management practices such as the introduction of improved soil and water conservation practices and cropping sequences can restrict depletion to a level that will sustain agricultural productivity (AD). Point C could also represent a degraded land which has been over-utilized and which may be eroded. Proper soil management practices using water management (harvesting and conservation or integrated land use) may restore the productivity of this land to an acceptable agricultural level (CD).

**The control of waterlogging and salinity** can in some cases turn a marginal area into one that is highly productive (CD). The waterlogging and salinity for example, is a common problem in the irrigated areas of the Indus basin. The battle against the menace is complex, and is being fought on many research fronts. Chances are that success will be incremental, with small advances and slight reductions in its impact on victims. However, every marginal improvement will directly translate into improved productivity in livestock and farming populations, with potentially large benefits.

In this same context **an irrigation system** can behave like a resource (the y axis is interchangeable with efficiency). Because of its physical structures and design, every irrigation system begins to deteriorate shortly after construction is completed. Unlike the other examples discussed above, sooner or later the system will require rehabilitation. The job of management is to ensure that rehabilitation comes later rather than early, thereby reducing the opportunity costs to other development investments. In another case, a poorly managed system can, in the worst scenario, led to salinization of large tracts of land within the command area (AB), as is common in Pakistan's, Indus basin, and the eventual abandonment of the land. Management strategies have been shown to alleviate or eliminate such occurrences.

In all these cases, research must determine where the resource is in terms of its level of productivity and the associated rate of increase or decrease in productivity. In many cases the resource may be closer to depletion than managers or farmers believe. In the absence of research, it is nearly impossible to determine what the sustainable level of a resource actually is. Because of site specificity of resource systems -- cultural, climatic, economic, and physical differences between sites -- no two systems are identical.

### 5.6. Technology Development and Transfer

Resource management and sustainability, in many respects, represent a new frontier in technology development and transfer. The challenge now lies in adapting research results and methodologies, generated in developed countries and strategic research institutions, to highly complex ecological and socio-economic environments. The need for a multidisciplinary approach is clear. Flexibility in administration, and the mobility to move into new regions, to transfer results from one location to another, is critical. Innovation exists on each frontier.

The four provincial and a national research centre have a common objective the optimization of resource use in a broad range of environments. The means for doing this is the development of appropriate management strategies; the end is sustainable production and a strong resource base for the future. In that context five themes run through the work of each centre. First, the research identifies and characterizes disadvantaged areas. Second, the research is holistic and multi-dimensional in nature, and requires a multidisciplinary approach. Third, the research must identify appropriate management practices or the particular resources, and whether or not such practices are being used. Fourth, a relationship must be identified between the economic development of a particular resource and the associated impact of that development on the environment. Finally, the work of each center must assist in developing the institutional capacity in the country to respond to and adapt to change.

The introduction of any technology, whether it is an improved crop variety, an improved agricultural practice, or a research methodology, requires a change in behavior on the part of resource users and managers. That means that the new technology must fit into the socio-economic and ecological environments in which it will be used. It must be both adaptable and adoptable. As the centres help lead the way into the less advantaged areas, which are often characterized by low productivity potential, large variability, and great fragility, it is essential that their first step be to characterize these areas.

Such characterization becomes increasingly complex as researchers move from more favoured to less advantaged areas. Specialized knowledge of the specific resource problems becomes increasingly important. The required research demands a holistic approach to resource use and management. Such an approach takes into account the multiple dimensions that each manager or user confronts in the field-- physical, social, economic or financial, and biological. Together, and independently, the forces and pressures exerted over time from within these various dimensions shape the supply and demand of a resource, and thus its sustainability. Research into resource management cuts across all these dimensions and responds to their total impact. A multidisciplinary approach is thus essential and common to all the centres.

Equity, which involves raising the income level of the poorest farmers and resource users, is a central issue in resource management. This implies a consideration of management, the rights of ownership--land, fisheries, and water rights and the rules that govern the access to a resource. In many, and perhaps most, cases inequity results from a lack of proper management.

Similarly, research must determine the proper relationship between the economic development of a resource and the environment. It is one thing, for example, to deal with externalities in a situation of high population densities. It is quite another to deal with them in a low population density situation. Similarly, the techniques used for improved resource management will be one thing in a situation where population resources are being drained out of an area. They will be something quite different when population is flowing into the region. And finally, water management problems and the techniques for improved use of water is one thing in a region that needs to diversify out of rice production. They are quite different in situations where prevailing water use is less intensive.

### 5.7. Institutional Issues

At the heart of the sustainability problem are the institutional arrangements that are charged with solving these problems. Institutions so charged must be able to change, adapt, and respond to the opposing forces or trends that impact a resource and its use. Ultimately, they must develop the capacity

to manage the adaptive change process themselves. This requires both technical knowledge and knowledge of the social, economic, and political factors which influence and govern the resource use.

Building institutional capacity and capabilities among provincial institutions is a central focus of the national centre. It is critical if cooperating institutions are to take an active part in research. And it is central to their mandates.

In the past three decades a significant gap has developed between what could be and what is in terms of the potential for research to aid provincial institutions in managing and developing their natural resources. There is an opportunity to develop full cooperation among the four provincial centres and a national centre to overcome the problems of sustainability now faced in the country. These institutions, with the support of federal government, can develop the critical mass necessary to further this pioneering effort.

An important feature of the present situation is the complementarity of the existing research institutions and programmes, both among themselves and with other international research centres, such as the CGIAR system. For example, biological innovations tend to be the stock in trade of the existing collaborating centres. But those biological innovations will not realize their full potential unless they are introduced and managed in the context of improved knowledge of the underlying resource base. That base includes soils, water, and modern inputs such as fertilizers and the management of pests. In this sense, the improved management of the underlying resources is the basis for improved management for obtaining a higher payoff from the existing research centres.

Similarly, little progress can be made in the growing use of agroforestry systems without access to the new crops and livestock technology produced by the research centres. In this sense, management of soil, water, and forestry resources is dependent on easy access to and close relationships with the research centres. Similarly, the full potential of fisheries resources to contribute to food production, and to the diversification of income, should also be realized in this same context.

Finally, there is a great deal of complementarity among the existing resource-oriented centres. Water management, knowledge of soils, and the use of fertilizers are obviously highly complementary with each other. But they are also complementary with insect management, with the recycling and establishment of forests, and yes, even with aquaculture.

### 5.8. Comprehensive Performance Assessment System

The development and introduction of performance assessment methodologies is an effective and necessary first step in bringing changes in OFWM programmes. Consistent use of performance indicators by research and development agencies generate information which provides the basis for defining monitoring and evaluating improved operational procedures.

The performance indicators can be grouped into three types:

- Ø water availability and management performance;
- Ø agricultural productivity and production performance; and
- Ø economic, social and environmental performance.

The major components of the performance assessment system are:

- Ø identification of objectives and performance indicators for research, training and implementation;
- Ø quantification of these indicators in selected systems through an integrated approach and by an interdisciplinary team;
- Ø development and specification of targets or assessment norms against which the actual values of performance indicators are to be compared; and
- Ø Comparison of actual values of performance indicators with targets and assessment norms to derive conclusions regarding the performance level of the command for a given period.

It is important to consider linkages between objectives and performance indicators. The objective of the policy maker may be one or more of the following:

- Ø maximizing irrigated area from given supplies of water;
- Ø meeting targets of food security and self-sufficiency;
- Ø employment for the unemployed rural communities;
- Ø equity - providing benefits to unempowered;
- Ø poverty alleviation for the rural communities including women; and
- Ø profitability and sustainability;

The performance indicators must be selected to reflect such concerns. The linkages between objectives and performance indicators are presented in Table 12.

The selection of relevant performance parameters will depend on the interest of the policy maker in assessing the contributions made by the irrigated agriculture.

In contrast to the policy maker, the concerns of the irrigation manager and OFWM specialists, would relate more specific aspects of management of irrigation system e.g., adequacy, predictability, equity and reliability. The farmers are interested about the effect of water supply on agricultural/farm productivity and net profitability (Table 12).

The preferred set of performance indicators is needed so that data can be collected in a timely and cost-effective manner. This set of indicators will vary based on site, specific conditions. To have appropriate set of indicators, there is a need to conduct field research to quantify the cost of measuring various indicators, ease of data collection by alternate methods (e.g. Sample Surveys, PRAs, GIS); and statistical reliability of each indicator. Hence, there is a need to field test a relatively large number of indicators in order to generate the desired information.

Once the type of performance indicators have been identified, the next step is to develop and quantify targets. Also outline indicators which will be used for comparison with the actual values of each performance indicator.

In order to generate data to develop assessment standards for OFWM projects, it is suggested to collect information on a limited set of indicators for a relatively large number of projects. These set of indicators include:

- Ø irrigated area per unit of water (surface and groundwater);
- Ø cropping intensity on a watercourse command;
- Ø crop yields of major crops; and
- Ø waterlogged and saline area on a watercourse command.

These assessments can be used to identify the determinants on account of which the performance falls short of potential values. This information can be used in selection of interventions for OFWM, or diagnostic analysis to evaluate the performance of the introduced interventions.

The diagnostic analysis should be organized based on participatory approaches so that community is involved in the planning and evaluation phasis.

### 5.9. Role of NGOs in Social Initiatives

The OFWM specialists must build the programme around the rural community so that people are directly involved in the regular planning and programming process. The existing Water Users' Associations in the irrigated areas may be the starting point to build multi-purpose community organizations. The command area concept is to be adopted considering the systems approach and the natural linkages and interdependencies. If left to the initiative of individual manager or specialists, the specific problems of the complex rural systems of resource-poor farmers might not be adequately brought into focus. There is strong tendency for scientists and engineers to become increasingly specialized as they move in the career.

An explicit regional approach to priority - setting and planning in Punjab Command Water Management Programmes and Idara-e-Kissan, Hala Livestock project has proved useful in Punjab. Sarhad Rural Support Programme in NWFP and Balochistan Rural Support Programme in Balochistan are good examples as well. Agha Khan Rural Support Programme in Northern Areas presents a highly useful example of community development in hard hit areas of NWFP.

The experience of Rural Support Programmes in Pakistan in the last decade provides an opportunity to evaluate possibilities for adoption of NGOs approach on larger scale in the Indus basin with required modifications considering the social stratification and capital shortage. One of the major misconception with Water Users' Association approach is that there is no associated cost to organize community. For instance, major cost components in OFWM programmes are either physical or biological. The formation of WUAs is considered as a pre-requisite and no resources are kept for the sustainability of WUAs. In contrast, the Rural Support Programmes, overemphasized the investment required for community organizations. On an average, about Rs. 200,000 to Rs. 300,000 are required to form and sustain the village organizations for the initial 2 years. The provision of support in physical infrastructure is additional to this cost.

## 5.10. Role of Commercial Enterprises

There is a need to develop an effective mechanism and collaboration between research institutions, NGOs and commercial enterprises to improve the efficiency of generating and diffusing technology. It is not possible for NGOs to take over the role of technology generation and diffusion. There is a need to expand the collaboration of commercial enterprises with research institutions so that desired technology can be generated considering the domestic resources and regional requirement.

The research institutions would generate appropriate technology on a recurrent basis in collaboration with commercial enterprises so that the transfer to end-users can be made effectively and efficiently. For instance, the MONA Reclamation Experimental Project and CSU - Field Team developed a model of such collaboration in the fabrication of pre-cast nakkas through Husnain Concrete Works, Sargodha. Such structures are now being sold in small towns by a number of small scale enterprises or retailers.

The other good example is the development of small scale enterprises in Orangi Town of Karachi to fabricate cement blocks and sewerage structures through providing technical information and credit to local people by the Orangi Pilot Project, Karachi. Over 6000 streets were provided sewerage facility by the community.

Similarly, the WRRI-NARC in collaboration with pump and plastic industry developed a model of such collaboration in the indigenization of sprinkler and trickle irrigation systems.

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**Table 1. Land Classification.**

| Type of irrigation | | Area (mha) | % age |
|---|---|---|---|
| 1) | Canal Irrigation | | |
| | - Perennial | 8.19 | 10.3 |
| | - Non-Perennial | 5.80 | 7.3 |
| | - Culturable waste inside CCA | (-)2.25 | (-) 2.9 |
| | Sub-Total: | 11.74 | 14.7 |
| 2) | Wells, Streams, Karezes, etc. | 5.22 | 6.6 |
| 3) | Sailaba (Riverain) | 1.25 | 1.6 |
| 4) | Sailaba (Torrent) | 0.97 | 1.2 |
| 5) | Barani (Rainfed) | 4.15 | 5.2 |
| | Sub-Total: | 11.59 | 14.6 |
| 6) | Total Cultivable Area | 23.33 | 29.3 |
| 7) | Other Land Uses | | |
| | - Range lands | 8.62 | 10.9 |
| | - Forests | 3.44 | 4.3 |
| 8) | Total Suitable for Agri. & Forestry | 35.39 | 44.5 |
| 9) | Total Unsuitable for Agri. & Forestry | 44.22 | 55.5 |
| 10) | Total Area of Pakistan<br>100.00 | | 79.61 |

Source: Agriculture Statistics, 1992.

**Table 2. Indus Plains Irrigated Area Affected by Salinity.**

| Type of salinity | Area (%) | |
|---|---|---|
| | 1953-65 | 1977-79 |
| Surface salinity | 32 | 26 |
| Profile salinity | 45 | 39 |

Source: Survey and research organization, Planning Division, WAPDA, 1981.

**Table 3. Surface Salinity (Percent of Area Surveyed).**

| Province | Area* Surveyed (mha) | Salinity Classes** Slightly saline | Moderately saline | Strongly saline | Total saline | Salt free |
|---|---|---|---|---|---|---|
| NWFP | 0.62 | 9 | 2 | 2 | 13 | 87 |
| Punjab | 10.17 | 7 | 4 | 3 | 14 | 86 |
| Sind | 5.58 | 19 | 11 | 18 | 48 | 52 |
| Balochistan | 0.35 | 17 | 5 | 4 | 26 | 74 |
| Pakistan | 16.72 | 12 | 6 | 8 | 26 | 74 |

* Representative of cultivable area out of 16.72 mha surveyed in 1978-79.

** ECe: salt Free < 4, saline-slight 4-8, Moderate 8-15, strong > 15.

Source: Survey and Research Organization, Planning Division, WAPDA.

**Table 4. Nature and extent of soil salinity**

| Salinity Classes | Area (%) 1962-65 | 1977-79 |
|---|---|---|
| Nonsaline and non-sodic | 55 | 61 |
| Saline | 6 | 11 |
| Saline and sodic | 27 | 24 |
| Non-saline and sodic | 11 | 3 |
| Miscellaneous | 1 | 1 |

Source: Soil Salinity Survey, Vol-II, data by Canal Commands, WAPDA, 1981.

**Table 5. Indus plains trends of water-table depths**

| Type of Land With Water-table Depth | Area (%) 1953-65 | 1977-79 |
|---|---|---|
| Very poorly drained (0-1 m) | 2 | 7 |
| Poorly drained (1-2 m) | 11 | 15 |
| Moderately drained (2-3 m) | 23 | 20 |
| Well drained (greater than 3 m) | 62 | 55 |
| Miscellaneous | 2 | 3 |
| Total area (water-table within 3 m) | 36 | 42 |

Sources: Survey and research Organization, Planning Division, WAPDA, 1981.

**Table 6. Indus plains province-wise trends of water-table depth (Area in %).**

| Province | Total Area (mha) | Water-Table Depths (m) < 1 | 1-2 | 2-3 | >3 | Misc | Total < 3 m |
|---|---|---|---|---|---|---|---|
| Punjab | 10.17 | 7 | 11 | 17 | 63 | 2 | 35 |
| Sind | 5.58 | 6 | 24 | 27 | 40 | 3 | 57 |
| Balochistan | 0.35 | 1 | 6 | 9 | 84 | 0 | 16 |
| NWFP | 0.62 | 6 | 12 | 6 | 66 | 10 | 24 |
| **Total** | **16.72** | **7** | **15** | **20** | **55** | **3** | **42** |

Source: WAPDA's Survey of 16.72 mha, 1977-79. Revised Action Programme for Irrigated Agriculture.

**Table 7. Mean annual rainfall.**

| Place | Mean annual rainfall (mm) |
|---|---|
| Jacobabad | 90 |
| Hyderabad | 180 |
| Multan | 180 |
| Karachi | 200 |
| Quetta | 240 |
| Lahore | 500 |
| Islamabad | 920 |
| Murree | 1500 |

Source: Irrigation and Drainage in the World, ICID Publication, Vol. II, 1982.

**Table 8. River flow supplies.**

| River | River Flows (bcm) | | |
|---|---|---|---|
| | Highest | Mean | Lowest |
| Indus | 148 (1959) | 114 | 88.5 (1971) |
| Jehlum | 33.8 (1958) | 27.3 | 19.0 (1970) |
| Chenab | 39.0 (1958) | 32.1 | 23.0 (1940) |

Source: Irrigation and Drainage in the World, ICID publication, Vol. II, 1982.

**Table 9. Surface storage.**

| Particulars | completion | Live Storage (bcm) |
|---|---|---|
| Mangla | 1968 | 6.5 |
| Chashma | 1972 | 0.6 |
| Tarbela | 1975 | 10.6 |
| Sehwan Manchar | 1982 | 2.2 |
| Raised Mangla | 1986 | 6.6 |
| Chotiari | - | 1.1 |
| Kalabagh | - | 7.9 |

Source: Proceedings of National Seminar on Waterlogging and Salinity, 1986, WAPDA, Lahore.

**Table 10. Siltation in the reservoirs.**

| Storage Reservoir | Original Gross Storage (bcm) ------ Year | Least (bcm) ------ Year | Siltation (bcm) | Annual Loss of Capacity (bcm) |
|---|---|---|---|---|
| Tarbela | 14.0 (1975) | 12.7 (1986) | 1.3 | 0.12 |
| Mangla | 7.3 (1967) | 6.6 (1985) | 0.7 | 0.04 |
| Chashma | 1.1 | 0.6 | 0.5 | 0.04 |

Source: Water resources Management Directorate, WAPDA.

**Table 11. Water losses computation in watercourses.**

| Investigation | % Losses reported |
|---|---|
| Earlier Studies (1 | 28.6 |
| Kennedy | 28.3 |
| Benton | 27.3 |
| Blench | 10.0 |
| Hunting Macdonald | 13.9 |
| Irrigation Research Institute | 15.0 |
| Expert Committee on Water Losses | 15.0 |
| Recent Studies (2 | 40 to 50 |
| Colorado State University | 47.0 |
| CSU/WAPDA (40 WC) | 45.0 |

Sources: Master Planning and Review Division, Water and Power Development Authority.

1) Last three post-water and exclude farmers channels.

2) Include farmers channels.

**Table 12. Linkages between objectives and performance indicators**

| User Groups | Type of Objective | Type of Performance Indicator |
|---|---|---|
| 1. Policy Maker | Food Security | - Food grain production as ratio of demand.<br>- Foreign exchange earnings/savings. |
| | Productivity | - Cropped area per unit of water.<br>- Gross return per unit of water. |
| | Equity | - Benefits to small farmers, tail-end farmers.<br>- Additional employment. |
| | Sustainability | - Area under salinity and waterlogging.<br>- Water quality.<br>- Area under fresh water zone with shallow water table. |
| 2. Irrigation Manager | Reliability | - Delivery performance ratio |
| | Adequacy | - Relative water supply. |
| | Predictability | - Ratio of actual to planned duration of water supply. |
| | Productivity | - Production per unit of water. |
| 3. OFWM Specialists | Equity | - Benefits to tail-end farmers. |
| | Adequacy | - Relative water supply. |
| | Productivity | - Production per unit of water, land and labour. |
| | Profitability | - Net value of additional output. |
| 4. Farmers | Predictability | - Ratio of actual to planned duration. |
| | Profitability | - Net value of additional output. |

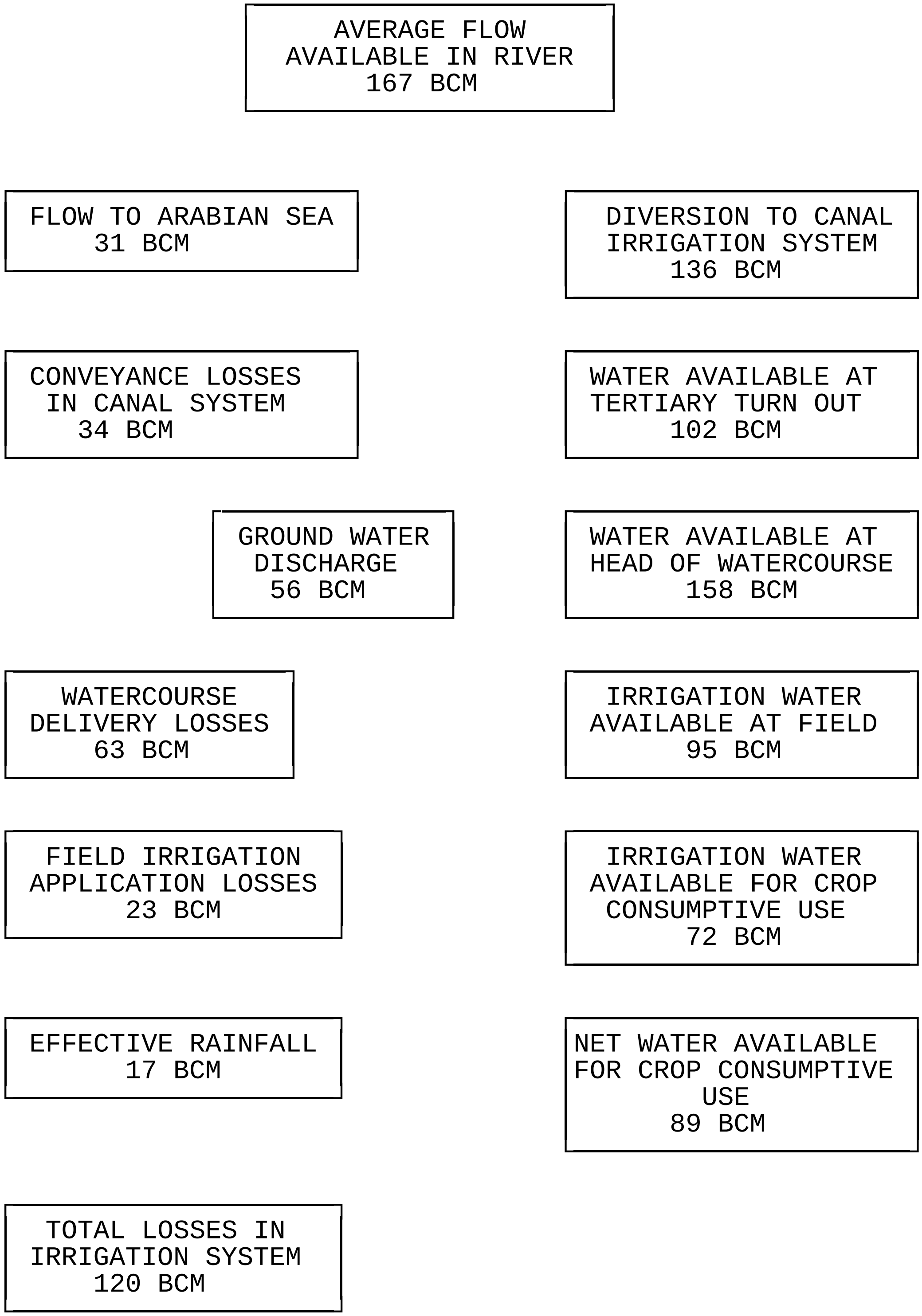


Figure 2. Water Budget of Indus Basin Irrigation System.

## PHYSIOGRAPHIC REGIONS

I INDUS DELTA
II SOUTHERN IRRIGATED PLAIN
III SANDY DESERT (a & b)
IV NORTHERN IRRIGATED PLAIN (a & b)
V BARANI LANDS
VI WET MOUNTAINS
VII NORTHERN DRY MOUNTAINS
VIII WESTERN DRY MOUNTAINS
IX DRY WESTERN MOUNTAINS
X SULAIMAN PIEDMONT

Figure 1. Physiographic Regions of Pakistan.