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IMPROVING FARM WATER MANAGEMENT IN PAKISTAN

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WATER MANAGEMENT
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IMPROVING FARM WATER MANAGEMENT IN PAKISTAN

by

Gilbert L. Corey and Wayne Clyma*

The irrigation system of Pakistan represents one of the largest modern conveyance systems in the world and is a marvel of engineering skill and technology. The hydraulic features, dams, barrages, canals, distributaries, structures, and appurtenances have been fully described in other publications. There is however a paucity of information and, indeed, a lack of understanding of that portion of the irrigation system with which the farmer deals. This refers to the system from the canal outlet (mogha) through the irrigated field. The farmer operates and manages this water with little or no governmental assistance. The procedures, rules, resources and constraints at this disposal determine his on-farm water management** practices which determine the crop production per unit of irrigation water. A description of this farmer operated system, the rationale for its present condition, an evaluation of the problems, and suggestions for improvement are presented herein with the hope that increased production through improved water management will result. The potential for increasing production through water management is great.

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**On-farm water management was defined in a Water Management Research Workshop in Lahore (January 1973) as "the use of irrigation water from the mogha to and through the irrigated field". This definition is used throughout this paper

The climate and soils of Pakistan are especially suitable for agriculture; however, precipitation is totally inadequate in some areas and insufficient in others for more than modest production. Without supplemental water this area would revert to deserts with only sparse vegetation. Irrigation is the key to a productive agriculture in Pakistan. The suitability of the soils and climate is evidenced by the fact that the first known practice of irrigation by man was undoubtedly along the Indus. Fifty centuries ago the Mohanjodaro civilization enjoyed the benefits of well designed water supply and drainage systems.* The broad, flat valley laced with five rivers was ideal for the inundation (sailaba) system or irrigation along the rivers. Though ancient, this system was very practical since the summer flood waters were utilized over the fertile lands adjacent to the meandering Indus river system. This type of irrigation, practiced for several thousand years, is still in use today to some extent along the Indus and its tributaries, the Jhelum, Chenab, Ravi and Sutlej.

A modern irrigation conveyance system was constructed by the British in the late 1800's and it is one of the largest in the world. There are about 40,000 miles of canals which command a gross area of over 33 million acres of fertile soils. About 25 million acres actually receive surface water. Today there are more than 80,000 tubewells

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*Water - Yearbook of Agriculture 1955, The United States Department of Agriculture, U.S. Government Printing Office.

supplementing the Indus system and providing water to an additional 8 million acres. Over 200,000 persian wheels also provide supplemental water. Therefore, there are about 33 million acres of deep alluvial soils under irrigation in the Indus Basin. This probably constitutes the greatest single agricultural potential in the world. These soils were brought into this great Basin primarily by water action from the young and rich Himalaya and Sullaman mountains.

The system is not only large with a vast potential but it is unique in several other aspects. One disappointing feature, however, is the present low production in light of the apparent highly suitable soil, water and climatic resources. These factors suggest a production potential many times greater than presently achieved. The "green" revolution increased production appreciably but even this appears to be far below potential and in many respects this so-called revolution today is stalled.

Many experts agree that the farming practices, including irrigation water management, must be modernized in order to achieve higher production. The White House-Department of Interior Panel on waterlogging and salinity in West Pakistan (Revelle Report) noted - "In West Pakistan we have the wasteful paradox of a great and modern irrigation system pouring its water on lands cultivated as they were in the middle ages..."* This observation is quite obvious

*"Report on Land and Water Development in the Indus Plain" by the White House-Department of Interior Panel on Water-logging and Salinity in West Pakistan. October 1964.

to anyone acquainted with irrigated agriculture in Pakistan, but the causative conditions and factors are neither obvious nor simple. It is ironic that the only Revelle recommendation meeting with any degree of success was the one which enhanced the "great and modern irrigation (conveyance) system". Since the Revelle Report was made public in 1964, essentially nothing has been accomplished relative to improving the irrigation farming practices which in fact today are still ancient and traditional and must be considered a part of the total irrigation system. The modern system ends at the "mogha".

The Pakistan farmer operates under a set of very difficult conditions. Given the same circumstances, services received, and resources undoubtedly few farmers could have performed more efficiently. Hard work, infinite patience, and tenacity mark his mettle, and where others would have undoubtedly given up in despair, he has persisted even today using methods unrelated to modern agriculture. The Pakistan farmer must make many difficult decisions which are imposed on him by the irrigation system and the very nature of the resources he must utilize without benefit of sufficient governmental services. His position is not readily comparable to that of farmers in irrigated regions of the world where water is more abundant. Often the comparison is made between Pakistan and the Imperial Valley in California. The soil conditions and the climate are similar which makes several of the irrigation problems identical; however, there are important differences which explain the tremendous gap in production. Some of these are: insufficient water supply, lack of proper land leveling, lack of irrigation water control, lack of salinity control, lack of water management extension services, use of ancient cropping systems with ancient tools, or in other words a very different on-farm water management system.

DESCRIPTION OF THE IRRIGATION SYSTEM

Annually, approximately 80 million acre feet of water are diverted through the canal system for about 25 million acres. It is estimated however that only 52 million acre feet reach the fields due to transit losses. This 2.1 acre feet per acre is further diminished by losses within the field due to nonuniform application of water. Assuming 50 percent field application efficiency, which is conservative, there would be little more than one acre foot of water per acre annually available for plant consumptive use. Considering the climatic potential for at least two crops a year, this is certainly an inadequate water supply. Evidently, no attempt was made initially to determine water requirements or to design a system to meet those requirements efficiently. The canal system was developed to utilize available water supplies to irrigate as much land as possible.

Government and private tubewells have been constructed in large numbers during the past decade. This has relieved the drought situation on approximately one third of the irrigated area. However, there are presently over 20 million acres of land which receive only the canal supply described above.

The irrigation system is so constructed that water flows from the minor canals through turnouts (moghas) supplying water to a village area. The farmers themselves operate and maintain their distribution system. There are no headgates at the moghas and if a particular canal has water in it, there is water in every watercourse (khal)* on that canal. It is like a giant river system flowing in reverse with each tributary getting an equal share. The farmers on the watercourse use the entire flow on a turn basis (warabundi). In other words, one has an allotted time interval for the flow based on his acreage and he has a fixed time each week, 10 days, or two weeks to use it. If there is insufficient water during a particular farmer's turn then he must forfeit his share of public canal water and wait for the next turn. There are some variations which are unofficial but water on demand is essentially unknown except in those areas served by farmer operated tubewells.

The watercourse system does not always flow full depending on supplies in the canals; therefore water available on the "warabundi" is not always constant. Canal

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*Watercourse as used in this paper refers to all the channels through which water flows from the "mogha" to the fields where crops are grown.

closures for repairs do occur and farmers are not usually notified in sufficient time to make alternate plans. Water charges are made on the basis of acreage of crop grown and water rates vary for different crops based on assumed consumptive rates. Mixed crops are assessed at the highest rates leviable on any one crop. If a portion of a field is irrigated the rate applies for the whole field unless such portion has been clearly demarcated by a well defined ridge. The assessment for irrigation water therefore is not based on the amount of irrigation water received; but on the acreage and species of crops grown in a particular season. The individual (potwari) who makes the levy for each crop is greatly underpaid and as a result of the vast amounts of water rates he levies he often finds it lucrative to reduce rates for special favors from farmers.

The topography of the Indus basin is flat. The general slope downstream averages from about nine inches to one foot per mile. Natural drainageways are not readily apparent since most of the area has low rainfall and runoff in the irrigated area is minimal. Practically no artificial drains have been constructed, therefore surface drainage for irrigation water is virtually non-existent either from artificial or natural drains. Irrigation water passing through each "mogha" is therefore utilized on that particular watercourse area as there is no provision to let it pass to an area of lower elevation.

The soils are characterized as having a special granulometric distribution. The ratio of silt to clay is high with some resemblance to loess soils. There is a lack of structure which is perhaps related to the quantity of organic matter in the soil. This lack of organic matter, improper tillage methods, and a problem of cementation of the homogeneous soil particles result in low infiltration rates for most of the silty and sandy loam soils.

The irrigation system and resources provide the farmer with special problems not fully understood by the casual observer to agriculture in Pakistan.

DEVELOPMENT OF PRESENT PRACTICES

The inundation or level basin system of irrigation is used extensively in Pakistan. The flat topography might suggest this practice but actually the constraints are such that no other system is possible. The non-runoff restriction requires either a system in which water is applied precisely according to the infiltration rate or it must be ponded. The low infiltration capacities of most soils make it impossible to get sufficient water into the profile during one irrigation turn. The level basin system has been utilized because it exactly fits these resources and constraints. Furrow irrigation is practiced with some crops and it is interesting to observe that the furrows are constructed to provide for a great deal of storage. The ponding method, then, is also used with this system; the furrows are made very broad and will store sufficient water to fill the soil reservoir even though infiltration rates require that the opportunity time be much longer than the "warabundi" turn. Apparently, the furrow system is only used with these crops such as tobacco and vegetables which will not tolerate inundation for extended periods. Regardless of whether basins or furrows are used, a ponding procedure requires a level system. Water must be stored on the surface during irrigation and allowed to stand and infiltrate into the plant root zone.

The farmer has attempted to farm his land on a dead level basis with traditional implements drawn by bullocks. He appreciates the very small tolerance in elevation difference required with such field design. A one inch difference in elevation frequently means more than a two inch difference in water stored in the root zone and this can be as much as fifty percent of the water needed for proper plant growth. His traditional tools for accomplishing land leveling have been less than ideal. Bullock drawn logs and boards (sohaga and karah) are commonly used. Tractor blades and bulldozers are now available to those with sufficient capital, however, none of these tools are appropriate for preparing fields precisely to a dead level tolerance. Precision land leveling can only be accomplished efficiently by utilizing known engineering principles and procedures for design together with proper machinery expertly handled. Machines which load and carry an appreciable amount of soil while scraping over a surface thin layer have proved ideal for this job. These machines act as planes and perform the very important job of compacting loose soil as well as cutting to a precise depth. Such machines which are usually called soil scrapers and land levelers are now manufactured in Pakistan and are increasingly available to the farmers.

Without this equipment or the technical skills required to design and construct a dead level field, the farmer has developed his own crude leveling procedure. He utilizes the water itself to provide a measure of leveleness and by continually re-leveling with the "sohaga" and the "karah" he maintains a reasonably workable field. Of necessity he has had to develop a system of very small fields because he cannot maintain a small tolerance over a large land area. Ordinarily he selects a parcel only about one acre in size as a unit for water control. He further divides this into four and frequently eight equal parts with dikes (bunds). It is common to observe a series of one acre benches each representing a separate irrigation unit.

A system utilizing small fields naturally results in an extensive water conveyance system. These open ditches supply water to practically every acre and it is difficult to find a point within an irrigated area which is more than three hundred feet away from a water supply ditch. The length of the watercourse per acre is very large due to the constraints of the traditional irrigation system. There is little alternative to such a system without external services and assistance to the farmer.

The prevalence of trees over the irrigated area is a natural consequence of the scarcity of wood in Pakistan which has only roughly 20 percent of the timber needed for a developing nation. Trees are allowed to grow along and in the ditch systems and in the fields and the general feeling is that these trees are a valuable by-product.

EVALUATION OF THE SYSTEM

Water management practices and procedures used today in the Indus Basin have developed logically over time but they do not represent an efficient or reliable system. An understanding of the problems associated with present practices is necessary before intelligent, reliable and workable recommendations can be made. On-farm water management problems can be divided into categories according to sequence of use; water supply, delivery, application, and use by crops.

Water Supply - The water supply is inadequate regardless of acreage of holdings except for areas receiving supplemental tubewell water. Available water is divided on an acreage basis and since the canal system delivers annually little more than 2 acre feet per acre year around production is not possible on all the land even though the climate suggests otherwise. By comparison, over 10 acre feet per acre is diverted into the Imperial Valley of California each year; more than four times that supplied the Pakistan farmer. With water so scarce he operates under a virtual drought situation all the time and this has been the case for centuries.

The water supply is not readily predictable. Spills, seepage, wastage, and location of "mogha" all contribute to variable flows. The irrigation schedule is rigid being fixed by the "warabundi" system. A particular farmer must take his "turn" even though the water might not be needed at a specific time and this leads to over irrigation. There is limited incentive for efficient use of water under such a system especially when water charges are based on acreage irrigated and not on water used. Drainage systems are inadequate or non-existent in most areas creating the necessity to utilize all the canal flow from a "mogha" all the time that water is in the system.

On about two thirds of the arable land, therefore, the farmer is supplied with little more than one-half the amount of water needed. It is supplied on a rigid schedule, unpredictable, and with no opportunity to vary the quantity or time received. The farmer is faced with a constant dilemma. It is next to impossible with such a system for him to improve production by utilizing this precious resource efficiently especially since the Government has not provided him with technologies to suggest improvements. The Agriculture Department is administered separately from the Irrigation Department and neither has the responsibility for teaching improved farm water management practices. The irrigation system is viewed essentially as a water disposal system and not a system to provide water to crops when needed. Its' capabilities are measured in terms of acres served and cost of operation not in crop production. The Pakistani farmer then is forced to operate the system as best he can. His present position is a logical consequence of the constraints he faces.

Water delivery - The Irrigation Department has jurisdiction past the "mogha" or outlet for the watercourse but does not exercise physical control of the water past that point. Thus, the watercourse is the community property of the farmers served by it. It was built and maintained largely by the skills, knowledge and efforts of the community of farmers on the watercourse. A major problem is the lack of knowledge to operate and maintain it properly. As a result many farmers are deprived of substantial quantities of water.

Seepage is not completely understood and it deprives many farmers of a valuable water supply. Water which seeps from a watercourse is not lost from the water delivery system of Pakistan since it goes to ground water and is available for reuse. However, to the farmer farther down the channel without a tubewell and without an adequate supply, the water is lost just as if it were piped to the sea. That farmer suffers from an inadequate water supply whatever the benefits someone else gets from the seepage water.

Losses from watercourses range from essentially nothing to most of the available flow. Table 1 presents some recently measured values of seepage losses. It is recognized that the procedure of converting to a rate of loss per mile tends to overestimate the true value; however, many watercourses are 20-30 miles long so large amounts of water can be lost. Water saved by reducing seepage has equal or greater value than tubewell water and equivalent costs are justified.

Considerable leakage occurs because the farmer is concerned with delivery of water only during his turn. When a poorly maintained channel breaks, a farmer repairs it only sufficiently enough to insure that it will deliver water during his irrigation turn. Thus, breaks and corresponding spills of water are common. The water gradually seeps through the thin channel bank or abruptly spills from a broken dike and is lost to the farmer who has that turn.

The water lost by a spill may go to a field that does not need water and become deep seepage or a wet spot that will be over irrigated the next time the field receives a planned irrigation. Either way the water is a waste that brings little or no benefits to any farmer. It may even result in a loss to the farmer who regularly receives spills from watercourse. Spills may equal or exceed deep seepage losses and should be justification for rehabilitation of a watercourse. Even watercourses that have little direct seepage loss will benefit from rehabilitation through reduction of spills.

Table 1. Values for seepage loss from Watercourses in Pakistan.

Source	Distance	Discharge Total	Discharge Loss	Percent Per Mile
(1)	Average for several watercourses			50
(2)	4000	2.48	.46	25
(2)	1000	2.48	.21	45
(2)	1500	4.00	.75	65
(2)	3000	2.25	0.10	5

(1) Ali, Arshad. Address to the Water Management Research Workshop, Lahore (January 1973).

(2) Unpublished data from Wayne Clyma.

The intricate tortuous system of channels used to deliver water from the "mogha" to a field may cause seepage losses to be four times as great as from a well aligned watercourse. Most fields presently have a maximum length of 220 feet and require nearly three times as much watercourse length as would be needed if the fields were constructed 800 feet in length. Since alternate wetting and drying increases seepage and other water losses, a long channel will have a proportionately higher average loss than will a short channel.

Trees, grass and weeds growing along and within watercourses have several specific effects that result in loss of water. They use tremendous quantities of water since they can transpire wastefully if water is readily available. This water is lost from the water delivery system and cannot be recovered. The process also leaves a residual of salts that increases the rate of salinization of the soils and water. The evapotranspiration lowers the water table under the channel and increases seepage losses. Roots penetrate the soil to the side and below the channel making the soil more permeable and increasing seepage losses. Weeds, trees, and sediment combine to increase channel roughness and reduce delivery to the farm. The increased depth of water caused by this vegetation in the channel increased the seepage because of increased flow area. The increased depth of flow also decreased the head difference across the "mogha" which usually operates submerged. The flow of water through the "mogha" and into the watercourse is therefore reduced. Trees also shade crops, harbor birds, and are hosts to many insects. The trees are valuable but the loss in crop production by allowing them to grow haphazardly may be an uneconomic use of water and land resources.

Watercourses in Pakistan are generally constructed in the manner illustrated in Figure 1(a). Soil is excavated from below the ground surface and piled on each side to increase the height of the sides. When water flows through the channel, the water level is at or near the ground surface. To irrigate, the farmer builds a dike across the channel high enough to raise the water level above the ground so water can flow onto the field. As a result, for several hundred feet the water level is near the top of the sides of the channel. This is one factor that results in many spills from the watercourse. The other major result of such construction is that water in the channel cannot be completely drained onto the field at the end of the turn but remains in the watercourse where it evaporates or seeps into the ground. In either instance that water is lost to the farmer.

An estimate of the amount of water lost by in-channel storage below the ground level has been made in Table 2. The average cross section below ground level was estimated from field observations of flow cross sections. The value presented is very conservative as many channels have two

Figure 1. (a) Typical cross section of most watercourses; and
(b) Desirable cross section.

Table 2. Water loss from in-channel storage below ground level in watercourses in Pakistan.

Average cross section below ground	1 square foot
Volume below ground per mile	0.12 acre feet
Number of acres per mile of watercourse*	20
Acres of irrigated land	30 million
Miles of watercourse	1.5 million
Volume of storage below ground	182,000 acre feet
Average number of times a watercourse is filled each year:	
High estimate	40
Low estimate	20
Annual water loss by in-channel storage below ground level:	
High estimate	7.2 million acre feet
Low estimate	3.6 million acre feet

*Estimated by measuring the length of channel in a watercourse and dividing into the number of acres served.

**Watercourses rotate on a one week to three week basis. Some canals are closed six months of the year. Maximum number would be 52 fillings and a minimum would be 20. A small portion of the watercourse has water flowing all the time and therefore not subject to this loss.

square feet below ground level. The number of acres per mile of water course is a judgment factor and was arrived at by estimation. An alternate procedure of assuming average dimensions for fields was used and 20 acres per mile of watercourse is a conservative estimate. These calculations indicate that from 3.5 to 7 million acre feet of water may be lost each year in channel storage below ground level.

Tarbela Dam is estimated to store 8 million acre feet of water when construction is complete. Undoubtedly no more than one-half of the water (4 million acre feet) released from Tarbela will reach the farm field. Tarbela cost approximately ten billion rupees. This simple calculation indicates that rehabilitation of watercourses to raise them above ground level could make more water available to farmers than a ten billion rupee Tarbela dam. A simple construction such as indicated in Figure 1(b) would also reduce many of the losses previously described as being common for watercourses in Pakistan.

The intricate system of ditches serving farmer fields results in another type of water loss. Some of the time allotted to a farmer is lost because of the time required to fill the ditch system in changing from one field to another. The time loss to fill the ditch is a water loss to that particular farmer. The amount of this loss varies depending on field position but in one case was noted to be almost 40 percent of the particular farmer's turn.

Water Application - When to irrigate; how much water to apply; and how to apply the water are questions basic to irrigation water application. Farmers consciously or unconsciously answer these questions and their answers determine whether or not they apply water properly to a field.

Irrigation application timing is frequently a question of waiting one, two or three weeks between applications with the rotation system of Pakistan. Many farmers, during the winter season, adjust the frequency of their wheat irrigations to three or four week intervals understanding that less frequent irrigations are needed during these cooler months. But some farmers irrigate on fixed schedules and pay no particular attention to rain or other climatic factors. Preliminary observations indicate that farmers irrigate all crops too frequently during the winter months.

How much water must be applied during a given irrigation depends on a number of factors. First in importance is how much water can the soil reservoir store. Other factors such as leaching of salts, depth of groundwater, providing moisture for germination, or minimum depth application to cover all the field are also important.

Farmer criteria for how much water to apply appears to be that all the field must be covered with water including an adequate depth over any existing high spots. In some fields high spots are not adequately covered consistently but farmers are aware that the result is salinization of these spots resulting in little or no yield of crop on that area.

The answers to the two questions of when to irrigate and how much to apply are interrelated, but farmers in Pakistan generally do not have adequate information to arrive at correct answers. A number of field application efficiencies have been measured in Pakistan by the authors. In fourteen trials the efficiencies varied from 10 to 50 percent with the majority of them being less than 25 percent. Efficiency was calculated as the ratio of the water needed to fill the root zone to the amount applied on the field. The most important factor causing low application efficiencies relates to the procedure followed in applying the water.

Most irrigation systems in Pakistan consist of one-eighth to one acre basins usually assumed to be level (zero grade). The maximum length or width of any basin is usually 220 feet while the actual dimensions vary dependent upon many factors. Small basins have been considered by many to be the most efficient system of irrigation for Pakistan.* Under conditions of poorly leveled land and limited water control, small basins are convenient, but not efficient.

The farmer wants to cover all his field including the high spots. This results in over application on most fields

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*Husain, Mohd. Studies on Scientific Irrigation and Agricultural Practices in West Pakistan. Research Publication, Vol. II, No. 10, Directorate of Land Reclamation; Lahore 1964.

during each irrigation and a waste of water. It is paradoxical that over irrigation occurs where water is a scarce resource. The obvious explanation is that some land lies idle during peak consumptive seasons and/or the irrigation interval is extended resulting in droughty conditions between irrigations.

Water Use by Crops - Water delivered and applied to a field is available for plant use, salinity control or other purposes. The water for plant use is stored in the soil and must be replenished throughout the growing season. Quantitative data on how soil moisture is maintained for proper plant growth are inadequate in Pakistan.

Water is applied to a field initially to supply moisture for tillage to prepare the seedbed. After tillage the surface is very loose and infiltration rates are high. The "rauni" irrigation, applied just before planting, is excessive because of the high infiltration rate of the soil and the small amount of moisture needed; usually not more than an inch. The first irrigation after the crop is planted is often excessive because of the relatively high infiltration and the limited soil water depletion. These irrigations also leach excessive amounts of nutrients from the soil further reducing the potential yield of the crop.

Soils that have severe infiltration problems, and there are many in Pakistan, restrict water penetration during irrigation and farmers are unable to effectively apply enough water for proper plant growth. Shallow rooting depths also limit the available supply of water and crop yields are low because of excessive moisture stress. This explains the common recommendation of light frequent irrigations, up to ten during the growing season for wheat. Even though not understanding all the implications of low infiltration and shallow rooting depths farmers have learned that frequent irrigations will improve yields.

Over irrigation also occurs in fields where soils exhibit moderate infiltration rates since as crop growth increases the surface retardance of the plants causes the necessity for larger and larger applications of water to force the water across the field. Over irrigation reduces fertility and crop yields. Infrequent applications of the large amounts of water result in plant water stress during the peak consumptive use periods. Water stress and low fertility both limit crop yield.

The fertilizer requirements of high yielding varieties are usually more than commonly applied by farmers. This is further complicated by the early over applications of water which leaches nitrates from the soil. Water management to eliminate over irrigations and optimum applications of fertility will do much to improve the low crop yields in Pakistan. The crop producing potential of water is wasted when it is applied to inadequately fertilized crops.

Salinity control is recognized by farmers as being important for good crop yields. The efforts invested in land leveling attempts and irrigation of high spots are evidence of farmer concern and knowledge. Management to control salinity is difficult because of improperly leveled land but also there is a lack of understanding that the leaching requirement is related to the amount applied, soil salinity, water quality and other management practices.

SUGGESTIONS AND RECOMMENDATIONS

An irrigation system should be managed with the object of increased agricultural production. Too often the water resource is considered to be of such importance that its mere presence will insure increased production. It is important, but it is only one input necessary for modern agriculture and its proper management on the farm cannot be neglected without disappointing results. Planners the world over have commonly divided irrigation system management into the engineering and the agricultural phases. This is a costly mistake since, under such an arrangement, no one is responsible for the entire system from the water source to the harvested crop. The result is the creation of several agencies, each responsible for certain phases and ordinarily not coordinating efforts in the interest of efficient use of water for maximum production. All governmental agencies in Pakistan dealing with the water and/or soil resources should dedicate themselves to realizing the greatest possible production per unit of water.

In Pakistan there is need to increase the supply of water available at the farm, discovering new sources is only one possible solution. Supplies can be increased by proper management and utilization of the water as it proceeds through the irrigation system to the harvested crop. To do this it is necessary to analyze the present practices which have developed from the rigid, inadequately supplied system. To utilize increased flows it may be necessary to alter some procedures. Several recommendations seem apparent and several less apparent ones will require detailed research to discover proper procedures and practices. The following are offered as possibilities for enchancing the irrigation system as well as modernizing farming practices to match the system. They are based on increasing available water and utilizing it more effectively and in most respects these are inseparable since efficient use means more water available.

1. Research programs dealing with on-farm water management should be given high priority.

A viable extensive agricultural research program is essential to modernize methods and techniques. It is a proven fact that money spent on agricultural research is returned to the economy many times over.

Irrigation water is only one input to successful agricultural production. However, its interactions and relationships with practically all of the other necessary inputs are important enough to warrant a full-scale research program in its own right. Irrigation water management and the associated soil-water-plant relationships are so vitally important that full benefits from other research can never be achieved until these are optimized. For example, potential yields from breeding programs will always be limited by the soil, water, and fertility management factors and if these are not given full attention results will be disappointing.

Researchers must use imagination and be willing to explore the unknown. Farmers are very flexible and research indicates that they will adopt practices which are proven to be profitable if the constraints facing them can be reduced. The planner or researcher cannot without research determine whether or not a given practice will be adopted by farmers. Too often the statement is made that the farmer cannot afford a given modern practice. Farmers are accomplishing many practices in Pakistan which are considered uneconomic in most of the so-called developed countries. Bench terracing, utilizing valuable irrigation water on fields containing less than fifty percent stands, irrigation pumping plants operating at efficiencies below fifty percent, and growing crops with practically no weed or pest control are all practices which are expensive. They would appear to be practices farmers cannot afford, yet in Pakistan they are practices today.

Optimum use of water will require further refinement of all factors influencing crop yields and conversely the full benefits to be derived from other factors such as fertilization will not be realized unless the crop has adequate water. When properly combined the right amount of water and fertility can double, triple, or even quadruple present yields. Other factors such as plant stands, weed, insect and disease control are equally important. When all inputs are put in proper combination maximum yields will be approached.

Much research is necessary before quantitative data are available on how best to manage soil moisture for maximum crop production. Moisture management in the soil is complicated and many crop cultural practices affect its distribution, retention and movement. Seed bed preparation, tillage practices, frequency and amount of irrigation, weed control, plant population, method of irrigation, disease control, rooting depth, fertility level, salinity, alkalinity, and climatic factors all have important effects on soil-water relations.

With such a complicated process it is obvious that maximum yields are not achieved, they can only be approached. The necessary research to find the proper combinations of inputs including amounts, methods and timings is a continuing process. The work is never complete. New approaches uncover new problems requiring research. The important benefit a viable research program creates is an ever increasing agricultural production. Yields approaching maximum today will be woefully small tomorrow.

2. <u>Conjunctive use of ground and surface waters should be encouraged</u>.

Tubewells represent a rather modern innovation which enhance the public irrigation system by supplying more water while maintaining ground water levels sufficiently low to permit land reclamation and increased agricultural production. Since most of the present irrigation system operates under a drought condition, supplemental tubewell supplies are exceedingly valuable.

A planned program of conjunctive use of ground water and surface water can make water available when needed as well as increase the total supply. Therefore benefits could be derived from better management of the total supply. Privately owned and operated wells should be encouraged since the farmer could control scheduling. Examination of ground water aquifer reservoirs in all locations will be needed so that excessive mining of water will not result in the exhaustion of the ground water resource.

Shallow, low discharge tubewells should be encouraged as new programs are adopted. Small discharges are easier to control and facilitate precise water control. This type of well is cheap to construct, does not require large power units, and more importantly does not drastically disturb the saline water underlying the sweet water aquifer.

Better methods of well construction and operation to skim sweet water need to be designed and tested. There are great quantities of good irrigation water lying in a rather thin layer on top of the very saline water beneath.

The entire river flow and irrigation system needs to be analyzed with the idea of utilizing to advantage all available water. Perhaps storage underground by water spreading is worthwhile. There is, in fact, sufficient water in the Indus system if properly apportioned, stored and utilized.

3. A national program of precision land leveling should be launched.

Precision land leveling and water control through systems designed to deliver the right amount of water in relation to the length and width of the field, the infiltration rate of the soil and the water needs of the crop would improve water application efficiencies in Pakistan. Greater lengths of fields would decrease the length of watercourses and facilitate other farming operations. A good job of leveling and water control would allow irrigation application efficiencies to increase to over 50 percent, more than doubling the water supply which is available for plant growth.

Farmers, especially those with smaller holdings, will require governmental assistance in order to do a completed job of precision land leveling. The program must include the engineering technical assistance to survey and design the fields as well as to insure the completed job meets design specifications. Research on the methods of applying water to the fields is needed to provide better design criteria for land leveling under Pakistan conditions.

4. <u>Watercourses should be rehabilitated for more effective field delivery</u>.

Rehabilitation of the watercourses should be done to provide increased capacity, improved cross sections, removal of unnecessary vegetation, protection against unnecessary spills and seepage. In areas where seepage losses are large, lined channels should be constructed to further reduce losses.

Seepage losses from watercourses can range from essentially zero to ninety percent of the flow at the "mogha". Water recovered by rehabilitation of watercourses has the same or greater value as water obtained from tubewells and equivalent costs are justified. Apparently, most farmers do not appreciate this economic fact since they generally adopt the tubewell alternative.

While renovation of all watercourses in Pakistan will require a long term effort, the benefits make the effort imperative. A country that can build the worlds largest earth filled dam can renovate 1.5 million miles of watercourse. The procedures can be labor intensive and the benefits are immediate improvement in food production through increased water availability. Such a program logically can be accomplished in conjunction with a land leveling program.

5. Rules and procedures for water delivery to the farmer should be reviewed.

The procedure of irrigating on a fixed schedule is not conducive to the development of a knowledge of plant needs for water as related to climatic factors and stage of growth. If water is only available at fixed times, plant needs cannot be effectively met. This practice causes wastage of water at times while a drought situation occurs at others. The result, of course, is reduced production per unit of water.

The feasibility of modifying the rules by which water is delivered should be investigated. Provisions of trading turns, for using only part of the flow of a watercourse, and the ability to store water in holding ponds on the watercourse for use at a later time need consideration and research. Methods of charging for and assessing water rates should be investigated. Making some segment of the Government of Pakistan responsible to farmers for efficient system operation could prove beneficial. One avenue to accomplish this would be through farmer Water Users Associations.