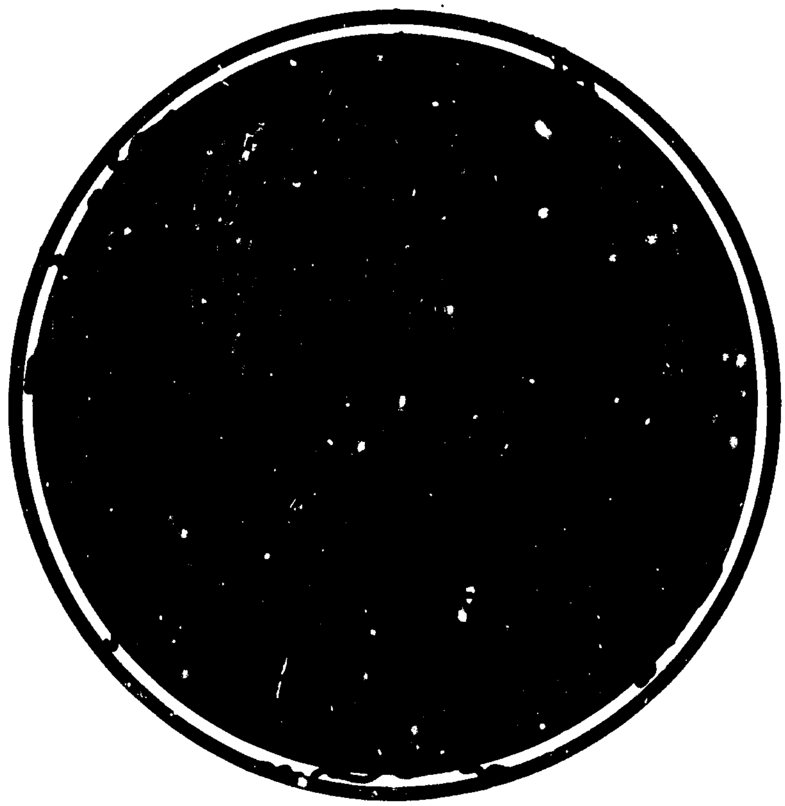

IRRIGATION DEVELOPMENT OPTIONS AND INVESTMENT STRATEGIES FOR THE 1980'S

PAKISTAN

USAID

WATER MANAGEMENT SYNTHESIS PROJECT

WMS REPORT 4

PAKISTAN/USAID

IRRIGATION DEVELOPMENT OPTIONS AND INVESTMENT STRATEGIES FOR THE 1980'S

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WMS Report 4

PREFACE

This study was conducted as part of the Water Management Synthesis Project, a program funded and assisted by the United States Agency for International Development through the Consortium for International Development. Utah State University and Colorado State University serve as lead universities for the project.

The key objective is to provide services in irrigated regions of the world for improving the design and operation of existing and future irrigation projects and give guidance to USAID for selecting and implementing development options and investment strategies.

For more information, contact the Water Management Synthesis Project for information about the project and any of its services.

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FOREWORD

This report was developed to focus on AID's past effectiveness in assisting irrigation and the expected priority, size and nature of future irrigation efforts country by country. It includes recommendations for directing any renewed USAID assistance programs in irrigated agriculture during this decade in Pakistan.

The review team visited Pakistan between July 25 and August 2, 1980, to develop this report. The members of this team were:

Jack Keller, Team Leader and Agricultural Engineer
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Thomas F. Weaver, Agricultural Economist

The team's visit was preceded by Dr. Max Lowdermilk, Water Management Extension Specialist, who set up, scheduled, gathered and analyzed information in advance of the team visit. The team concentrated on the following development issues and strategies, as outlined in the Levine report (see WMS Report No. 3: Bangladesh/USAID Irrigation Development Options and Strategies for the 1980's): (1) irrigation vs. rainfed; (2) expansion vs. intensification; (3) large projects vs. small; (4) hardware vs. software; and (5) main system vs. on-farm, giving major emphasis to (1) and (2).

The report which follows was developed from information gathered during the interviews with Government of Pakistan officials, AID Mission personnel and a review of many of the related documents available at the AID offices in Islamabad with primary reliance upon the listed references. In addition to interviews and document reviews, the team visited both improved and unimproved watercourses in the Northwest Frontier Province near Peshawar and in Punjab Province in the vicinity of Sargodha, plus the facilities at the Mona Reclamation Experiment Project.

The team appreciates the cordial support which was provided by AID Mission personnel and extends special thanks to Mr. Ed Rice for his assistance. We are also grateful for: the candid interview with Mr. A.M.H. Kango, Director (Water Management), Ministry of Food, Agriculture and Cooperatives; the assistance of Mr. Mohammed Munn, Director of the Water and Power Development Authority (WAPDA) Reclamation Project at Mona, for his assistance in showing the team various research activities and water management demonstrations; and Mr. Saeed Ahmad Bhatti, Water Management Coordinator, for accompanying the team on field visits of watercourse improvement projects near Sargodha.

SUMMARY AND RECOMMENDATIONS

The Indus Basin irrigation network supplies water to 13.6 million hectares of land. This is the world's largest continuous interlinked irrigation system. There is relatively little surface storage in the system and most of the canal water is diverted directly from rivers. Water conveyance and application efficiencies are low. This causes waterlogging and salinity problems, but it also recharges the groundwater aquifer. Since existing and potential surface storage is insufficient to meet peak use rate demands, tubewells to tap the very large groundwater reservoirs are an important component of the comprehensive irrigation system. This conjunctive use of surface and groundwater is also important in efforts to control waterlogging and salinity.

The unlined canal systems deliver continuous flows of 1 to 3 cfs (30 to 60 lps) to command areas which usually exceed 250 acres (100 hectares) for each cfs (30 lps). Unlined public watercourses were originally constructed along with the main canal system. These watercourses are maintained and operated to deliver 1 to 1.5 cfs flows through earth outlets on a fixed weekly rotation schedule (waribundi) to each farmer's fields. Typical operational holdings range from 10 to 25 acres, and in accordance with the waribundi schedule, each farmer is supposed to receive the full watercourse flow for a length of time proportional to the area of his holdings.

The public watercourses are poorly maintained, field ditches are usually inadequately graded for efficient irrigation. Thus, cropping intensities have not improved to the degree expected and crop yields have remained low in spite of the costly development of major storage dams, barrage and canal systems, and tubewells. It has become evident that more cost effective means of increasing irrigation water availability must be pursued -- one such is that of improving water management at watercourse and field levels. With this in mind, both the World Bank and Asian Development Bank are presently considering loans totaling over $100 million with the major emphasis on watercourse and distribution system improvements and surface drainage.

The principal watercourse improvement activities suggested in these Bank projects involve unlined channels. The pending Bank projects provide little support for: adaptive research to develop and test model projects; train the technical staff needed to design, construct and monitor the projects; and conduct studies to move strategically targeted investments in terms of water tables and conjunctive use.

In addition to the 13.6 million hectares of cultivated land which can potentially be served by irrigation, there are approximately 5.9 million hectares of cultivated land that depend entirely on rain. Much of this rainfall area is in hilly regions and this is where poverty is greatest.

The main text contains additional descriptive and background information for the recommendations which follow. The recommendations are presented to provide guidance for any future USAID investments in irrigated agriculture in Pakistan during the decade of the 1980's.

1. The study team endorses an AID strategy that fully develops the potential for irrigation. It recognizes, as discussed elsewhere in this report, that the potential for creating a new irrigation capability is limited. Given this, a dual strategy of addressing both irrigation and rainfed agriculture seems highly appropriate.

2. It is apparent that there is only limited potential for expansion; i.e., 120 Billion Cubic Meters (BCM) current withdrawals (from the river inflows to the Indus Basin) vs. 139 BCM potential. The team suggests that some of this potential for expansion be directed to: rainfed hill areas by developing small reservoirs (tank) projects to provide supplemental irrigation; and possible tubewell developments outside of existing command areas where water depths and quality are suitable. This would be one way of addressing the equity issues and providing benefits to those farmers most in need. The study team also suggests that any studies of tank or tubewell development include a consideration of the new technologies (low pressure sprinkler, buried pipes of various designs and layout configurations, and so forth) which are under development in India and Bangladesh.

3. Since the pending Bank projects are heavily focused on financing watercourse improvements, the study team recommends the following programs as appropriate for USAID's dealings with intensification within the existing Indus Basin irrigation command area:

    a. An evaluation of the existing shallow tubewell pumping in terms of: present (and projected) numbers, distributions, capacities and duration of operation per year; and static and dynamic lifts, drawdown charcteristics, service life and overall pumping plant energy use efficiencies.

b. A general analysis of the existing irrigation system (including conjunctive use) to develop overall basin, subbasin and specific area models of water balance, water quality and drainage projections for different development and improvement scenarios.

c. A comprehensive economic analysis of the tradeoff between: canal, watercourse and on-farm irrigation improvements; development and operating costs for deliveries more nearly on a requirement or demand basis; and shallow tubewell development and operating costs in light of inflating energy costs and pending shortages.

d. If appropriate in light of the above, a program of shallow tubewell development that compliments total water resource management.

e. An applied research and development program to improve the cost effectiveness of shallow tubewell pumping plants in terms of investment cost, maintenance, operating costs and discharge capacity for the ranges of pumping lifts encountered. After selecting and development the ideal pumping plants, provide aid to existing pumps and power unit manufacturers to develop in-country capability to produce the units.

f. Aid in extending rural electrifications to service shallow tubewells and consider possibilities for increased generating capacity by direct river-run hydroelectric power plants.

4. The team recommends that AID support increased emphasis on the importance of promoting water users organizations which are politically acceptable and the role they must play in improving on-farm water management and better use of the water resource. In close association with this, and in view of the Bank's watercourse improvement program, the study team believes AID should support the development and distribution of training materials and also support training programs for field and professional personnel. The efforts which AID has already expended in this direction appear to have been thoughtful, well executed and valuable.

5. The team feels a continuation of the adaptive research programs developed under earlier AID projects are essential to provide models for the large pending Bank projects and

make better use of the available water. Given the upper limit on water availability, production increses in the foreseeable future will be totally dependent on: an aggressive research system; and an efficient extension and training network. This area of development can scarcely be overemphasized, and the review team recommends that AID provide significant support for adaptive research to improve water management and crop production under both rainfed and irrigated agriculture.

PAKISTAN/USAID

IRRIGATION DEVELOPMENT OPTIONS AND INVESTMENT STRATEGIES FOR THE 1980'S

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INTRODUCTION AND BACKGROUND

Agriculture is a major sector in Pakistan's economy. In FY 1978-79 it accounted for about 32 percent of Gross Domestic Product (GDP), employed 57 percent of the total labor force, and accounted for an estimated two-thirds of the country's export earnings. The growth of agricultural production declined from 8 percent per year in the decade ending 1969-70 to 1.2 percent from 1969-70/1978-79. This reduced agricultural performance partly reflected a slowing of productivity increases after the Green Revolution of the late 1960's; however, production has improved in recent years when good climatic conditions prevailed.

Wheat, rice and maize are the main cereals produced, and cotton and sugar cane are the principal cash crops. Average yields are low because of inadequate support services, inefficient irrigation and insufficient agricultural inpouts. The production of wheat, Pakistan's main staple, has been less than the nation's requirements and the gap has been filled by imports which now average more than one million m.t. annually. Wheat production in 1978-79 increased by 18 percent over the previous year to 9.9 million m.t. Production of rice, a major export crop, in 1978-79 attained a record level of 3.3 million m.t., an increase of 11 percent from the previous year. Production of cotton (which tends to be lower during a good rice year), also an important agricultual export, decreased by 18 percent to 473,000 m.t. in 1978-79.

The country's agricultural development program, as set out in the Fifth Five-Year Plan for 1978-79/1982-83, called for major increases in food and cash crop production. Attainment of the Plan's production targets would significantly contribute to economic development and improved export earnings would ease the country's balance of payments difficulties. The government, accordingly, is pursuing the following agricultural policies and programs in line with the production goals:

1. Improvement of agricultural infrastructure, including irrigation and drainage works, and the reclamation of saline and waterlogged areas.

2. Increasing the availability of agricultural inputs.

3. Improvement of technical knowledge through research and extension services and farmer training in water management.

4. Institutional improvements, including land reforms, better

agricultural credit availability and development of the marketing system.

5. Provision of economic incentives through appropriate pricing policies.

Because of the country's relatively dry climate, intensive cultivation is possible only under irrigated conditions. Of the country's 19.5 million hectare cultivated area, about 70 percent (13.6 million hectares) is at present irrigated. Irrigated areas have been increased by more than 2.5 million hectares during the past decade by means of construction or improvements of major storage dams, barrage and canal systems and tubewells. Despite the costly efforts, cropping intensities have not improved to the degree expected and crop yields remain low. It has become evident that more cost effective means of increasing irrigation water availability must be pursued -- one such is that of improving water management at watercourse and field levels.

Existing Irrigation System

The existing irrigated area is served by an interesting system. Perennial canals have an almost steady flow throughout the year with at least a one month shutdown in January for maintenance. River flows are only sufficient to operate the perennial canals an average of 300 days/year and the range is 241 to 336 days/year. The main distribution network is composed of huge main canals which serve large distributary canals (which, without forewarning the farmers, are shut off on a rotational basis during periods of low river flows) that feed groups of minor canals. Non-perennial canal systems have a similar setup, except they only operate for an average of 180 days and the range is 124 to 228/year. Control structures are fixed and the minor canals serve groups of watercourses from fixed (always open) outlets along the minor canals which continually deliver a relatively fixed quantity of water.

This relatively constant flow of water is delivered to the farmers through their public watercourse on a rotational basis. The rotation schedule, called a waribundi, is usually once per week with all of the available water flowing through one single farm turnout at a time. Usually the rotation starts from the first turnout downstream from the outlet at the minor canal and proceeds to the end of the watercourse with the length of time each turnout receives water estimated from the proportion of land served by the turnout compared to the total land under command of the watercourse. (Obviously, the farmers at the end of the watecourse recive less water than those near the beginning because of losses along the watercourse.) Water discharging from each turnout is transported to the individual fields through networks of field channels built by the individual farmers themselves. All channel construction and rotation of water past the turnouts is handled by the farmers involved.

The fixed weekly rotation schedule and constant flow rate gives farmers a constant quantity of water per week regardless of crop requirements. Farmers try to select cropping programs (different crop, planting dates and cropped areas) to have constant water requirements to match the rather constant supply, but it is not possible to match it very well. One suggestion might be to let farmers have water in demand, but considering the overall irrigation system and the complexity (from the standpoint of both hardware and management requirements) of a demand system, a demand system is totally impractical.

Fortunately, because of the high water table throughout practically all of the Indus Basin, supplemental water can be pumped on demand to provide the degree of flexibility which is needed to compliment the constant supply rotational canal delivery system. Thus, the conjunctive use of groundwater partially provides the desired demand component and a degree of flexibility for the fixed flow canal system. Furthermore, the pumped groundwater provides needed water during periods when canal deliveries are not yet available (annual and unscheduled shutdowns of perennial canals and short runs for non-perennial canals). Unfortunately, the salinity in much of the groundwater is quite high and it must be blended with high quality canal water to make it more suitable for irrigation.

USAID On-Farm Water Management Project

A five-year pilot on-farm water management project was launched in 1977 with a $22.5 million loan from USAID to improve 1,500 watercourses serving about 175,000 hectares in selected areas. Technical assistance was provided through a contract with the Soil Conservation Service and the Pakistan Ministry of Agriculture was the operating agency. While progress of this project has been slower than expected, implementation has progressed and it is estimated that about a third of the project target area has been reached.

Improvement of these watercourses involves properly engineered reconstruction in terms of proper size, gradients and alignments; selective lining (about 10 to 15 percent lined and the rest compacted earth section); an installation of permanent, formal turnout structures and checks. A substantial function institutional base has been created under this project in all four Provinces of the country for:

watercourse improvement, water management extension and training and planning and implementation of future on-farm water management projects.

There has been considerble difficulty in establishing the returns from investment in the USAID On-Farm Water Management Project. There are several resons for this: (1) a lack of reliable data on changes in farming practice after completion of the projects; (2) a lack of experimental data for estimating the total and marginal value of water; (3) lack of complete analysis of the data that is available; and (4) a failure to establish the opportunity cost of the watercourse improvement investment.

Early in the water management project, analysis was made which recognized that any water saved by improved water management could be used to: (1) increase the quantity of water applied to areas already under irrigation; and (2) to bring additional acreage under cultivation. Accordingly, attempts were made to determine the marginal value of water for valuing additional water in areas already under cultivation and the average value of water for valuing additional irrigated acreage. These efforts produced production estimates at various levels of fertilizer application. The plotted functions indicate a higher marginal (lower average) response to increased water at low compared to higher fertilizer levels and a water use greater than estimates of ET based on climatic data. This latter conclusion may be correct because of percolation and runoff losses, but since water use is not defined in the study reports, it is difficult to judge the reasonableness of the estimate. Overall, a knowledge of production relationships in other regions does suggest caution in interpreting the study results.

The marginal product would normally be expected to be lower than has been estimated, particularly at the higher water application rates. An analysis of the significance of the coefficients would be useful for understanding this data. This point is somewhat critical because of the possibility that the water saved by the improved water management practices may be relatively low valued water. Indeed, it has been estimated by other sources that on the average, farmers are only applying sufficient irrigation water to meet 60 to 70 percent of the crop water deficit, but that this quantity of water is supplying 85 to 90 percent of the crop potential under prevailing husbandry techniques. Given a declining marginal product, this suggests a very "rational" approach to water application on the part of the farmers. It implies that the farmers are well aware that water is best managed by equating the incremental benefit to the incremented cost of water. This, for example, seems true in the case of private tubewells where we note that there is unused pumping capacity. It is estimated (and we observed this during our field interviews) that the average private tubewell is only pumped between 20 and 30 percent of the available time.

It is useful to consider another implication of this possibility. It has been noted that there are very frequent cases of water stealing, and this is cited as evidence of the demand for greater quantities of irrigation water. In actual fact, it may be well that the demand for water is quite high if water can be obtained at zero cost (assuming that there are no costs associated with stealing). This tells you nothing about the demand for water at the price at which it is available from water management improvement or from tubewells.

The project analysis also attempted to establish benefit/cost (B/C) ratios for improved water management under: (1) varying ratios of lined to rebuilt and improved unlined channel; and (2) under several scenarios with improved unlined channels plus routine maintenance and with heavy maintenance only. These analyses assumed that the water saved was applied to leveled fields, meaning that the irrigation efficiency, and thus return to irrigation, were at a maximum. The analysis did note that reduction in benefits would be necessary if this was not the case. And indeed, as it turns out, land leveling has virtually been eliminated from the present water management project.

Another difficulty in estimating the benefits was the necessity to use a linear interpolation between the extreme values for estimating water channel losses at midpoint situations. Also, since soil type and supply rates are not included as a variable (i.e., channels in sandy soil with low supply rates are likely to have proportionally higher seepage losses than in clay soil with high supply rates), the results are difficult to interpret. In addition there are no estimates of the variance of the extreme values, so it is not possible to establish likely site applicability of the B/C conclusions.

To summarize, the early analysis of benefits was frustrated at every turn by data limitations, not all of which are discussed here. In fact, considerable ingenuity was required to develop the estimates which were possible.

Several important observations were made early in the project development, three of which are:

1. That if watercourse improvement did increase water deliveries without a subsequent improvement of watercourses (field branches) in farmers' fields, a portion of the increased

flow would be lost to seepage and overflow in that portion of the distribution network. However, data were not available to incorporate this into the economic analysis of costs and benefits.

2. The assumption that water losses are not recoverable holds only where groundwater is too saline for use.

3. In low water supply areas, the first priority is to increase water supplies, which may be most effectively done, not by watercourse improvement, but by shallow tubewell development.

In addition to the direct benefits of more efficient water use and control to farmers along the improved watercourse, and in view of the second observation, it is possible that the lining of the watercourses will have much of their benefit in reducing salinity and water logging over a relatively wide area. In this case, a more equitable method of financing a portion of the improvements would be out of the general revenue fund. The cost of these improvements might then in large proportion be charged to all farmers in the area by an increase in general land revenue charges.

Although the analysis to support the third observation is not available to the study team, there is evidence that water supplied by tubewells is of higher value than that saved by water management because it is available on a demand basis. One would expect that farmers would demand water at those times when its marginal value is the highest (that is, they would supplement the canal water with tubewell water during peak demand periods, or when canal water is shut off). Water saved by watercourse improvement cannot be stored for use in the periods of the season where the response to water is highest. However, storing water in the groundwater aquifer is a reality. It should be pointed out that the water saved by watercourse improvements can be effectively used to expand the area irrigated since a canal discharge of 1 cfs typically serves a 250 acre or larger command area; but tubewell water would still have a higher value for peaking and backup purposes. However, energy costs and availability do restrict tubewell pumping.

More recent project studies (1979) on the effects of watercourse improvement do not shed much additional light on the potential benefit streams. In these studies, management practices of farmers with improved watercourses are compared with those of a control group. The differences are small, so that in the absence of any statistical analysis of differences in cropping intensities, labor use, yields and fertilizer use, it is possible to form impressions but not conclusions. Group interviews with farmers in the improved watercourse areas do suggest considerable support for the program. The interviews were not pointed enough to establish which components of the program the farmers were satisfied with.

These studies do show that watercourse efficiency decreased with the number of cropping seasons after improvement, i.e., maintenance programs have not been kept up. One possible explanation is the difficulty of organizing the farmers, or at least the lack of attention given to organizing them. Another is that the farmers do not perceive that the benefits are greater than the costs. In fact, after the installation of the pucca nukkas (concrete water control and turnouts), the farmers at the head of the watercourse may have received all the benefits that the program will ever provide them. The farmers between the middle and the tail end, who are the main benefactors, are left to bear most of the cost of maintenance, since they are receiving the greater portion of the ongoing benefits. With a smaller number of cultivators involved, the costs per cultivator are increased, perhaps to a point where cots are greater than benefits.

Even with the considerable efforts devoted to convincing farmers to maintain their improved earthen watercourses, maintenance has not been sufficient. Without continuous maintenance, the channels will rapidly degenerate. In two or three years, they may have as many leaks as before along the waterline. However, the lined sections and concrete turnouts are enduring improvements. The reason for the rapid deterioration of the earthen channel improvements is that the maximum leakage due to breaks and holes made by animals and insects (rats and ants, etc.) occur around the waterline on any canal. This is because they like to be right above the saturated zone, but not submerged. Without maintenance these waterline leakages soon reoccur. Evidence of this concentration of leakage at the waterline is presented in reports dealing with what is called "heavy cleaning." This practice involves extensive cleaning of both weeds and silt, plus repairs along the waterline. This heavy cleaning is much less costly in terms of manpower than constructing improved channels. Studies have shown that heavy cleaning results in lowering the water level in the channels by two or more inches and that 50 percent of the losses occur in the top two inches -- thus, significant savings at low cost. However, the animals and insects soon relocate and/or the water level raises due to new weed growth and silt, so the leakage will again increase.

Observations of Watercourse Improvement Program

Technical manpower requirements are staggering for either an extensive heavy maintenance program and installation of concrete checks and turnouts or a complete watercourse renovation program involving some lining and improved earth watercourses plus concrete checks and turnouts, etc. It is easiest to do heavy maintenance during periods that the main canal distribution system is shut down. A past attempt at a heavy maintenance and concrete checks program required 225 technical professional to be in the field for a two week period in order to handle only 105 watercourses. The complete renovations (lined plus improved earth channel watercourse) program requires a trained technician to work at the project site for from three to six months. However, if several (say 5) adjacent watercourses could be improved simultaneously, the same technicians can handle all of them simultaneously.

According to Mr. Saeed Ahmad Bhatti, the Water Management Coordinator (Faisalabad) for the On-Farm Water Management Development Project in the Punjab, this year's target for each of their 50 Land Development Officers and his team is three completely renovated watercourses plus 200 acres of precision land leveling. Thus, the target in the region is 150 improved watercourse plus 10,000 acres of precision land leveling. The officers hold B.S. or M.S. degrees in Agriculture or Agricultural Engineering, and are given a three month special training program which was developed by the AID-sponsored Colorado State Univesity Water Management Team. Considering this level of output per professional Land Development Officer, and the estimated 87,000 watercourses in Pakistan, points out the magnitude for providing sufficient training and manpower needs for extensive watercourse improvement programs.

According to Mr. Bhatti, his officers have been finding average steady state seepage losses (with all water flowing from the inlet to the last turnout) ranging between 30 and 40 percent in unimproved watercourses. Assuming a uniform spacing of turnouts and uniform duration of flow from each turnout, the average seepage loss would only be about 50 percent of the steady state loss, or 15 to 20 percent, i.e., on the average the water is only running half the length of the watercourses.

For 10 qually spaced turnouts along a watercourse, a percentage of the steady state seepage loss in each successive 10th of the watercourse length (beginning from the downstream end) is: 1%, 2%, 3%, 4%, 5%, 6%, 7%, 8%, 9% and 10% (sum = 55%). The accumulated percentage of the steady state loss for each successive 10th of the watercourse is: 1%, 3%, 6%, 10%, 15%, 21%, 28%, 36%, 45% and 55%.

Thus, if 40 percent of the watercourse is lined, the seepage loss would only be about 21 percent of the steady state losses, even if the rest of the watercourse were left unimproved. This would produce about the same overall benefit as lining 10 percent of the watercourse and constructing a new improved earth watercourse for the remaining 90 percent, or lining 20 percent and providing heavy cleaning for the remaining 80 percent.

The above improvements would require the following investments based on 150 Rs/m for lining, 60 Rs/m for an improved earth watercourse (assuming the farmers have an alternate market for their time at 15 to 20 Rs/day), and 15 Rs/m for heavy cleaning:

For 10% lined and 90% improved: (.1)(150) + .9(60) = 71 Rs/m
For 20% lined and 80% heavy cleaning: (.2)(150) + (.8)(15) = 42 Rs/m
For 40% lined and 60% left as is: (.4)150 = 60 Rs/m

While the 20 percent lined and 80 percent heavy cleaning provides the greatest initial benefit per unit cost, it also requires a continuous maintenance program (as does the 10 percent lining and 90 percent improvement program) which has proven to be difficult, if not impossible, to achieve. However, the "40 percent lining and 60 percent left as is" program will achieve similar initial benefits at a reasonable cost and requires no extra maintenance over the current standard practices.

DEVELOPMENT OPTIONS

The development options (issues) which will be addressed herein are: irrigation vs. rainfed; expansion vs. intensification; and large projects vs. small projects.

Irrigation vs. Rainfed

The total geographical area of Pakistan is approximately 79.6 million hectares. Of this, now only 19.5 million hectares are cultivated. Of the cultivated total, some 13.6 million hectares are irrigated and the remainder (about 5.9) depend solely on rainfall.

To date, the development of irrigated agriculture has been the primary dimension of agricultural development in the country. In addition, projects are currently under construction which will bring at least another one-fourth million hectares under irrigation. The reason for the emphasis on irrigation is readily apparent from a comparison of annual evaporation and annual rainfall.

As shown below, there is on the average a substantial water deficiency (measured as rainfall-evaporation) in both summer and winter in both the northern and southern rgions of the country:

Season	Water Deficiency (inches)*	
Winter	North	South
(Oct-March)	14.4	26.2
Summer		
(Apr - Sept)	25.4	46.4

*Measured as the difference between rainfall and evaporation

Clearly, with this climatic circumstance, irrigation is of obvious importance.

It is worth noting that the total water requirement for irrigation is generally higher in the summer (kharif) than in the winter (rabi) season even though rainfall is typically concentrated in the summer monsoon season. it is not surprising, then, to find that in the rabi season there is a smaller amount of irrigation water available from river diversion, but it irrigates a greater acreage.

The preceding is not the total picture. There are rainfed areas in both the north and western hill country which receive as much as 35 inches of rainfall. There are over four million acre in the Punjab and some two million acres in the Northwest Frontier Providence classified as rainfed. More than 10 million people live in these areas where wheat is the most important crop. In these areas, yields and farm income are typically low compared to irrigated agriculture.

In recent years, some attention has been directed at the rainfed areas. A 1972 study team specifically addressed rainfed agriculture. They generally recommended that studies be made of the opportunities to conserve soil moisture and increase infiltration of rainfall using husbandry and management techniques. The underlying rationale for this approach is that even in the areas which receive the highest rainfall, production is limited by both available rainfall and the rainfall distribution.

A different approach to rainfed farming has been developed under USAID Contract AID/NE-C-1217, "Dryland Agricultural Development - Pakistan Barani Project." This program was initiated in the early 1970's and involved the development of field testing and demonstration of agricultural practices which would improve production under rainfed conditions. Over 250 adaptive research and verification trials for rabi crops were planned for the rainfed ares of the Punjab and Northwest Frontier Providence.

This program was based on the research outpout of some 20 years which concluded that there was considerable potential for increasing yields under more scientific conditions -- as much as 100 to 200 percent in the higher rainfall areas. The initial package of practices were NPK fertilizer improved varieties and plant protection measures for wheat. Later, efforts recognized the need for water management and a complete cropping system approach to development.

Demonstration plots and field trials showed modest to substantial increase in net income dependent on the particular areas. In general, as expected, high increases were associated with areas of greater rainfall. Adoption of the package of practices seemed to be particularly well correlated with knowledge of the demonstration plot results and availability of a small amount of irrigated acreage.

In general, it appears that the adoption of a package of practices designed to increase production has been slower in the rainfed than in the irrigated area. Nevertheless, it has been well demonstrated that a technology does exist that can increase incomes under rainfed conditions. Doubtless, there may be even greater income increasing possibilities if the recent approach, which includes attention to moisture conservation, can be well developed and extended to the rainfed farmers.

Generally, the study team endorses a strategy that fully develops the potential for irrigation. It recognizes, as discussed elsewhere in this report, that the potential for creating a new irrigation capability is limited. Given this, the present dual strategy of addressing both irrigation and rainfed agriculture seems highly appropriate.

Expansion vs. Intensification

Average river inflows to the Indus Basin between 1965 and 1978 were in the neighborhood of 170 billion cubic m (BCM) per year and canal withdrawals ranged from 107 BCM to 126 BCM with an average value of about 110 BCM. In years of adequate river flow, typical total canal withdrawals are about 120 BCM, which would provide a gross depth of 880 mm, or 0.88 meter (0.88 m), (35 in.) to the 13.6 million hectares of irrigated land in the Indus Basin. Considering the base river flow requirements and existing treaties, the withdrawals (development) is limited to about 139 BCM.

If one assumes the groundwater basin is in balance hydrologically, i.e., running average water table depths have no definite raising or lowering trend, then inflows and outflows must obviusly be in balance. Inflows are derived from: (1) losses from rivers, canals and surface drainage channels; and (2) irrigation losses from watercourses and fields, and percolation from rain. Outflows are: (1) pumping for beneficial crop use; (2) evaporation from water surfaces and soils; (3) transpiration by trees, natural vegetation and phreatophytes; (4) return flow to the rivers; and (5) groundwater leakage out of the basin.

It has been estimated that the annual contribution of rain to crops is in the neighborhood of 10 BCM. The estimated evaporation and rainfall by regions and season in inches and (mm) is:

Season	Item	North	South
Winter (Oct - March)	Evaporation	18(460)	27(690)
	Rainfall	3.6(90)	0.8(20)
Summer (Apr - Sept)	Evaporation	41(1040)	49(1240)
	Rainfall	15.6(400)	2.6(66)

The average annual evaporation minus rainfall (inches of moisture deficit) ranges from about 40 inches in the north to 73 inches in the south with the average value for the irrigation region is in the neighborhood of 60 inches.

Expansion. From the above general observations, it is apparent that there is only limited potential for expansion, i.e., 120 BCM current withdrawals vs. 139 BCM potential. The team suggests that some of this potential for expansion be directed to: (1) barani hill areas by developing small reservoirs (tank) projects to provide supplemental irrigation; and (2) possible tubewell developments outside of existing command areas where water depths and quality is suitable. This would be one way of addressing the equity issues and providing benefits to those farmers most in need.

Intensification. At present the World Bank is considering two relatively large projects (approximately (200,000,000 total) involving on-farm and command area water management improvement. Watercourse improvement, precision land leveling, improved irrigation practices, drainage and reclamation and distribution system improvement on a country-wide basis make up the major elements of these two projects. The Asian Development Bank is also considering a $30,000,000 project which focuses on watercourse improvement and improved irrigation practices.

The Bank projects will rely on the substantial and functional institutional base which has been created under the USAID On-Farm Water Management Project decribed earlier. Only a very small portion (less than 3 percent) of the estimated program costs have been allocated to training and practically nothing to research and the study of conjunctive use of surface and groundwaters.

Originally, the groundwater table was quite deep but seepage from the total distribution system plus deep percolation from irrigation applications raised it close to the ground surface (within 20 feet) throughout most of the irrigated areas by 1960. In fact, in many areas the water table raised too close to the surface, causing waterlogging and salinity problems. The expansion of both deep and shallow tubewells has stabilized, and in many areas, lowered the water tables to tolerable levels. Consequently, the tubewells serve a dual purpose. They provide: (1) needed vertical drainage (in the Indus Basin where the slope is so small that horizontal drainage is very difficult); and (2) high value (because it is available on demand) irrigation water. To minimize pumping lifts (and consequently, energy inputs and pumping plant costs) and make skimming (non-saline water which overlies brackish water) easier, it may be advisable to maintain the water table at the highest levels which do not cause waterlogging and salinity problems (and excess water losses from phreatophytes and sinks).

The pumped groundwater is a renewable resource, as it is replenished by channel seepage and deep percolation from irrigation (and a little from rain). Unfortunately, much of the deep groundwater is too salty for profitable agricultural use and some of the recharge water becomes too contaminated (with salt) and is lost; therefore, even if energy were available for profitable deep pumping, there is little possibility for mining the deep groundwater. Since no water can be manufactured within the system, it becomes obvious that losses from the canal system and irrigation are the source of groundwater recharge and provide a possibility for the conjunctive use of surface and groundwater. This will eventually reach the point where equilibrium is established. One might even speculate that with the recent rapid development of shallow (private) and deep (public) tubewells, that the system may be close to this equilibrium in many areas. It is interesting to note that the estimated numbers of watercourses and private tubewells are 87,000 and 150,000, respectively, or an average of almost two tubewells per watercourse. Therefore, it is critical that the entire system be carefully monitored and studied before inputs or withdrawals are significantly altered.

The tubewell pumping, which in 1977-78 was estimated to be 41 BCM (as compared to total canal withdrawals of 126 BCM), is still estimated to be expanding at the rate of 2+ BCM/year. Intensification has already progressed to a large degree through this reported development of over 150,000 private shallow tubewells. Assuming the officially suggested average discharge of 1.0 cfs per private tubewell (which is probably on the high side), the collective discharge of all the private tubewells is 4,250 m^3/s (as compared to the 6,990 m^3/s collective capacity of all the main canals).

We did not evaluate any shallow private tubewell pumping plants, but suspect that fuel use efficiencies may be quite low. Assuming a 1.0 cfs discharge at a 17.6 foot average total pumping head (that is a 15 foot lift plus 2.6 feet for velocity head and friction losses) and a 67 percent pump efficiency, a 3 hp. electric motor or a 5 hp. diesel engine should be adequate. With efficient power units, the fuel requirements would be 2.5 Kw-hr/hr of electricity, or 0.2 U.S. gallons of diesel per hour. Our sparce interviews with farmers and observations indicated that typical fuel usage may be much higher than necessary.

The total canal withdrawals (water inputs other than rain) only supply a gross depth of 35 inches to the irrigated areas. However, there must be some unavoidable losses from the system to contaminated groundwaters, phreatophytes, sinks, return flow to the river, and beneficial trees, shrubs and forage. If this is assumed to be as small as 20 percent, then only 28 inches of water is available to augment rain. With an average annual water deficit of approximately 60 inches, one can see that a cropping intensity greater than 1.0 to 1.6 (depending on croping patterns) may be impractical.

In view of the above, the study team recommends the following programs as appropriate for USAID's dealings with intensification within the existing Indus Basin irrigation command area:

1. An evaluation of the existing shallow tubewell pumping in terms of:

   a. Present (and projected) numbers, distributions, capacities and duration of operation per year.

   b. Static and dynamic lifts, drawdown characteristics, service life and overall pumping plant energy use efficiencies.

2. A general analysis of the existing irrigation system (including conjunctive use) to develop overall basin, subbasin

and specific area models of water balance, water quality and drainage projections for different development and improvement scenarios.

3. A comprehensive economic analysis of the tradeoff between: canal, watercourse and on-farm irrigation improvements; development and operating costs for deliveries more nearly on a requirement or demand basis; and shallow tubewell development and operating costs in light of inflating energy costs and pending shortages.

4. An applied research and development program to improve the cost effectiveness of shallow tubewell pumping plants in terms of investment cost, maintenance, operating costs and discharge capacity for the ranges of pumping lifts encountered. After selecting and developing the ideal pumping plants, provide aid to existing pumps and power unit manufacturers to develop in-country capability to produce the units.

5. Aid in extending rural electrifications to service shallow tubewells and consider possibilities for increased generating capacity from direct river-run hydroelectric power plants.

Large Projects vs. Small Projects

As already noted in other contexts, the opportunities for large scale project development have been mainly exhausted. With the addition of the projects now under construction, little new water remains in the system. Given this, future projects will be small (shallow tubewells and dikes and small tanks in the rainfed hill ares). One possible exception might be the requirement for a massive drainage program if water quality is not maintained by careful management of the total water resorce system.

The study team recommends exploration of the potential for small reservoir and tank development in the rainfed hill areas and a program of shallow tubewell development that compliment total water resource management. The team suggests that any studies of tank development include a consideration of the new technologies (low pressure sprinkler, buried pipes of various designs and layout configurations, and so forth) which are under development in India and Bangladesh.

INVESTMENT STRATEGIES

Since the bulk of the potential physical irrigation system is already in place in Pakistan, the study team restricted its recommendations concerning investment strategies to: hardware vs. software and main system vs. on-farm.

Hardware vs. Software

The physical system serving the irrigated lands is operating more as a hydraulic system than one to serve the crop requirements. Modifications providing a supplemental supply through tubewell development have improved the flexibility, but the system remains largely a hydraulic one. The management flexibility on the part of the farmers is therefore greatly reduced and remains largely locked into a status quo. However, farmer organizations for operation and maintenance below the minor canal turnouts to the watercourses can bring about changes in the rotation schedule, cropping patterns, fertilizer use and other inputs to maximize the scarce water resource. The team recommends that increased emphasis be placed on the importance of promoting water users organizations which are politically acceptable and the role they must play in improving on-farm water management and better use of the water resource.

The large watercourse improvement projects which are now under negotiation by the banks will require about 1,000 land development officers and their crews. However, these proposed projects provide insufficient support for training the necessary manpower.

In view of the above, the study team believes AID should continue to support the development and distribution of training materials and increase the support for training field personnel. The efforts which have already been expended in this direction appear to have been thoughtful, well executed and valuable. Training should provide skills in: priority problem identification; development of solutions; assessment of technologies, planning and design; implementation and construction; and evaluation and monitoring of irrigation systems. The mode of training should be interdisciplinary and include some academic graduate training for a few selected positions. However, the main focus should be on in-service training programs for agronomists, economists, engineers and extension workers. Courses should be from a few weeks to a few months in duration and provide hands-on experience in improving on-farm irrigation.

Also, the team recommends that AID support a continuation of the adaptive research program which is essential to make better use of the available water. Given the upper limit on water availability, production increases in the foreseeable future will be totally dependent on: (1) an aggressive, adaptive research system; and (2) an efficient extension and training network. This area of development can scarcely be overemphasized.

Main vs. On-Farm

Consistent with a total water resource management approach, it is necessary to pay attention to all divisions of the water supply system. At the present time, on-farm water use has lagged considerably behind main system development. We discuss elsewhere the necessity for on-farm water management practices.

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APPENDIX A

LOWDERMILK TRIP REPORT FOR ASIAN BUREAU TEAM

LOWDERMILK TRIP
FOR ASIAN BUREAU TEAM

JUNE 25-30, 1980

Purpose: To obtain an update on on-farm water management projects and plan for a visit by team members in August 1980, which will examine irrigation issues and strategies with AID Mission and GOP.

Background

The CSU-USAID Mission component of the OFWMP has been completed. Due to Section 669 of the U.S. Foreign Assistance Act (Nuclear Non-Proliferation) the Mission was prohibited from obligating additional development funds planned for a redesigned OFWMP. As a result of the intensive project review in June 1979, the GOP and Mission agreed to extend the terminal date by one year to allow more time for the project to reach its objectives and to disburse remaining loan funds. In November 1979, a general evacuation of U.S. employees and dependents was ordered and both CSU and SCS personnel were evacuated. In March 1980, the two SCS team members returned to complete several work activities. Presently the World Bank and the Asian Development Bank have teams in Pakistan with the purpose of both continuing the work OFWMP began with extensions and developing other improvement projects.

Several evaluations of the project have been completed and the Asian Bureau Team is provided with the second Joint U.S. Pakistan Evaluation of September 16 - October 13, 1979. This document provides details on a number of issues and strategies which have evolved from a project which helped Pakistan to rethink its total strategy for irrigation planning and development. Several issues have relevance for other countries of the region which are also involved in irrigation improvements.

The Pakistan case is well-documented and some members of the present Asian Bureau Team have both experience in the programs of Pakistan and access to most of the relevant documents.

Persons Contacted in Pakistan

1. Dr. Hasan, acting AID Mission Director

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2. Dr. Ed Rice, Agricultural Officer

3. Mr. Dennis Wendal, Program Officer, responsible for irrigation activities

4. Dr. Mohammad Afzal, Local Government Unit, Central Government

5. Mian Mohammad Ashraf, Chief Engineer of WAPDA Master Planning

6. Chaudrey Rehmat Ali, Director of Master Planning, Watercourse Studies

7. Mr. M.S. Cheena, Director of On-Farm Water Management Project (OFWMP), Dept. of Agriculture, Punjab Province

8. Dr. Bashir Ahmed, Joint Chief Economist, Planning and Development, Punjab Province

9. Musthaq Gill, Deputy Director, Training and Research, OFWMP, Punjab Province

Mr. Dennis Wendel accompanied Lowdermilk in the visits and conversations with individuals listed from 1 to 5 above in Islamabad and Mr. Chugtai of the AID Mission in Lahore was with him on the Lahore visits. Time was not available for visits to field sites. A briefing meeting was held in Islamabad with AID staff on June 25th to describe the purpose of the team visit.

A. <u>Preparations for team visits in late July or early August</u>

1. Dr. Ed Rice requested that the Mission be notified of the actual dates of the visits three days in advance. Dr. Rice of AID and Mr. A.M.H. Kango, Director, OFWN Cell of the Ministry of Food and Agriculture, Islamabad, will likely be members of the team in Pakistan.

2. AID will arrange the contacts for visits and transportation. In Islamabad, reservations will be made at Holiday Inn and in Lahore at the Hilton Hotel.

3. The team will want to visit a number of field sites at Fasilabad and perhaps at other places to see field activities in progress.

4. All individuals with whom discussions were held feel that the visit will be useful at this particular time when irrigation programs initiated and funded by AID are being funded by World Bank. Negotiations are also under way between the GOP and the Asian Development Bank for other projects. Many feel that at this critical period in the Mission's program, it is important to evaluate issues and strategies highlighted in recent evaluation studies. No one is clear as to what future involvement of AID may be in Pakistan but, for the long run, it is important to strategize about possible further cooperation with the GOP when the political situation allows such involvement. AID wants help from the Team in sorting out strategic areas where AID may focus within the context of new programs in which CIDA, the World Bank and the Asian Bank will be involved.

B. Impressions about issues and strategies for investigation by the team in Pakistan

1. As indicated in the press on June 27, 1980, by the Finance Minister, and in discussions with officials, the GOP is committed at every level to improvement of its irrigation systems at the farm level. One major issue, however, is that, to date, the Irrigation Departments in the Provinces have not played a role in the OFWN improvement programs. This is a concern to many as to what ways and means can be developed to gain that cooperation.

2. Another issue raised by Mr. Iftakhar Ahmad is how to speed up the program of cleaning and maintenance of the 80,000 watercourses. He currently seems to favor a top-down directive approach.

3. An issue being discussed presently is the establishment of legal authority for water user associations. To date, only informal farmer committees have been used in the improvement activities. The team should discuss this and study the report of the seminar on water user associations conducted with George Radosivich and GOP officials in 1979.

4. There is concern about the role of testing and research related to on-farm improvement technologies since CSU is no longer involved. Which agency will, or should, carry on the continued research needed? Is this possibly a

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role for which the Irrigation Research Institute might begin to develop capabilities? What are the other options?

5. Continued monitoring and evaluation of on-farm improvement. The GOP has been on again and off again on the importance of this component. Presently plans are being made to give this activity to WAPDA (Water and Power Development Authority). In-country rupee funds are likely to be provided by AID, but final approval has not been granted. One of the weaker aspects of the OFWM Projects is the lack of monitoring and evaluation.

6. Components of an improved on-farm irrigation program. These will vary from country to country, but, in Pakistan, there are many who now question one of the components especially, which is precision land leveling. This should be examined. Data are available on costs and performance to date of precision land leveling.

7. Resource commitment by farmers is an issue. What level and in what form? What mix of incentives seems to work? Cost sharing approach? Assessments through land and water tax mechanisms?

8. Public versus private tubewells is a present issue. Given the costs and benefits of both and performance overtime, some policy makers want to see the focus given to private tubewells. The O&M for public tubewells has reached levels which raise many questions. Which strategy is best under which set of situations? What about long-term conjunctive use and a rational approach to control of waterlogging? Pakistan provides an excellent case study to examine this issue.

9. Lined watercourses versus improved earthen watercourses. As a policy in Pakistan, only those sections are lined where seepage rates are high. Questions being asked are: what is the life of benefits from improved earthen watercourses when farmer maintenance is not adequate? What incentives and controls are needed to assume continued maintenance? What are the advantages and disadvantages of both the GOP approach in the East Punjab or India? What lessons are there to learn?

10. Training Personnel. For irrigation improvement programs, what types of training? For whom? How long?

Where? Questions which need to be examined. What could be AID's role in assisting training in countries which are involved in irrigation improvements and development? What areas of training are now being missed or neglected? Irrigation managers? Project managers? Field technicians? Water Management advisors - extension, etc.?

11. Role of Private Sector in providing services to farmers for irrigation and other improvements. The team may want to examine this issue, which should have relevance in many countries.

12. Target beneficiaries of improvement programs. This is an issue to examine in Pakistan. The Project Paper established selection criteria related to the target audience. The Evaluation Report of October 13, 1979 recommends that more focus be given to small farmers and the poor. In practice, there have been problems. Examine this in terms of AID's new directions and the actual problems involved in achieving this in the Pakistani Program context.

13. Issue of institutional linkages for large-scale improvement programs. Interagency coordination versus single agency responsibility. Permanent versus non-permanent organizations?

C. Final comment

While there have been a number of issues which have surfaced as a result of Pakistan's programs which are being examined openly by officials, there is no doubt that the GOP, at all levels, is committed to large-scale projects for the future. Much has been accomplished and lessons are being learned which have relevance to other countries in the region. The Team should study carefully the two documents attached:

1. The Second Joint U.S.-Pakistan Evaluation of the OFWM Project

2. The AID Mission Comments and Response to the Recommendations.

Given this information, plus that gained from contacts at the federal, provincial and field levels in Pakistan, the Team should be able to identify several issues and strategies which will be useful in the accomplishment of our Mission for the Asian Bureau.

APPENDIX B

THE WATER BALANCE FOR PAKISTAN*

by

George H. Hargreaves, Research Director
International Irrigation Center
Utah State University

*This appendix was added in order to illustrate the methodology and as an indication of the limitations of rainfed agriculture and the needs for irrigation.

THE WATER BALANCE FOR PAKISTAN

by

George H. Hargreaves, Research Director
International Irrigation Center
Utah State University

Table B-1 presents climate and the water balance for Pakistan for 13 locations. Except for some mountainous locations, rainfall is generally inadequate for rainfed agriculture. Agricultural production therefore depends for the most part upon availability of irrigation water.

The data presented are from the World Meteorological Organization 30 year records. The following describes the table headings:

Heading	Description
PM	Mean monthly precipitation in mm
PMI	Minimum monthly recorded precipitation (30 years)
P79	The 79 percent probability of precipitation occurrence
P60	The 50 percent probability of precipitation occurrence
PMX	Maximum monthly recorded precipitation
TMC	Mean monthly temperature in degrees Celsius
HM	Mean monthly percent relative humidity
HMC	Percent relative humidity calculated from sunshine
S	Percentage of possible sunshine
SC	Percentage of sunshine calculated from HM
PD	Dependable precipitation - the 75 percent probability of precipitation occurrence
ETP	Potential evapotranspiration
ETDF	Potential evapotranspiration deficit (ETP - PD)
MAI	Moisture availability index (PD/ETP)

Table B-1. Climate and the Water Balance for Pakistan.

DALBANDIN PAKISTAN — EL= 849 LAT= 28 53 N LONG= 64 24 E KS=10.0

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	25.	18.	12.	5.	2.	1.	7.	0.	0.	0.	1.	13.	84.
PMI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	6.
P79	7.	0.	1.	0.	0.	0.	0.	0.	0.	0.	0.	0.	59.
P60	14.	5.	5.	2.	0.	0.	0.	0.	0.	0.	0.	8.	76.
PMX	77.	50.	114.	26.	20.	9.	87.	4.	0.	1.	11.	61.	196.
TMC	9.2	12.5	17.4	23.1	28.4	31.9	33.4	31.6	26.8	21.0	14.8	10.3	21.7
HM	56.	43.	35.	31.	23.	19.	23.	21.	20.	23.	33.	44.	31.
SC	66.	75.	81.	83.	88.	90.	88.	89.	89.	88.	82.	75.	83.
PD	8.	1.	2.	0.	0.	0.	0.	0.	0.	0.	0.	2.	53.
ETP	62.	81.	131.	174.	227.	247.	257.	235.	182.	134.	86.	65.	1881.
ETDF	54.	80.	129.	173.	227.	247.	257.	235.	182.	134.	86.	63.	1863.
MAI	.14	.01	.01	.00	.00	.00	.00	.00	.00	.00	.00	.03	.03

DERA ISMAIL KHAN PAKISTAN — EL= 174 LAT= 31 49 N LONG= 70 55 E KS=11.0

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	14.	18.	27.	20.	9.	9.	65.	36.	14.	2.	3.	6.	223.
PMI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	34.
P79	1.	1.	[illegible]	1.	0.	0.	10.	2.	0.	0.	0.	0.	135.
P60	5.	5.	14.	9.	0.	5.	25.	16.	5.	0.	0.	0.	173.
PMX	49.	73.	142.	78.	58.	40.	275.	146.	51.	29.	45.	48.	554.
TMC	12.1	15.1	20.2	26.3	32.1	34.8	33.6	32.6	30.9	25.6	18.9	12.7	24.5
HM	62.	53.	53.	49.	39.	41.	61.	64.	58.	55.	57.	65.	55.
SC	68.	75.	75.	79.	86.	84.	69.	66.	71.	74.	72.	65.	74.
PD	2.	2.	10.	3.	0.	1.	13.	5.	1.	0.	0.	0.	144.
ETP	64.	83.	132.	180.	244.	256.	230.	206.	174.	132.	84.	60.	1944.
ETDF	62.	81.	122.	177.	244.	255.	217.	201.	173.	132.	84.	60.	1308.
MAI	.03	.02	.08	.01	.00	.00	.06	.02	.01	.00	.00	.00	.03

FORT SANDEMAN PAKISTAN — EL=1406 LAT= 31 21 N LONG= 69 27 E KS=10.3

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	24.	30.	42.	27.	21.	13.	49.	47.	6.	1.	6.	14.	280.
PMI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	216.
P79	7.	7.	18.	11.	2.	2.	23.	9.	0.	0.	0.	2.	232.
P60	19.	15.	29.	21.	8.	6.	40.	33.	0.	0.	0.	4.	253.
PMX	63.	86.	132.	68.	82.	57.	123.	103.	66.	23.	84.	69.	543.
TMC	5.9	9.1	14.1	19.9	25.7	30.0	30.3	29.4	26.5	20.1	13.9	8.7	19.5
HM	51.	41.	46.	39.	31.	31.	49.	49.	40.	33.	35.	42.	41.
SC	72.	79.	76.	80.	86.	86.	74.	74.	80.	84.	83.	78.	79.
PD	10.	9.	20.	13.	3.	3.	27.	14.	0.	0.	0.	2.	242.
ETP	53.	69.	111.	155.	211.	233.	222.	203.	167.	123.	79.	58.	1654.
ETDF	43.	61.	91.	142.	207.	230.	195.	189.	167.	123.	79.	56.	1584.
MAI	.18	.13	.18	.08	.02	.01	.12	.07	.00	.00	.00	.04	.14

Table B-1 Continued.

HYDERABAD PAKISTAN — EL= 29 LAT= 25 23 N LONG= 68 25 E KS=10.3

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	4.	5.	1.	2.	4.	6.	69.	44.	15.	3.	1.	3.	157.
PMI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	32.
P79	0.	0.	0.	0.	0.	0.	10.	0.	0.	0.	0.	0.	76.
P60	0.	0.	0.	0.	0.	0.	45.	11.	0.	0.	0.	0.	91.
PMX	30.	35.	12.	17.	28.	48.	274.	277.	193.	47.	14.	26.	527.
TMC	17.2	20.6	26.0	30.8	34.1	34.3	32.5	31.3	30.9	29.3	24.3	19.1	27.5
HM	48.	42.	41.	39.	47.	57.	65.	67.	64.	49.	47.	51.	51.
SC	74.	78.	79.	80.	75.	68.	61.	59.	62.	74.	75.	72.	71.
PD	0.	0.	0.	0.	0.	0.	17.	2.	0.	0.	0.	0.	79.
ETP	94.	112.	168.	207.	236.	222.	209.	192.	171.	159.	116.	93.	1979.
ETDF	94.	112.	168.	207.	236.	222.	191.	190.	171.	159.	116.	93.	1959.
MAI	.00	.00	.00	.00	.00	.00	.08	.01	.00	.00	.00	.00	.04

JACOBABAD PAKISTAN — EL= 56 LAT= 28 18 N LONG= 69 28 E KS=10.1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	8.	8.	7.	2.	4.	6.	37.	22.	1.	0.	1.	3.	99.
PMI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	4.
P79	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	33.
P60	1.	1.	2.	0.	0.	0.	5.	0.	0.	0.	0.	0.	67.
PMX	54.	43.	43.	17.	30.	63.	330.	129.	16.	4.	10.	26.	407.
TMC	14.7	18.3	23.9	29.9	34.9	36.8	35.2	33.6	32.2	28.1	22.0	16.6	27.2
HM	49.	39.	37.	29.	27.	40.	53.	59.	57.	43.	45.	51.	44.
S	78.	77.	72.	74.	75.	69.	60.	72.	80.	86.	92.	79.	76.
PD	0.	0.	0.	0.	0.	0.	1.	0.	0.	0.	0.	0.	40.
ETP	83.	99.	148.	192.	240.	238.	220.	220.	195.	160.	114.	84.	1993.
ETDF	83.	98.	147.	192.	240.	238.	219.	220.	195.	160.	114.	84.	1991.
MAI	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.02

KALAT PAKISTAN — EL=2017 LAT= 29 2 N LONG= 66 35 E KS=10.1

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	54.	46.	38.	15.	6.	3.	30.	14.	2.	0.	3.	19.	230.
PMI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	78.
P79	18.	7.	11.	3.	0.	0.	0.	0.	0.	0.	0.	2.	161.
P60	31.	22.	20.	9.	1.	0.	4.	1.	0.	0.	0.	8.	195.
PMX	177.	130.	167.	46.	46.	26.	287.	78.	58.	2.	40.	81.	470.
TMC	2.8	5.2	9.2	13.9	18.3	22.3	24.4	23.2	18.9	13.3	8.3	4.6	13.7
HM	61.	57.	53.	42.	38.	35.	44.	43.	39.	35.	60.	57.	46.
SC	63.	66.	69.	77.	80.	81.	76.	76.	79.	81.	74.	66.	74.
PD	21.	10.	13.	4.	0.	0.	1.	0.	0.	0.	0.	3.	168.
ETP	0.	57.	92.	129.	167.	188.	195.	179.	140.	103.	65.	48.	1403.
ETDF	-21.	47.	79.	124.	167.	188.	194.	179.	140.	103.	65.	45.	1310.
MAI	.45	.18	.14	.03	.00	.00	.00	.00	.00	.00	.00	.07	.12

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Table B-1 Continued.

KARACHI/MANORA PAKISTAN EL= 22 LAT= 24 55 N LONG= 67 9 E KS=13.9

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	7.	11.	6.	2.	0.	7.	96.	50.	15.	2.	2.	6.	204.
PMI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	19.
P79	0.	0.	0.	0.	0.	0.	9.	1.	0.	0.	0.	0.	65.
P60	1.	0.	0.	0.	0.	0.	44.	3.	0.	0.	0.	0.	115.
PMX	69.	51.	56.	31.	7.	58.	392.	428.	252.	69.	41.	66.	676.
TMC	18.9	21.2	24.3	26.9	29.2	30.4	29.3	28.2	27.6	27.1	24.9	21.3	25.8
HM	61.	70.	77.	79.	83.	83.	83.	85.	84.	79.	67.	60.	76.
SC	87.	76.	67.	64.	57.	57.	57.	54.	56.	64.	80.	88.	67.
PD	0.	0.	0.	0.	0.	0.	16.	1.	0.	0.	0.	0.	75.
ETP	108.	113.	149.	169.	186.	188.	189.	171.	151.	141.	123.	110.	1799.
ETDF	108.	113.	149.	169.	186.	188.	172.	170.	151.	141.	123.	110.	1781.
MAI	.00	.00	.00	.00	.00	.00	.09	.01	.00	.00	.00	.00	.04

LAHORE PAKISTAN EL= 214 LAT= 31 33 N LONG= 74 20 E KS=11.3

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	31.	23.	24.	16.	12.	38.	122.	123.	80.	9.	3.	11.	492.
PMI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	277.
P79	8.	2.	8.	2.	0.	4.	73.	40.	1.	0.	0.	0.	300.
P60	15.	5.	16.	6.	1.	20.	96.	83.	31.	0.	0.	1.	396.
PMX	95.	111.	84.	76.	29.	153.	284.	292.	526.	80.	33.	71.	851.
TMC	12.2	15.3	20.5	26.6	31.8	33.9	32.1	31.2	29.9	25.4	18.0	13.8	24.3
HM	73.	61.	55.	43.	37.	43.	66.	73.	66.	64.	70.	75.	60.
S	67.	74.	65.	75.	73.	68.	59.	62.	73.	83.	84.	71.	71.
PD	9.	3.	10.	3.	0.	7.	78.	49.	7.	0.	0.	0.	320.
ETP	65.	83.	124.	178.	223.	226.	205.	193.	173.	139.	91.	66.	1766.
ETDF	55.	80.	114.	175.	223.	218.	128.	144.	165.	139.	91.	66.	1599.
MAI	.15	.03	.08	.02	.00	.03	.38	.25	.04	.00	.00	.00	.19

MULTAN PAKISTAN EL= 123 LAT= 30 12 N LONG= 71 26 E KS=11.2

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	7.	10.	13.	6.	8.	8.	45.	33.	20.	10.	2.	5.	167.
PMI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	23.
P79	0.	0.	0.	0.	0.	0.	1.	1.	0.	0.	0.	0.	96.
P60	1.	2.	5.	1.	1.	0.	23.	14.	0.	0.	0.	0.	120.
PMX	37.	36.	73.	24.	75.	59.	212.	162.	108.	17.	57.	40.	348.
TMC	13.1	16.5	21.9	28.4	33.4	36.1	34.5	33.4	31.8	27.4	19.8	15.1	25.9
HM	62.	49.	51.	43.	35.	39.	57.	61.	56.	50.	58.	65.	52.
SC	69.	80.	78.	85.	90.	87.	73.	70.	74.	79.	73.	66.	77.
PD	0.	0.	1.	0.	0.	0.	6.	4.	0.	0.	0.	0.	101.
ETP	70.	92.	144.	198.	257.	266.	241.	216.	184.	146.	91.	69.	197-.
ETDF	70.	91.	143.	198.	256.	266.	236.	212.	184.	146.	91.	69.	1962.
MAI	.00	.00	.01	.00	.00	.00	.02	.02	.00	.00	.00	.00	.05

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Table B-1 Continued.

QUETTA PAKISTAN EL=1601 LAT= 30 15 N LONG= 66 53 E KS=11.2

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	37.	43.	42.	12.	7.	1.	18.	4.	1.	1.	6.	23.	195.
PMI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	122.
P79	22.	14.	18.	7.	0.	0.	0.	0.	0.	0.	0.	5.	164.
P60	41.	30.	31.	12.	5.	0.	2.	0.	0.	0.	0.	11.	212.
PMX	129.	177.	110.	69.	38.	68.	182.	55.	6.	8.	52.	113.	399.
TMC	4.0	6.1	10.7	15.9	20.6	24.2	27.2	25.4	20.5	14.1	8.7	4.8	15.2
HM	69.	62.	59.	51.	47.	41.	47.	49.	44.	41.	53.	65.	52.
S	67.	71.	64.	72.	82.	85.	76.	83.	82.	89.	86.	72.	77.
PD	26.	17.	21.	8.	1.	0.	0.	0.	0.	0.	0.	6.	174.
ETP	48.	60.	92.	131.	181.	202.	210.	197.	147.	108.	69.	49.	1494.
ETDF	22.	42.	71.	123.	180.	202.	209.	197.	147.	108.	69.	43.	1414.
MAI	.54	.29	.23	.06	.01	.00	.00	.00	.00	.00	.00	.13	.12

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Table B-1 Continued.

QUETTA PAKISTAN	EL=1601 LAT= 30 15 N LONG= 66 53 E KS=11.2												
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
PM	37.	43.	42.	12.	7.	1.	18.	4.	1.	1.	6.	23.	195.
PMI	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	122.
P79	22.	14.	18.	7.	0.	0.	0.	0.	0.	0.	0.	5.	164.
P60	41.	30.	31.	12.	5.	0.	2.	0.	0.	0.	0.	11.	212.
PMX	129.	177.	110.	69.	38.	68.	182.	55.	6.	8.	52.	113.	399.
TMC	4.0	6.1	10.7	15.9	20.6	24.2	27.2	25.4	20.5	14.1	8.7	4.8	15.2
HM	69.	62.	59.	51.	47.	41.	47.	49.	54.	41.	53.	65.	52.
S	67.	71.	64.	72.	82.	85.	76.	83.	82.	89.	86.	72.	77.
PD	26.	17.	21.	8.	1.	0.	0.	0.	0.	0.	0.	6.	174.
ETP	48.	60.	92.	131.	181.	202.	210.	197.	147.	108.	69.	49.	1494.
ETDF	22.	42.	71.	123.	180.	202.	209.	197.	147.	108.	69.	43.	1414.
MAI	.54	.29	.23	.06	.01	.00	.00	.00	.00	.00	.00	.13	.12

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