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IMPROVING IRRIGATION WATER MANAGEMENT ON FARMS

ANNUAL TECHNICAL REPORT

Colorado State University
June 1978

PN-AAG-615

Annual Technical Report
IMPROVING IRRIGATION WATER MANAGEMENT ON FARMS
April 1, 1977 to March 31, 1978

Submitted to
The U.S. Agency for International Development
Contract AID/ta-C-1411

June 30, 1978

Water Management Research Project
Colorado State University
Fort Collins, Colorado 80523

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Appendix

A. Annual Report Summary Sheet

Project Title: Improving Irrigation Water Management on Farms

Contract Number: AID/ta-C-1411

Principal Investigators: Gaylord V. Skogerboe, W. Doral Kemper and John O. Reuss

Contractor: Colorado State University

Contractor's Address:
Water Management Research Project
Engineering Research Center
Colorado State University
Fort Collins, Colorado 80523

Contract Period: April 1, 1977 to March 31, 1980

Reporting Period: April 1, 1977 to March 31, 1978

Total Expenditures and Obligations Through Previous Contract Year	$741,008 April 1, 1977 to March 31, 1978
Total Expenditures and Obligations for Current Contract Year;	$1,008,992 April 1, 1978 to March 31, 1979

Narrative Summary

Among the most significant accomplishments during this report year are: (1) continuation of field studies with WAPDA at the Mona Reclamation Experimental Project (MREP), including preliminary results of the watercourse cleaning and maintenance research program, which could be implemented throughout the country; (2) continuation of watercourse surveys, including physical and socio-economic aspects; (3) participation with the USAID Mission to Pakistan and the Soil Conservation Service in implementing the On-Farm Water Management Pilot Project; (4) development of cooperative efforts with the Department of Agriculture in the three provinces of Punjab, Sind and North West Frontier in order to implement the On-Farm Water Management Pilot Project; (5) research proposal funded for field studies in cooperation with the University of Agriculture, Faisalabad (UAF) regarding alternatives for organizing farmers in order to improve on-farm water management; (6) preliminary development of training materials, initial training of trainers, and training of first class of Water Management Extension Officers for pilot project, with participants representing all four provinces in Pakistan; (7) development of research proposal, "Water Management Research Programme for Rural Development" with UAF using an area of 37 villages to provide field research experiences for faculty and more meaningful field experiences for the Water Management Extension Officer trainees; (8) successful development of concrete nakka lids in the Punjab, with this technology to be transferred to the other provinces for use in the provincial On-Farm Water Management Development Projects; (9) cooperative efforts with the major agricultural research centers in Pakistan on significant research pertaining to wheat, rice, cotton and maize; and (10) the transfer process being developed for use in other countries has evolved into three major phases; namely, problem identification, development of solutions, and implementation.

Annual Technical Report

IMPROVING IRRIGATION WATER MANAGEMENT ON FARMS

B. Background

1. General

Inadequate water is the primary constraint on agricultural production in a large portion of the developing countries. The technology for using available water supplies most efficiently is either lacking or not adapted to the available resources, in many of these countries.

Recognizing that these water management problems were common to many countries, it was apparent that solutions gained in one country should be, to some degree, transferable to others. Consequently, it was decided that a coordinated effort should be made to build up a fund of transferable water management technology. A consortium of universities was formed to develop this fund of water management information and gain experience in the factors limiting or accelerating its adaptation in new countries. CSU was initially assigned the Near East-South Asia, with Pakistan and Vietnam as the study areas in which on-farm water management principles and concepts would be developed and adapted to resources similar to those available in many other developing countries. The present contract focuses upon: (a) continuing the on-farm water management research program in Pakistan; (b) developing the transfer process that can be utilized by other countries for improving their on-farm irrigation water management practices; and (c) providing limited technical assistance to AID Missions for initiating on-farm water management programs.

2. Pakistan

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 his disposal determine his on-farm water management practices, which in turn determine the crop production per unit of irrigation water.

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. 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. There are important reasons for the low crop yields and lack of agricultural production, including 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, there is a need for a much improved on-farm management system. The potential for increasing production through improved water management is great.

C. Project Objectives

1. General Objective

The general objective of this research is to develop, design and implement guidelines for improving irrigation water use efficiency and effectiveness on farms.

2. Specific Work Plan

a. General Activities

Any technological improvement must be acceptable to those who will provide for, utilize, and manage it. It is therefore essential that the research on this project take into account the special needs of the farmer including the interrelationships among technology, institutions and the prevailing economic, social and cultural factors. Therefore, the laboratory for the research will be primarily the farmer operated and managed sub-irrigation system. This includes the water transport system among farms and on farms, the crop fields, and the institutional and procedural arrangements involved in managing the water supply.

Previous work on this project has identified several acceptable technologies for improvement. Under this contract the contractor will test and evaluate these separately and in combination under farmer conditions. Most research will be conducted on watercourse areas being pilot tested under the

USAID/Pakistan On-Farm Water Management Project No. 391-4130, hereafter referred to as the "pilot project." This large-scale "pilot project" will require considerable technical assistance effort from the contractor to develop training materials and trainers, for the variety of functions required in the integrated package of improvements. An important aspect of this program will involve organizing farmers on watercourses to effectively implement the management program, as well as insure the continued usefulness of the improvements through effective operation and maintenance procedures in succeeding years.

The contractor will conduct a two pronged research program involving: (1) the study of problems, constraints, procedures, training, institutional, technical and economic requirements associated with implementing, managing, and maintaining the improvements, and; (2) the articulation of results (especially the investigative and procedural requirements for technology selection and implementation) clearly and concisely and in a format readily usable in other socio-economic environments.

The technologies to be tested and evaluated by the contractor include: (a) watercourse improvement, (b) improved structures for water control, (c) land shaping and farm field layout, (d) augmentation of water supply with wells and on-farm storage, and (e) optimal utilization of increased water supplies. The contractor will provide technical services to ensure that these technologies are installed on at least ten (10) watercourse areas. These areas will preferably be a part of the "pilot project." However, in case that project is unduly delayed or fails, the contractor will provide the same services to install the improvements on ten areas through the research project agreements between USAID and WAPDA and/or USAID and the Punjab Department of Agriculture under which the contractor-Colorado State University is presently working. These watercourse areas will become the principal laboratory areas for the research. Since the contractor will address the technical, training, institutional, and economic aspects of implementation and management of the improvements, data collection on these areas will be necessary throughout the implementation, management, and maintenance process.

b. Specific Activities

(1) Technical Activities

The contractor will give technical guidance on the watercourse rehabilitation and land leveling aspects of the "pilot project" being especially careful that these components are technically correct on all watercourse areas comprising the laboratory for this research. A series of watercourses will be reconstructed with concrete and masonry control devices at every major junction and outlet. Existing ditch banks will be removed and the watercourse will be reconstructed to proper channel size and elevation, compacting the earth in the banks. The labor will be provided by the farmers. These reconstructed watercourses will be designed on the basis of a complete topographic map of the area, measurements of the flow to be handled, the number and position of structures and culverts needed and basic principles of open channel flow. As each watercourse is completed and evaluated, utilizing benchmark data compared with improved conditions, the lessons will be used to refine guidelines for future watercourse improvement projects.

The contractor will also test an "essential improvements program." This will involve minimum engineering and capital outlay. Losses at degraded junctions will be reduced by filling borrowed areas and bringing watercourse banks to proper cross sections. Observable leakage through banks will be stopped by simple core compaction techniques. Degradation and subsequent leakage due to animal traffic will be minimized by designing and constructing compacted earth watering and bathing stations and sediment will be controlled with earthen sediment traps. One or two major junctions will be improved with concrete control structures when the farmers have finished their earthen improvements and they will be given cost information. The farmers may then decide to invest in more of these structures. The professional services will be provided primarily by extension agents who will have had special short course training provided by the contractor.

The contractor will determine the maintenance and educational requirements of precision land leveling to ensure that properly designed and constructed fields remain in good order.

The research will include an analysis of crop water needs and cropping patterns to efficiently utilize water. Obviously, it is not possible to include all crops and related variables in such a program. Therefore, a synthesis of cropping recommendations and related cultural practices appropriate to the increased water supplies will be field tested with farmer cooperators. The approach will be to use water requirements as a focal point. Climatic records will be examined and water needs for various crops as a function of time computed for normal and dry years. Cropping mix, planting dates, or irrigation practices will be shifted to best match the available water supply to the needs of the crop. Such programs will be tested in farmer cooperators' fields. The research component will consist of documenting the performance of the improved cropping system as compared to previous or unimproved systems.

Field evaluations of tubewells and pumping devices will be made to develop guidelines for designing and operating skimming wells such that water of satisfactory quality (salinity) can be safely extracted.

(2) Training Activities

The contractor will provide personnel assistance (for the "pilot project") in design of a training program. This will include development of materials and methodologies for implementation and evaluation. Major inputs will be organization, development of training methods and materials, and training and evaluating trainers and trainees. Evaluation and refinement of the program will be major activities during both the classroom and on-the-job training periods.

The entire training project experience will be analyzed and developed into a manual which describes and recommends minimum training requirements for various aspects of the water management improvement process. The evaluation will include selection of trainees, methods for training, and content of material to be taught. Throughout the training exercise, the contractor will assay the possibility and feasibility of developing a worldwide or regional training center in the field of water management development. In this effort, linkages with other agencies (IRRI, SEARCA, East West Center for example) will be examined.

(3) Institutional Activities

In order that improved farmer operated irrigation systems can be maintained and managed properly, the farmers must be organized in some manner. The contractor will develop evaluative tools to measure the effectiveness of farmer organization and with these tools evaluate a representative number of farmer organizations formed under the "pilot project." The interrelationships between these organizations and the individual farmer and the relevant government institutions will be identified and evaluated.

(4) Economic Activities

A major focus over the contract period will be given to several types of economic analyses to determine the cost/benefit ratios of alternative technologies and methods for watercourse improvements, increasing cropping intensities, and improving irrigation and cropping practices. These economic studies are of critical importance for policy makers in planning both short and long term research and development programs on a country wide basis.

Water management alternatives will be analyzed using cost-benefit methods to determine the relative value of various combinations of technologies for varying water supply situations over various time periods.

Specific economic studies will focus on the following areas: (1) *Economic benchmark studies* of ten pilot experimental watercourse areas to document the economic benefit-cost ratios resulting from specific technologies. These studies will document the costs of labor and materials and determine the increases in cropping intensities, crop yields, and net farm income resulting from adaptation of technologies; (2) *Farm management studies* to ascertain alternative changes in cropping intensities and crop mixes to increase net farm income resulting from the increased water supplies due to reduction of water losses and improved field application practices. Special focus will be given to small and medium sized farms. (3) *Costs of production of water from private (both diesel and electric) tubewells will be analyzed.* The relationship between degree of utilization and availability and dependability of canal water supplies will also be studied. Data on the productive life of different tubewell and pump components as well as actual pumping rates will be collected and analyzed; (4) An intensive *socioeconomic benchmark evaluation* will be made on a sample of the 1500 watercourse areas under the "pilot project." The methodologies and socioeconomic analyses will be specified and documented such that replication of the process with site specific data can be accomplished expeditiously.

(5) Utilization and Extension Activities

The results of the research efforts in Pakistan under this and previous contracts will be presented in a set of manuals which can be utilized in other LDCs to identify farmer irrigation water management problems and to select and implement solutions in a manner consistent with their own social, economic, and physical constraints.

A manual of first importance is a description of the methodology or systematic process (herein called the *transfer model*) which has evolved from the research experience in Pakistan. This process of problem identification, development of appropriate solutions, and demonstrations on farmers fields preceding full-scale implementation will be defined in sufficient detail that others could utilize it in developing and implementing on-farm water management programs. The development of the transfer model will begin immediately since it involves the synthesis and articulation of all aspects of the project into a model which can be utilized by others in other places. A preliminary description will be presented to AID where it will be extensively reviewed in TAB, Regional Bureaus, and selected Missions. The model will be finalized as the research and development phases are concluded and the technological components of the management improvement processes are formalized. The process (model) description will be developed by all disciplines involved in the project with assistance from AID/W and the Mission in Pakistan as representatives of the donor agency.

A by-product of the transfer model is a set of technologies which have proved to be successful in Pakistan in improving irrigation water management. Each of these will be presented in manual form. The material will be presented such that another LDC can utilize the manual to make a determination as to whether the particular technology is socially, economically, and technically acceptable in its environment. If it is found to be acceptable, the manual will also contain detailed instructions on how to implement and manage it. Specific subject matters to be covered in these technological manuals will include:

a) watercourse improvement,
b) land shaping and field arrangement for efficient use,
c) crops and cropping patterns for efficent utilization,
d) institutional and organizational needs,
e) system maintenance
f) augmentation of supply by wells and farm storage

One of the most important aspects of the water management research experience in Pakistan is determining the degree of transferability of the research results. Although there is considerable confidence that much of the research findings have value in other LDCs, this must be documented by and in other LDCs. Contractor professionals and in some cases their Pakistani counterparts will provide limited technical assistance to AID for irrigation water management project planning and evaluation. Approximately the equivalent of one full-time professional will be allotted from project funds for this purpose. Specific Mission requests will be reviewed by TAB and the Contractor to determine relevance and availability of suitable technicians. Two purposes will be served by this activity. The Missions will receive needed technical assistance for project development and/or evaluation and Colorado State will gain experience and data valuable in refining the transfer process and determining the transferability of the Pakistan water management project. It will also serve to acquaint project personnel with AID's project development process.

D. Continued Relevance of the Objectives

Our research findings, surveys in Pakistan, and consultation with experienced water management personnel from USAID, FAO, the World Bank and several developing countries indicate that accomplishment of the original objectives will benefit the developing countries and contribute substantially to the fund of transferable water management technology. In fact, there is a growing awareness among international donors of the importance of on-farm irrigation water management for LDC's.

E. Accomplishments During the Reporting Year (April 1, 1977 to March 31, 1978)

1. Summary

Among the most significant accomplishments during this report year are: (1) continuation of field studies with WAPDA at the Mona Reclamation Experimental Project (MREP), including preliminary results of watercourse cleaning and maintenance research program, which could be implemented throughout the country; (2) continuation of watercourse surveys, including physical and socioeconomic aspects; (3) participation with the USAID Mission to Pakistan and the Soil Conservation Service in implementing the On-Farm Water Management Pilot Project; (4) development of cooperative efforts with the Department of Agriculture in the three provinces of Punjab, Sind and North West Frontier in order to implement the On-Farm Water Management Pilot Project; (5) research proposal funded for field studies in cooperation with the University of Agriculture, Faisalabad (UAF) regarding alternatives for organizing farmers in order to improve on-farm water management; (6) preliminary development of training materials, initial training of trainers, and training of first class of Water Management Extension Officers for pilot project, with participants representing all four provinces in Pakistan; (7) development of research proposal, "Water Management Research Programme for Rural Development" and UAF using an area of 37 villages to provide field research experience for faculty and more meaningful field experiences for the Water Management Extension Officer trainees; and (8) successful development of concrete nakka lids in the Punjab, with this technology to be transferred to the other provinces for use in the provincial On-Farm Water Management Development Projects.

Besides the research programs with WAPDA and the provincial departments of agriculture, the CSU Field Party is working with the major agricultural research centers in Pakistan on significant research pertaining to wheat, rice, cotton and maize. Besides other Government of Pakistan institutions, the CSU Field Party has joint efforts with the University of Agriculture at Faisalabad, Quaid-i-Azam University (formerly the University of Islamabad), Sind Agricultural University and University of Peshawar.

The transfer process being developed for use in other countries has evolved into three major phases; namely, problem identification, development of solutions, and implementation. A report has been prepared describing the transfer process. A first draft of the problem identification manual is completed, while the remaining two manuals will be undertaken immediately.

The following three personnel have served with the CSU Field Party in Pakistan during this entire report period: Dr. John

O. Reuss (Agronomist) who became Chief-of-Party on August 1, 1977; Dr. Sidney A. Bowers (Soil Scientist); and Mr. Tom Trout (Agricultural Engineer, Irrigation). Dr. W. Doral Kemper (Soil Scientist) served as Chief-of-Party until his departure for campus in July 1977; Dr. Alan C. Early (Agricultural Engineer, Irrigation) departed for employment with IRRI in the Philippines during May 1977; Dr. Sam H. Johnson III (Agricultural Economist) departed for employment with the Ford Foundation in Thailand during August 1977; and Mr. Larry Nelson (Agronomist) returned to campus in December 1977. Dr. Helmer Holje (Agricultural Economist) joined the CSU Field Party in February 1978; Dr. Dwayne Westfall (Extension Agronomist) arrived in early March 1978; and Mr. Norman Illsley (Agricultural Engineer, Equipment) also arrived in early March 1978. At the end of the report year, the CSU Field Party in Pakistan consisted of six personnel, with the seventh member, Mr. Douglas Merrey (Social Anthropologist) arriving the following month (April 1978).

2. Water, Soil and Crop Management

a. Moisture Stress and Fertilizer Response

Results of water management related experiments with several crops over the past years tend to consistently bring certain patterns into focus. Moderate stress levels that reduce irrigation application to 60 or 70 percent of optimum will usually only result in a 10 to 15% yield decrement, and will produce reasonably good yields under good management conditions. Fertilizer responses are usually somewhat less under stress than under optimum conditions, but fertilizer is still a good investment. Crops normally responsive to fertilizers, such as wheat or sugarcane, when fertilized and placed under stress (60% of optimum water), will outyield crops without fertilizer that have plenty of water.

Perhaps most important is that in virtually all cases good yields were obtained with irrigation levels substantially below those usually considered optimum, and that highly profitable fertilizer responses were consistently obtained under substantial moisture stress. Agronomists are fond of saying that fertilizer is only effective if ample water is applied, or that the new high yielding varieties require more water. Our results indicate that these statements may be misleading. Certainly fertilizer and improved varieties give maximum benefits with ample water, but even when available water is reduced to 60% of that commonly applied to Northern Punjab crops, both are usually good investments. Over a substantial range of both fertilizer and water levels, increasing either input results in yield increases and the optimum combination of the water and fertilizer inputs depend on their costs. These results obtained to date in the Punjab do not support the view that lack of fertilizer adoption is due to the fact that many crops come under water stress and therefore do not respond to fertilizer applications.

These experimental results would also tend to support the view that optimum use of the scarce water resource would favor increasing cropping intesity on the average tubewell supplemented watercourse up to at least 1.6 crops/year, even if this results in some stressed crops. Only as fallow lands are more fully utilized should full water supply be given. Linear programming analysis of cropping systems tend to support this conclusion.

b. Crop Stands

Stand establishment is a major limitation in production of crops in Pakistan, particularly kharif crops. Practically all irrigation is by the basin method and crops are sown in moist soil following a pre-irrigation. Rains occurring shortly after kharif planting almost invariably result in crusting, which damages emergence causing poor yields.

CSU has been concerned with methods of irrigation involving such practices as furrowing or bedding, crust breaking, irrigation for crust or temperature control, and surface drainage. Results of crust breaking trials have been somewhat inconsistent, probably due to the fact that this procedure is highly sensitive to timing and care in the operation. Results of furrowing and bedding with postplant irrigation for germination have been very encouraging, but adoption will not be easy. Very little equipment is available in Pakistan for this purpose and what is available is generally ill adapted to either the power resources available or field sizes as they exist in Pakistan. The potential of this practice for attaining good stands is evident to anyone who saw the cotton field trials at Chak 11 at Mona last year. Emergence was virtually perfect and stands were actually in excess of optimum, a very unusual condition in the Punjab.

The potential of surface drainage and the effectiveness of ridge or bed planting in alleviating the damaging effects of flooding from heavy rains has also been demonstrated, but the transition from these plot trials on surface drainage to effective utilization given the surface topography of the Indus Plain and the existing field layouts will be a difficult process.

c. Consumptive Use Trials

CSU staff have been cooperating with Pakistani Institutions coordinated by the Agricultural Research Council on a USDA, P. L. 480 financed research program to determine consumptive use requirements of major crops at selected locations in Pakistan. This is an on-going program and reports are now accumulating. These data will be very useful in developing the overall water balances and for irrigation advisory purposes. While much of the data appears to be consistent, some institutions are finding results that are readily explainable in climatic terms. These institutions need help from the ARC and CSU to evaluate and refine their techniques and operating procedures. CSU team time available for this purpose is limited, ARC travel facilities are so limited that the technically trained assistant coordinator cannot make regular visits to the more isolated sites, and the personnel at some of these locations appear to be irresponsive to suggestions for improvement of their procedures. At some of these locations, improvements should be made or the sites eliminated from the project.

d. Optimum Management

Several research cum demonstration trials have been conducted on various crops. The results of each are interesting and there have been several spirited discussions among agronomists as to which of the several practices included in the experimental design were most effective in increasing productivity. Suffice it to say that high yield levels can generally be attained when good practices are followed. Many of the yields have been impressive, yet there have been virtual failures in these trials as well. The most conspicuous failure was a kharif maize crop whose stand failure resulted from heavy rain after planting, the same problem that consistently plagues the farmer with his kharif crop.

e. Water Quality

Interpretation on the water quality criteria research work is essentially complete. Mr. Ghulam Hussain is in the final stages of preparation of his dissertation which will be defended in late April or early May. The final conclusion reached is that the Residual Sodium Carbonate criteria does not contribute much to the prediction of water quality problems and should be dropped. Theoretical evaluations using an equilibrium-solution computer program shows that alkalinity should in fact have a major effect on the final calcium concentration of the soil solution, but have little effect on the magnesium concentration. These investigations indicate that the practice of using combined analysis for Ca and Mg, in areas such as Pakistan where high Mg waters are common, should be discontinued. Analytical methods accurately separating these ions should be used and the interpretation should consider them separately. In addition, the effects of the high Mg waters on the Ca/Mg balance in the soil and the resulting implication as to soil condition and plant growth must be investigated.

3. Watercourse Improvement Programs

Several significant accomplishments have been achieved relative to increased knowledge concerning the functioning of the farm water distribution system in general and the watercourses in particular, as well as improvements in design and methods of rehabilitation.

a. Delivery Efficiency

Watercourse delivery efficiency measurements have continued. Several of these have been "warabundi" studies which consist of round-the-clock inflow-outflow measurements for a full week rotation turn. These measurements continue to show that about 50% of the water that enters the watercourses in the Mona area reaches the field.

Other important findings of these studies are the identification and quantification of the means by which these losses are occurring. The farmers are conscious of dead storage losses, but in fact they generally do not account for more than about 3 to 5% of total inflow. We have also made considerable efforts to call attention to visible losses such as leaky junctions, nakkas, rat holes, etc. While these visible losses are significant, measurements lead to the conclusion that they are secondary to the nonvisible losses that occur as a result of the high infiltration rates in the upper portion of the watercourse banks.

b. Watercourse Losses

It has been established that watercourse losses are generally an exponential function of depth of water in the watercourse of the form:

$$\frac{dQ}{dD} = ad^b$$

Where Q is the loss in volume per unit time, D is distance along the watercourse, d is depth of water in the watercourse and a and b are constants dependent on the shape and condition of the watercourse. Depth, of course, is a function of the rate of flow entering the watercourse and the gradient. In unimproved watercourses, b tends to be greater than 1.0, with the result that as depth increases the loss rates increase very sharply. In properly designed and constructed earthen watercourses with adequate freeboard, b is very near 1.0, so that the relationship between depth and flow is approximately linear.

c. Demand Deliveries

A great deal of interest has been generated regarding the possibility of developing demand irrigation conveyance systems that will allow water to be delivered at times and in amounts more nearly matched to crop needs. CSU personnel have often noted the desirability of such a system. Increased delivery during time of heavy water demand can be achieved by storage. Tank storage at the watercourse level is being considered, but problems such as local conflicts, equitable water allocation, operational losses, etc. must be taken into account.

Tubewells presently offer the best potential method of matching water supplies to crop water requirements. One system under consideration is a farmer association controlling public tubewell pumping times, with operating costs assessed according to actual usage. This would alleviate the problem of not being able to pump due to inadequate budget for power supplies, as well as eliminate pumping when demand is low. Even greater flexibility is provided by constructing small tubewells near the point of use, with the added advantage of reducing conveyance losses.

d. Watercourse Losses as Related to Pumpage

A recent analysis of the interaction between watercourse losses and the ground water table shows that the efficiency of ground water control by tubewell pumpage is closely related to the efficiency of water conveyance and application within the watercourse command area. A consideration of the potential evapotranspiration rates of the areas along the watercourse covered by phreatophytes and affected by spills and leakages suggests that at least 75 to 80 percent of the conveyance losses and practically all of the application losses must eventually reach the ground water table. In addition, ground water recharge is augmented by monsoon rains and by seepage from canals and distributaries. If the ground water table is near the surface, upward capillary flow to the root zones of growing crops and to the surface will be a major factor in controlling depth of ground water, but this process is likely to result in waterlogging and salt accumulation.

If the ground water is sufficiently deep that upward flow is negligible, water delivery efficiencies of 50 percent or less mean that ground water pumpage from public tubewell systems must be about equal to canal deliveries to maintain ground water equilibriums. (Assuming that the application efficiency is approximately equal to the fraction of the water lost in delivery and application which reaches the groundwater.) This means a tubewell pumping continuously is required having the same capacity as the canal outlet, or in order to achieve flexibility so that pumping could be limited to the 50% of the time to provide supplemental supplies, installed capacity would have to double the canal delivery capacity. The problems inherent in recirculating water from tubewells into inefficient watercourses become very apparent.

Conversely, if system efficiencies above about 75% were consistently obtained, it would likely result in insufficient recharge for using the ground water aquifer to provide supplemental water from tubewells during high demand periods, but would reduce energy requirements, waterlogging and salinity.

e. Structures

One of the most significant improvements in watercourse structures for use in Pakistan is a modification of the pre-cast concrete, orifice type turnouts. These are used for both turnouts and check structures. The panels and closure lids are pre-cast reinforced concrete and are installed in short brick masonry channel sections. These structures have evolved over some time. The early versions required either a rubber gasket or a mud seal; both would work, but the gaskets were subject to deterioration and were often lost or stolen. The mud seals were often not placed carefully or would crack and leak after a drying cycle. The newest version has a convex concrete sealing surface in the panel that is precisely cast using a machined steel form. The matching closure lid is then cast directly in the panel in which it is to be used. Prior to pouring the lid, the panel surface which is to contact the lid is greased to prevent sticking. Improved quality control and the absence of sharp corners reduces chipping and breaking. Cost of a 20 inch panel with lid is about Rs. 60 (Rs. 9.90 = $1.00). Leakage is practically eliminated and farmer acceptance is excellent. The use of these "nakkas" is a major factor in farmer demand for watercourse improvement programs. The present version is the result of a cooperative effort between CSU staff and a local fabricator.

f. Low Cost Linings

Several types of low cost linings are being considered. Some tests have been run on "cores" or impervious materials imbedded in the watercourse banks to minimize seepage. These included compacted earth, plastic, brick, and soil-cement block. Tests on these are not yet conclusive. Several test sections have been built using lower cost methods of brick, concrete panel, or soil-cement block sections. As water loss largely occurs through the sides, some of these are without linings on the bottom. Costs of these are about one-third of the cost of the traditional nine-inch brick masonry sections (Rs. 15-20 per foot as compared to Rs. 45-60). Several of these are performing well but have not yet been evaluated under monsoon conditions. Results to date show that these thin linings need to have sloping sides (trapezoidal section) in order to minimize backfill pressure so as not to cause failure. Also, the earthen pad on which these linings are placed should be well compacted in thin layers.

g. "Low Operating Level" Designs for Watercourses

As watercourses age, the upper portion of their banks become increasingly riddled with holes of rats, insects and worms and the exponential relationship between level of water in the watercourse and water loss becomes more pronounced. The practical "inevitability" of this process raised the question of whether a watercourse could be designed so that leaky banks would not cause large water losses. An apparent solution was to design the watercourse so its normal operating level was at or below the level of the surrounding soil surfaces. This type of watercourse requires more freeboard and check structures which can raise the level of water about 6" above operating level at the points of delivery into the fields. Water levels will be raised from the check points upstream from some distance depending on the slope of the watercourse, but during most of its travel to the fields, water can stay low in the channel.

The watercourse serving Tubewell 81L was designed with a "low operating level" to determine whether this would significantly affect the loss. The measured losses on the watercourse serving TW 81L averaged 1.87%/1000 ft. prior to cleaning and 1.10%/1000 feet following cleaning. Average losses on the other improved watercourses prior to cleaning were 5.07%/1000 feet and were 2.78% following cleaning. These data indicate that designing and constructing watercourses with "low operating levels", extra freeboard and high rise check structures can reduce water losses from watercourses by more than 50%. The labor and structure costs involved in building "lower operating level" watercourses are only slightly higher than for the normal watercourses now being used in Pakistan.

h. Structures for Elevating Canal Water to Serve High Lands

Sediment deposition on lands near the canal has raised the elevation of the land. Near the tail end of distributaries, full supply levels are not maintained. When tubewells begin to pump water into these watercourses, the water level often rises in the watercourse until little or no water is coming through the moghas from the canal.

In most cases, the problems can be solved by enlarging and cleaning the watercourse. However, in some cases the level of the land to be served is often near or even below the level of water in the canal. One of the possibilities for raising the canal water to properly command these high fields was the use of a large capacity, low lift jet pump. A considerable amount of energy (about 3 or 4 feet of head) is available in the water in the fall box of government tubewells which could be used to help push canal water up to levels 6 to 12" above the supply levels. Design and performance information was not available for such large capacity low lift jet pumps. Consequently, a study is in progress at the CSU hydraulics lab which has already shown that such "jet junctions" are feasible and can often raise canal water to the desired levels with the energy of water available in the tubewell fall box. Cost estimates are about Rs. 1600 for installation of such a "jet junction" which could raise canal water 6 to 12" above its original level. With current designs, pump efficiencies for these junctions ranged up to 42% and there are possibilities for increasing to even higher efficiencies.

i. Low Cost Siphons

The only completely leakproof outlet from a watercourse is a siphon. Use of siphons is restricted in Pakistan by their relatively high cost. Siphons were constructed of used automobile tires at costs ranging from 30 to 40 rupees, that can carry from 0.2 to over 1 cusec of water. The cost of these siphons is less than 20% of known alternatives. They provide an economical new tool for water management.

j. Cleaning and Maintenance

The standard design for improved watercourses adopted by the On-Farm Water Management Pilot Project (OFWMPP) consists of earthen improvement with concrete panel turnouts and checks set in short brick masonry sections. Lined sections are installed in areas of high loss or heavy traffic. This system was developed by CSU and is still an excellent method. It does, however, require substantial technical input for structures. Lately, CSU and the Mona cooperators have spent substantial effort on what was started as a, "cleaning and maintenance" research program. In fact, it was carried out more as a rebuilding program in which no structures were used. Excess trees and vegetation were removed. The banks were built up to proper thickness and about half of a foot of freeboard over normal operating level provided. Earth was brought in to rebuild degraded areas around outlets and junctions. No engineering assistance was provided; farmers built the sections to provide the necessary freeboard above what they knew to be operating level. About 10 watercourses have presently undergone this treatment. Several important lessons were learned. A three mile main watercourse could be restored in about three weeks with thirty laborers working, averaging about 6 feet per man-hour. At prevailing wage rates, this is a cost of about Rs. 0.20 per foot. Once the heavy earthen rehabilitation work is completed, periodic cleaning and maintenance (three or four times a year) can be done with much less labor. One man can then clean about 20 ft. per man-hour, 150 ft. per day, which amounts to an annual cost for maintenance of about Rs. 0.25 per foot. Flow measurements immediately after maintenance of this type suggests loss rates very similar to those from earthen improvements with permanent structures. Farmers reported an average reduction of 34% in the time required to irrigate one acre.

The cost per unit of water saved on this program is lower than for any other type of program tested and the investment is largely in the form of village labor. In the long run, serious degradation of the earthen nakkas and junctions can occur again if soil is not properly replaced. However, with a major extension effort and enforcement of the provisions of the Canal and Drainage Act under which water is not to be delivered to watercourses that are not in good condition, virtually all watercourses in the Punjab and Sind could be restored in a matter of months and field deliveries of water increased by 15 to 25 percent. Farmers were somewhat reluctant to take part in this program where no incentives are offered probably because farmers on surrounding watercourses who were participating in the improvement program were receiving concrete water control structures. Probably the optimum course for the Punjab and Sind would be the implementation of an immediate and massive "cleaning and maintenance" program followed by a slower rebuilding program that includes structures. Requiring a cleaning and maintenance program by the farmers as a precondition for participation in the On-Farm Water Management Pilot Project could benefit both programs.

4. Economics of Watercourse Improvement

Several attempts have been made to evaluate costs and benefits from watercourse improvement programs. Costs have varied from well over Rs. 50 per linear foot of main channel for conventional brick and mortar watercourse linings to somewhat less than Rs. 2 per foot for earthen improvements with pakka structures if little or no lining is involved. Even lower costs are encountered for cleaning and maintenance programs where no permanent structures are provided.

Benefit/cost ratios from the various improvements vary widely depending on the assumptions made concerning the life of the improvements and maintenance costs. The actual life can only be determined with experience and is dependent on the level of follow-up extension effort that can be maintained. However, several very general relationships do appear, such as lower cost improvements tend to give the highest return on investment. Second, costs are closely related to the amount of lining. In view of these two generalities, it would appear that lining should be kept to a minimum. However, as experience is gained it appears that high traffic areas, particularly in the villages, degrade very rapidly if not lined, and this consideration probably has not been adequately taken into account in the above generalization. Also, lining watercourses in the village areas does appear to substantially improve the quality of life in the villages. Some of the low cost test sections, costing in the neighborhood of Rs. 20/ft or less, appear to be performing well, but it has not been possible to achieve a reliable estimate of their life at this time. At any rate, data collection and analysis concerning these aspects must be a priority item for some time to come.

Several of the economic analyses depend heavily on the value assigned to the water saved. If cost of replacement by tubewell water is considered to be the criteria, watercourse improvements generally appear to be economically favorable. Certain precautions, however, must be taken as using TW water cost is only valid if the marginal return from the water is greater than the pumping costs.

5. Training Water Management Extension Officers

Saving water in watercourses is not productive unless the water is used effectively to increase crop production. CSU has been asked to work with the University of Agriculture, Faisalabad (UAF), in developing a training program which will prepare one Water Management Extension Officer for each water management development field team under the On-Farm Water Management Pilot Project. His responsibility will be to help farmers improve their production through better management of his expanded water supply, leveled land and other essential inputs (seed, fertilizer and weed and pest control). Dr. Early, Dr. Lowdermilk and Dr. Johnson developed an outline for this training which has served as the basis for an agreement between the Punjab Government and the University of Agriculture, Faisalabad. In addition, the Sind, North West Frontier Province and Baluchistan provincial governments developed similar agreements with the University of Agriculture, Faisalabad. CSU will help develop training materials that can be used by all four provinces, and will assist to the extent of available personnel and as requested by the respective provincial governments.

The first course was given June 10-October 20, 1977. There were 16 participants (8 from the Punjab, 4 from the Sind, and 2 each from the North West Frontier and Baluchistan). Eight faculty trainers were involved along with 2 CSU advisors. Additional training materials were developed afterwards in preparation for the second training course scheduled to begin in April 1978.

6. Water Users Associations

The first pilot watercourse improvement project was carefully selected on the basis of leadership and organization being inherent in the farmers group which would allow them to complete the improvement successfully. However, studies by Mirza and Freeman and by Lowdermilk indicate that water users on most watercourses are divided by long standing disputes, caste differences, and other factors, to the extent that the degree of cooperation and organization is a primary factor limiting watercourse cleaning, maintenance and improvement projects. Radosevich has studied and outlined the types of water users organizations effective in managing water in the primary irrigated areas of the world and has suggested organization guidelines, rules and policies which appear to be adapted to Pakistan's physical and cultural characteristics. It is probable that implementation of some of these guidelines, rules and policies may provide the foundations of cooperative organizations, which have had a profitable experience in watercourse improvement and maintenance, and will have sufficient credibility and prestige to help the farmers cooperate in ownership of equipment, tractors, tubewells and other activities, thereby allowing these farmers with small acreages to participate in the new technologies previously available only to those with larger holdings.

At the request of USAID/Islamabad, Colorado State University agreed to develop a research project to test and identify the organizations that might help farmers more efficiently use their water. Dr. David Freeman was invited to come to Pakistan for six weeks to organize the study. David Freeman, working with Ashfaq Mirza and Ali Moh'd Chaudhry at the University of Agriculture Faisalabad (UAF), developed a concrete project proposal and also prepared the survey instruments and statistical measuring techniques. It is planned that Drs. Radosevich, Lowdermilk and Freeman will come to Pakistan on TDY assignments to advise Mr. Ashfaq Mirza (faculty member at UAL, who received two years training at CSU under the Water Management Research Project) on this study. In addition, Mr. Douglas Merrey, who joined the Field Party in April 1978 and will be stationed in Faisalabad, will work cooperatively with Professor Mirza.

7. <u>Water Management Research Program for Rural Development</u>

The University of Agriculture at Faisalabad was asked by the Punjab Agriculture Department, and later by the Sind, NWFP and Baluchistan Agriculture Departments, to provide training to their personnel who would work as Water Management Extension Officers (Agricultural Officers) in their On-Farm Water Management Development Projects. The University of Agriculture at Faisalabad agreed to provide the necessary training in the classroom and field aspects of water management utilizing existing information, facilities and the experience of its faculty. As the materials were assembled and the presentations developed for these classes, it became apparent that this course could be an important factor in bringing the faculty closer to the problems of the farmers. Since most of the problems do not presently have satisfactory solutions and the farmer is still largely an unpredictable factor in water management, this research program will allow the faculty an opportunity to identify problems and test alternative solutions. In developing the course content, Colorado State University suggested that this training be strongly field-oriented (25% classroom, 75% in the field). Thus it became apparent that a primary need for the trainees would be to identify farmers' problems in the fields, observe well-planned demonstrations of how to motivate farmers to adopt improved practices, followed by opportunities to work directly with the farmers and practice the demonstrated techniques.

The major objectives of this proposed research project include the following:

a. To provide research results which will prove useful to policy makers in the future implementation of the On-Farm Water Management Development Projects of the provinces.

b. To strengthen the University research and training curricula in water management and increase faculty involvement in the solution of farmers' problems.

c. To develop appropriate water management technologies through research and demonstration of farmers' fields, which are suitable to the harsh environment of the mid-doab, that will provide a long-term balance between the use of surface and ground water in order to alleviate waterlogging and salinity problems while increasing crop production.

d. To provide technology and guidelines to be used by Watercourse Engineers and Irrigation Engineers to facilitate their doing a better job of motivating farmers and implementing technological change.

e. To directly support the training course for the Water Management Extension Officers by providing planned educational field experiences in technical aspects of water management and essential interaction with farmers to motivate them to adopt new technologies.

f. To provide technology and guidelines to be used by the Water Management Extension Officers, including the development of an effective package of extension materials for watercourse improvement, improved agronomic and irrigation practices, farm management planning and organizing and motivating farmers to improve their water management practices.

8. Specific Studies Reported in Appendix

A short summary of each appendix report is presented below. Each summary is reported in the same sequence as the listing of appendix reports (e.g., summary e corresponds with Appendix 5).

a. Fertilizer Water Interaction Experiment On Wheat

Experiments involving fertilizer and irrigation variables on wheat have been conducted by the Cereal Section of the Punjab Agricultural Research Institute (PARI) for several years. Results have shown that maximum or near maximum yields can be obtained with three or at most four irrigations after emergence rather than the five to seven previously thought to be optimum, and that fertilizer responses generally were attained both under condition of moderate stress and where optimum water was applied. Results of these trials have resulted in a reduction of the number of irrigations and increasing rates of phosphorus in the recommendations made to farmers. Such trials need to be continued to provide a larger sample of years and environmental conditions for the testing and refinement of recommendations. One of the next logical steps is to determine both the effect of fertilizer on the plants' need for water and on its ability to extract water from the soil.

An experiment was conducted at PARI near Lyallpur (now Faisalabad) during the 1975-76 rabi season in which the effect of nitrogen, phosphorus and irrigation treatments on root development, yield components, and water use by the Sandal variety of wheat was investigated. Early season root and shoot development were both increased by phosphorus fertilizer. Mid season root development between the 1 and 3 foot depths was depressed by high levels of N and increased irrigation.

Yields of more than 35 maunds per acre or more were attained by some fertility treatments with only one irrigation after planting, applied on December 20, plus 2.34 inches of rainfall. Maximum yield was obtained using 5 irrigations but the advantage over 3 irrigations was generally small and would probably be nil except for the effect of increased lodging with 3 irrigations caused by adverse weather at the time the final irrigation was applied to the 3 irrigation treatment.

Yield responses to both N and P fertilization were obtained at all irrigation levels. Water use, particularly in the 1 to 3 foot depth region was increased by nitrogen fertilizer, an effect that appeared inconsistent with the rooting data. This was largely a late season phenomenon and was found at all irrigation levels. This increased use totaled about 1.5 inches for the season. The increased use of water by the fertilized treatments, however, does not support the contention that fertilizer should not be applied unless extra water is available, as yield responses were obtained from fertilizer even with only one irrigation.

Another important aspect was the fact that acceptable yields could be obtained with a total use of only 9-10 inches of water used between seeding and harvest, including stored soil moisture, rainfall, and irrigations applied well below the amount often considered necessary for wheat production. Well watered wheat used 13 to 16 inches depending on fertility treatment, an amount consistent with open pan evaporation of 16.8 inches during the growing season.

b. Influence Of Water Level And Soil Puddling On Yield Of Basmati Rice

Paddy rice, by virtue of its flooded management, uses considerable water. One of the assumed benefits of soil puddling is that it reduces the permeability of the plow zone and thus decreases deep percolation. Based on cited literature, it appears that by accepting yield reductions, water utilization could be reduced by not flooding rice paddies. This not only reduces head contributing to increased permeability but also reduces surface evaporation. This experiment was initiated to test the effects of various water and soil treatments on water consumption and to determine the effect of reduced water application on yield.

Under conditions of this experiment, decreasing the water to Basmati rice decreased the yields from a high of 3.01 Mt/ha for the continuous flooded treatment to a low of 2.27 MT/ha for the treatment which attempted to maintain the soil water contents near field capacity. While the treatment which maintained soil moisture near field capacity had the lowest yield, its production per unit of water was highest. Reduction of the total water by 39 percent and irrigation water by 60 percent reduced the yield by 25 percent. Thus it appears that when water is in short supply acceptable yields can still be achieved by holding the water in the paddies at moisture contents between saturation and field capacity.

c. Deep Water Rice Variety Trial

Due to annual flooding, early planting of kharif crops on the Ravi River bottom lands near Lahore is hazardous. The flood generally occurs in late June or early July and may damage or destroy all crops, including paddy rice, planted on these lower lands. Usually planting is delayed until after the flood recedes.

To determine the feasibility of utilizing the full season, 70 deep water rice varieties were imported from IRRI and planted in a non-replicated trial on June 22, 1977. The varieties were direct seeded, two seeds per hill, in four meter rows, and one row per variety. The plant and row spacings were 25 cm x 25 cm.

During the first week of July five continuous days of flooding occurred. Following recession the trial was maintained in a flooded state (approximately 5 cm depth) until the latter part of October. Twenty-seven varieties (including one local check) were harvested between November 8 to November 17, 1977. All varieties which had not matured by this latter date were considered unsatisfactory for this region. The local variety provided the lowest yield of the 27 harvested varieties, while the Lab Mue Nakng-111 variety from Thailand produced the highest yield.

d. Irrigation Evaluation Procedure for Flooded Rice Crops

Pakistan has abundant natural resources in the form of water, soil, people and favorable climate for food production, yet the agricultural yields are far below their potential when compared with world yield statistics. There are various causes and certainly poor water management practices are a major factor in this situation. The common concern in considering low yields in Pakistan is that a shortage of water exists, while field experience shows that under irrigation sometimes occurs and over irrigation frequently occurs. The objective of an irrigation evaluation is to determine the water use efficiency of the irrigation application. The concept of irrigation efficiency is not the ultimate measure of irrigation effectiveness (the crop yield is the ultimate measure), but it is a useful measure of how the water is being used and can be helpful in identifying specific problem areas where water losses may be reduced.

Rice is one of Pakistan's major cash crops. Farmers generally do not know how much water should be given to their rice fields. They just irrigate so that the fields are ponded with the full supply of water. In this way much water is wasted due to overirrigation. Accurate measurements are important to determine how much is water used in the rice fields, and how much could be saved and utilized for other crops.

This methodology paper is designed to delineate the unique considerations for lowland rice water requirements, to indicate the procedure for irrigated lowland rice water use efficiency evaluations, and to specify the equipment required to complete the evaluation. A blank data form is attached and the methodology for computation is presented.

e. A Computer Program For Punjab Evapotranspiration Estimates

Numerous investigators have generally accepted as fact that atmospheric demand for moisture as a function of short term meteorological factors is the primary determinant of the consumptive use of water by plants. The primary forces influencing this process are solar radiation and air movement as shown by Penman. Several methods of estimating evapotranspiration based on the combination energy and aerodynamic effects of climate include the Jensen-Haise and the Penman methods have been investigated.

This report provides detailed methodology for the calculation of potential evapotranspiration based on the Penman method using a digital computer program, which is found to be an appropriate method based on the data base available in the Punjab Province of Pakistan. Several innovations for facilitating the estimation of the potential day length, the radiation at the outer surface of the earth's atmosphere and slopes for curves in the Psychromatic chart have been included.

f. Traditional And Improved Irrigation Practices In Pakistan

Irrigation practices, qualitatively and quantitatively defined, describe the state-of-the-art (SOTA) of irrigation in a particular area. Systematic definition of the state-of-the-art provides knowledge for determining the status of irrigation practices in an area and forms the basis for identifying the needs of farmers for improvement. The concept of a state-of-the-art is applied in a qualitative and quantitative description of irrigation practices in Pakistan. The benefits and problems of two technologies, precision land leveling and farmer irrigation advisory services, are evaluated and discussed.

g. Potentials For Increasing Crop Yields Through Improved Water Management In The Barani Lands Of Pakistan

Crop responses to water, obtained in the irrigated areas of Pakistan, indicate potentials for increasing the barani (rain-fed) yields of wheat and maize from their present average yields of 6 to 8 maunds per acre up to 40 and 50 maunds per acre respectively by increasing the amount of water available during the growing season up to 35 cm under adequate fertilization. In areas where ground water and canal supplies are not available, the only source of additional water is retaining water which presently runs off, or utilizing runoff from some areas to supplement incident rainfall on others.

In areas where runoff exceeds 15%, the benefits derivable from benching the land to retain all the incident rainfall exceed the cost of construction where the slope of the soil ranges from less than 1% to 4% and when rainfall available during the growing season is in the range from 30 to 40 cm. When the rainfall and runoff are in this range and the original slope of the land is less than 2%, it appears that the returns during the first cropping season can exceed the total investment.

When rainfall available during the crop season is less than 25 cm, satisfactory yields are not attainable for maize and wheat, even when all the incident rainfall is made available for crop use. If a substantial percentage of the rainfall on these areas can be induced to runoff from "watershed areas" supplementing incident rainfall on cropped areas, substantial crop yields on the cultivated area appear to be possible in much of the barani tract which is presently considered to have no significant productive potential. Whether these runoff-runon systems are feasible depends on the percentage of the rainfall that can be induced, by reasonably priced treatments, to runoff from the watershed areas. If as much as 25% can be induced to runoff, many areas can productively use this type of water management system. If runoff can be increased to 50%, this type of farming holds the potential of bringing most of Pakistan's dry barani lands into production.

h. Watercourse Conveyance Losses In The Mona Reclamation Experimental Project Area

Any hydrologic system naturally seeks a steady state condition where inflow to the system is equal to outflow. The equilibrium of the Indus Basin system was perturbed with the advent of major irrigation works in the late 19th and the 20th centuries. Water which previously flowed directly to the sea through river channels was being spread across the plain with the intent of serving the evapotranspiration needs of the newly planted crops. But, as with all irrigation systems, only a portion of the diverted water is actually used by the plants. A large proportion of the remainder eventually seeps downward from canals, watercourses and fields, until it reaches the groundwater.

In earlier reports, where watercourse conveyance losses were assumed to be 10%, only 4.5 million acre feet (MAF) of water was projected to be entering the groundwater from this source in 1975. The MREP-CSU data on watercourse losses indicate that 40 to 50% of the watercourse inflow is lost in SCARP areas. Assuming the same watercourse inflow and evaporation losses as stated in earlier reports, that losses from SCARP watercourses are 45% and from non-Scarp watercourses, 35%, and that 25% of the diverted water flows in SCARP watercourses, the total inflow to the groundwater from the conveyance system is 30 MAF, an increase of 25.5 MAF over the projected value. This implies that the net inflow to the groundwater is much greater than previously assumed, and either groundwater storage is continuing to increase, or other factors in the water balance are incorrect. Twenty-five million acre feet of water could raise the water table about three feet under irrigated areas if there is no additional outflow. If the types of watercourse improvements presently being initiated in the provinces are carried on throughout the Indus Basin, this inflow could be reduced by 50%, or about 15 MAF per year, reducing the pumping requirement and the amount of water completely lost to saline groundwater areas.

i. Review of Watercourse Loss Measurement In Pakistan

Kennedy, Benton and Blench estimated that 28% of the water supplied to watercourses was lost before it reached the farmers' fields. The Lower Indus Project used a ponding method to measure water losses in selected straight sections of 11 watercourses in the Sind in 1963-64. The Irrigation Research Institute (Punjab) used the same criteria to select 12 uniform, straight sections 500 feet long on 12 watercourses and used the same method of measurement. The average losses reported by these two groups were 1.8 and 1.5%/1000 feet respectively. These losses have been coupled with an average length of watercourse from mogha to field of 5000 feet to conclude that watercourses lose no more than 10% of the water passing through them.

Measurements taken by WAPDA, CSU and Agricultural Department personnel using the inflow-outflow method on 606 sections of 51 watercourses indicated loss rates varying from 4 to 72% per thousand feet of watercourse. These data, taken under operational conditions indicate that almost half of the water supplied to the watercourses was lost before it reached the farmers fields.

The reasons for the inflow-outflow method used by WAPDA-CSU yielding higher losses than the ponding method used by the LIP and IRI are: (1) The sections chosen by LIP and IRI avoided (or sealed) the junction and nakka areas which have been found responsible for about half of the loss; (2) The water levels at which loss rates were measured in the IRI studies were lower than operational levels for most of the time over which the averages were taken, and it has been found that loss rates are reduced by about 50% when the water surface is lowered 0.2 feet in the average watercourse;

(3) During the measurements taken by the WAPDA-CSU teams, losses were determined as they exist in the watercourse system. Losses through rodent holes, broken bunds, overtopping, etc., were allowed to continue unless the farmers stopped them. The LIP-IRI studies were conducted to determine seepage and evaporation losses (unavoidable losses) only, and they cannot be used as an estimate of operational losses.

The difference between the average operational losses as measured by WAPDA-CSU and the unavoidable losses as measured by LIP-IRI is about 40% of the present supply to the watercourses of Pakistan. It is a good measure of the potential improvement of water supply to farmers' fields that could be achieved by careful, well-designed earthen improvement of watercourses.

j. Operational Conveyance Losses On Tubewell 81-R Watercourse

Colorado State University Water Management Research Project and Mona Reclamation Experimental Project are working to determine means to improve on-farm water management in Pakistan's irrigated regions. An important component of this system is the network of small watercourses which convey the water from the government distributary outlet, the "mogha", to the field being irrigated. Although the primary portion of this conveyance system is authorized by the government, all practical upkeep and maintenance of the entire system is left to the farmer. Potential improvement in such a system is first assessed from a knowledge of the existing workings and inefficiencies of the system.

In the past four years, many measurements of the water losses from these village watercourses have been made by CSU engineers and their Pakistani cooperators. These measurements have indicated that from 30 to 50 percent of the water presented to the farmers at the mogha is lost from this conveyance system on most watercourses. However, all of these measurements have essentially been taken while the system was in steady state, or flowing at a constant rate. This type of measurement fails to measure the additional operational losses present in the watercourse systems. Operational losses include water initially infiltrated into the dry channel banks, water losses from the watercourses during the movement of water from one field to another, dead storage water left in the bottom of channels after their use, and losses resulting from short term breaks or leaks in the watercourses, both intentional and accidental.

This study was conducted to determine the total water losses, including operational losses from a village watercourse system during one complete week. This time period was chosen because in the studied watercourse, and in most watercourses in Pakistan, the water is allotted to the farmers on a turn basis ("warabundi") over a one week rotational period. In order to better understand the present system and to determine potential design improvements, an attempt was made not only to measure total losses but also to determine their causes and distribute them to the various categories.

A flow chart depicting where the water went that flowed into the Tubewell81-R watercourse during the week of December 8, 1976 was developed. The data is not necessarily representative of all Pakistan watercourses, but does give an indication of where some of Pakistan's most limiting agricultural resource is going. It is interesting to point out that the portion going to normal wetted perimeter infiltration, 9%, represents what may be the minimum achievable losses without channel lining. The excess bank and bed seepage is a result of the high permeability of the porous banks and the high effective wetted perimeter resulting from the network of rodent and insect holes. As a result of this warabundi study, the following conclusions were reached, which pertain only to the particular watercourse studied (in the near future, the results of similar warabundi studies on many more watercourses will be reported which allow more general conclusions to be reported).

(1) Conveyance efficiency was measured to be 44%.
(2) The increased losses caused by flume installation could account for an increase in real efficiency to as much as 54%.
(3) Two-thirds of the losses occur in the sarkari khal.
(4) Losses were higher by 5% at night.
(5) Thirteen percent of the losses are due to operational conditions.
(6) Farmers who fill sections of the sarkari khal lose 45 minutes' worth of water per 1000 feet filled and are compensated for only 15 minutes in the warabundi.
(7) 2700 cubic feet of water was lost per 1000 ft of watercourse filled.
(8) Dead storage accounts for nearly half of the operational losses, but amounts to only 5% of the total losses. Thirty percent of the dead storage lies in the sarkari khal.
(9) Total visible leakage is a small percentage of total inflow, but its prevention presents an economical means of saving water for the farmers.
(10) If losses could be reduced to seepage through the wetted perimeter at the normal soil intake rate, a conveyance efficiency of 90% could be achieved.
(11) Farmers perceive that they need 50% more water.

(12) Conveyance losses cause a very unequal distribution of the water resource across a watercourse.

(13) Farmers with less water achieve higher crop outputs per unit of water input.

k. Water Conveyance Losses On Tubewell 81-R Watercourse After Improvement

Watercourse TW 81-R (mogha 31574/R) of the SCARP II area was selected for a complete warabundi loss study. Throughout an irrigation turn of one week (168 hours) the water was followed from field to field and flow rate measurements made simultaneously at the mogha (distributary outlet), in the authorized channels, and at the farmer's field. By integration of the resulting flow rate-time curves and analysis of other collected data, it was concluded that the overall watercourse conveyance efficiency was 44 percent; 13 percent of the loss was operational. Two-thirds of the resulting loss occurred in the sarkari khal (government authorized channels).

Following the warabundi study, watercourse TW 81-R was renovated. This included a complete rebuilding of banks, junctions, cross sections, etc. according to new design criteria. In addition, concrete pipe culverts and brick and concrete check and turnout structures were installed. The complete sarkari khal was improved plus one farmers' branch.

Based on integrated flow volumes into the watercourse and out to the field, the mean watercourse delivery efficiency was 56.7 percent or 1.40 cusecs. This is a 12.3 percentage point increase in delivery efficiency due to improvement. By measurement, improvement increased delivery to the watercourse field flumes by 4.32 ac-ft. (4.08 ac-ft. to fields) during the complete warabundi. This extra water allowed irrigation of 13.5 additional acres. Seventy-three percent of the loss occurred in the sarkari khal; the average loss rate was 0.20 cusecs/1000 ft. Twenty-seven percent was lost from farmers' field channels where the loss rate was 0.35 cusecs/1000 ft. Significant differences between night and day losses were not detected.

l. Operational Conveyance Losses On Two Punjab Watercourse Systems

In an effort to increase, or even maintain, the nutritional standards of an ever growing population, Pakistan agriculture must increase its production. In order to increase production, present constraints to production must be alleviated. One of the most limiting physical constraints in the semi-arid

Indus Basin is the water resource. Land availability, labor availability, and climate is such that, with an increased water supply, more crops could be grown.

The water supply at the farmers' fields can be increased by either increasing the supply of water entering the irrigation system, or by increasing the efficiency of that system in getting the water to the crop. In a country such as Pakistan, where the need for food and increased agricultural output is growing so rapidly, both methods must be exploited.

Recognizing the general lack of knowledge about the workings and efficiency of the Indus Basin irrigation system after it enters the cultivator's domain below the "mogha" (distributary outlet), studies have recently been carried out to better understand and evaluate the on-farm irrigation system.

Colorado State University Water Management Research Project personnel and their Pakistani cooperators are working to determine means to improve on-farm water management in Pakistan. An important component of this system is the network of small watercourses which convey the water from the mogha to the field being irrigated. Though the primary portion (the "sarkari khal") of this conveyance system is authorized by the government, all practical upkeep and maintenance of the entire system is left to the farmer.

A decision that will have to be made in any watercourse conveyance loss reduction program is, how much of the system should be improved. Costs are based on feet of channel improved, but benefits are based upon the hours of usage of the channels. As improvement is taken farther from the head, the useage decreases and the footage increases. There are more than 6 times more farmers's branches on both studied watercourses than sarkari khal. However, 80% of the usage is in the sarkari khal. This means that if loss rates were the same in both sections, the payoffs in the sarkari khal would be 30 times greater. On the other hand, operational loss rates are higher in the farmers' branches by 2 times on TW 81-R and 5 times on Tikriwala #1 watercourse, and this loss rate will increase after sarkari khal improvements when inflows to the branches will increase. Although the payoff will still be larger within the sarkari khal, total delivery efficiency achievable will be reduced from nearly 85% to perhaps 75%, and a 50% loss reduction in the sarkari khal might lead to only a 25% overall conveyance loss reduction.

Although as thorough an improvement program probably need not be undertaken in the farmers' branches as is proposed in the sarkari khal, some improvement, such as enlarging the flow cross section and strengthening the banks, must be made if the benefits of watercourse improvements are to be fully realized.

The data is not necessarily representative of all Punjab watercourses, but the varying conditions found on the two watercourses do indicate that concurrence between them should be generalizable. Further operational loss studies which are planned, will support or contradict these initial findings. The following conclusions were reached.

(1) These studies concur with past measurements that indicate that watercourse steady state conveyance losses in the Punjab are in the range 30 to 50%.
(2) Transient losses are about 8% of the inflow, and steady state loss measurements should be increased by about 8 percentage points to reflect operational conditions.
(3) Loss rates in the farmers' branches are much higher than in the sarkari khal.
(4) Flow measurement flumes may cause 3 to 6% of additional induced losses.
(5) About half of the transient losses are dead storage.
(6) If losses could be reduced to normal channel wetted perimeter infiltration rates, conveyance losses could be reduced to about 15%.

m. Simplified Design of Earthen Watercourse Improvements

In order to facilitate the rapid training of Watercourse Development Officers (WDO) an attempt has been made to simplify the design of watercourse improvements to the most basic elements. A discussion of the iterative procedure utilizing Mannings equation and the design charts is presented followed by a detailed outline of the field information required before the design is undertaken. A detailed design procedure is outlined and accompanied by the necessary charts for design using a roughness coefficient n=0.04 and slide slopes of 1:1 and 1.5:1.0 (horizontal to vertical) of an assumed trapezoidal channel cross section. These two combinations of roughness and side slope will potentially cover the major possibilities for watercourses that require renovation in Pakistan. These combinations assume earthen improvements and the current level of watercourse maintenance and the current state of nakka design and construction technology.

n. Low Cost Siphons From Used Tires

Irrigation water losses are aggravated by two problems. The first is water leakage at the check or control structures in the watercourses, and the second is leakage at the field outlets. Siphons have frequently been discussed as a solution to these problems; however, a six-inch siphon in Denver, Colorado currently costs $30. This same device delivered to Lahore would probably cost between $60 and $90, and represent hard currency exchange. On the local job market, this equals 60 to 90 days labor to earn one siphon.

The concept of a siphon is sound; it permits the transfer of water without disturbing the banks over which the water is being conveyed. Siphons also allow the water to be taken over the bank at a number of places simultaneously or in turn. When the siphon is removed there is no leakage, and there is no piece of equipment remaining in the field unguarded.

With these thoughts in mind, an attempt was made to construct a siphon of approximately six inch diameter out of material with minimum value, that would be portable and sturdy. It was reasoned that, if a worn out automobile tire could be cut in half, and the space between the beads sealed in some way, this would make an effective siphon. The cost of worn out tires depends on their value for other uses in the country considered. In Pakistan, prices from 10 to 25 rupees per tire have been quoted. When the tread from the opposite side of the tire is used to complete the cross sectional perimeter of the tire, the additional materials requiredare: 12 screws (about Rs. 2), about 2 ounces of rubber or silicone cement (Rs. 3), 2" of copper tubing and 3 feet of plastic tubing (3/8" ID) (about Rs. 5) for a total material cost of about Rs. 30, if the used tire is bought for Rs. 20. Tire shop mechanics with a hack saw, a sharp knife and a hand drill should be able to build at least one of these per hour for a labor and facilities cost of less than Rs. 10/siphon. It appears feasible to construct these siphons at a total cost of about Rs. 40/siphon in Pakistan.

Considering that concrete outlets costs from 100 to 300 rupees and that these large siphons can be moved and used at many locations, the siphons appear to offer a new low cost means of controlling water and transferring it from the watercourse to the field (or branch channel). It also appears feasible to make reasonably good calibrations of head loss vs flow rate for these siphons, so that they could be used, along with a device to measure head loss, to estimate flow rates and amounts of water appled to fields.

o. Feasibility And Design Of A Low-Head Jet Pump For Irrigation In Pakistan

Pakistan has many fields suitable for agriculture at a higher elevation than the water in the watercourse. The present method of raising the water is an ancient water wheel powered by water buffalo or camel. Tubewells in Pakistan discharge water at a relatively constant rate and a low hydraulic head of 3-6 feet. This paper investigates utilizing the tubewell discharge to power a low-head jet pump.

A 1:1 model was constructed at the Hydromachinery Lab, Colorado State University. Several different parameters which affect jet pump efficiency were investigated including location of driving nozzle, length of mixing chamber, flow ratios, and head capacity curve. The maximum efficiency achieved was 42%. The head capacity curve seemed to be linear, and the efficiencies only changed 4% when the flow rate changed + 30% indicating a flat efficiency curve. The length of the mixing chamber was an important influence on efficiency, the most efficient configuration being a length of 56" plus a diffuser.

Cost estimates indicate the jet pump could be manufactured in Pakistan from concrete and steel at a cost of $158.00, much more economical than the cost of a Persian lift which costs about $1153. The low-head jet pump is a feasible solution for lifting water in irrigation canals in Pakistan.

p. Essential Improvement By Farmers Of The Watercourse Serving Tubewell #MN 60

Experiences on several Pakistani watercourses had indicated that illiteracy was not a major barrier to the farmers accepting the challenge to improve their watercourses. Increased water supply to their fields and concrete control structures were the results of farmers efforts at watercourses serving Tubewells No. 56, 57, 51, 81R and 81L. This series of watercourses has been improved as consecutive research studies to help develop a watercourse improvement program that is beneficial and acceptable to the farmers. This watercourse improvement program has become a major component of the "On Farm Water Management Development Project", a development program currently underway in the Punjab, Sind and North West Frontier Provinces. That program includes provision of concrete control structures to the farmers. Current reports indicate that the rate at which these structures can be installed is limiting the rate at which the program is being implemented. Consequently, the question has arisen as to whether the increased water supply was sufficient incentive to motivate the farmers to improve their watercourses, or whether the concrete structures were essential incentives. Consequently, the following effort was made to motivate the farmers served by Tubewell No. 60 to improve their watercourse, with the only initial incentive being assurances by the government personnel that the water deliveries to their fields would substantially increase.

If farmers can be convinced that the government officer has come to them to help them solve their problems and that he has successful experience, they will engage in watercourse improvement projects with no incentives other than the probability of an increased water supply. They will invest their time and energy in such a project when their group decides to go ahead with it--even though their individual caloric intakes may be low.

Farmers perceived that the water supply to their field following this essential improvement program averaged about 160% of the water supply prior to improvement. This was a larger increase than has been measured on other watercourses where more intensive improvements have been made. The perception of more increase than has actually occurred is common to other improvement projects where the perceiver has been personally involved as the change agent.

The general tendency of man to overrate his own accomplishments must be considered in developing methods for evaluation of projects. The tendency also emphasizes the importance of letting farmers take leadership in the project as far as possible. The tendency can also be used to good advantage in advertising the program, by bringing farmers from other watercourses to hear these farmers tell the enthusiastic story of their improvement program.

The cost of concrete control structures appears to be a reasonably good capital investment (benefits/cost about 1.5), whereas the investment of farmers' labor to improve the watercourse is an excellent investment (benefits/cost ratio greater than 4). Moreover, labor is an available resource to most of these farmers, whereas capital is practically nonexistent with a substantial portion of them.

Some of the larger farmers have the capital to invest in structures, but a general program which required farmers to pay for their own structures would be a hardship on the poorer farmers. A program of this type would tend to exclude watercourses serving large numbers of poor farmers. Consequently, it is recommended that government programs for essential watercourse improvement either have no provisions for control structures or, if such structures are included, that they be provided to all farmers at government expense.

Methods of involving masons as private specialists in control structure installation should be investigated in terms of how structure installation can be facilitated so that it does not slow down the improvement program.

The low cost to the government of this "essential improvement" of the watercourse at Tubewell 60, benefits perceived by the farmers, their enthusiastic participation and the rapidity with which the improvement was accomplished all argue for further consideration of this type of an improvement program to assist the country to quickly bring about the first major improvement of water supply to the farmers fields.

q. Watercourse Cleaning And Maintenance Program: Its Organization And Influence On Conveyance Loss

Studies conducted in Pakistan during the past four years show that the water conveyance efficiency on most watercourses is approximately 50 percent. Several techniques for reducing conveyance loss have been tested. The most successful were both lining and earthen improvement of watercourse channels. The use of the former has generally been discouraged because of its high cost. The latter proved most successful both because of its loss reducing capacity and because of farmer participation and its subsequent low cost. However, since this earthen improvement alternative involves complete reconstruction according to new design criteria, engineering assistance is required. There is not now nor will there be in the near future sufficient engineer assistance to improve Pakistan's 80,000 watercourses.

Yet, a third alternative for reduction of water conveyance losses exists! Cleaning and maintenance of watercourses! Pakistani farmers have cleaned watercourses for decades; they are aware that excessive vegetation and sediments retards flow, increases the water level, causes overtopping, etc. However, their cleaning practices appeared irregular in timing, poorly organized, and with little maintenance. Actual data on water loss reduction due to cleaning and maintenance are rare. Yet intuitively, coupled with some observation, it was anticipated that timely cleaning and maintenance could significantly reduce water loss with negligible cost and, with no requirements for professional engineering input. For cleaning and maintenance to be truly effective it must be done frequently and on time. This requires a degree of cooperation and organization rarely found on Pakistani watercourses. Formal organization of water users are practically unknown.

There are perhaps two primary unknowns in this program: 1) how effective is cleaning and maintenance in reducing loss, and 2) what are the most effective techniques for organizing a viable cleaning and maintenance program on the watercourses. It is to both these points this report is addressed.

Twenty watercourses were selected from the Mona Project Area for this study. Fifteen unimproved watercourses were randomly selected; an additional five earthen improved watercourses were assigned to the study. These improved watercourses were not randomly selected since five were the total which had, as of that date, been improved in the Project area. All twenty watercourses had tubewells; only one did not have, in addition, a supply of canal water.

Based on a limited selection of extension techniques:

(1) a successful approach to organizing farmers on a watercourse is to identify the watercourse leader in a general group meeting and then try to organize through these identified individuals.

(2) Group social pressure proves very effective in convincing reluctant farmers to participate in cooperative programs.

(3) Extension hand-out materials and field demonstrations did not appear effective as extension tools.

(4) Various social problems and rivalries on a watercourse may prevent cooperation among the various farmers on a watercourse.

(5) Certain physical constraints, such as excessively high silt banks and sandy soils, may disallow the participation of certain watercourses, in the present cleaning and maintenance program.

(6) The previous watercourse improvement program hinders the establishment of a cleaning and maintenance program on unimproved watercourses in the Mona project area.

(7) The water loss rate decreased on the average 8.53%/1000 ft and 1.75%/1000 ft respectively for unimproved and improved watercourses.

(8) Farmers perceived a 50 percent increase in water delivery due to cleaning and maintenance.

(9) On the average farmers cleaned and maintained 6 ft/hr of channel at an approximate cost of Rs 0.17/ft.

r. <u>Improving Watercourse Conveyance Efficiency Through Cleaning And Maintenance</u>

Recent studies conducted at Mona and elsewhere in Pakistan indicate that about half of the water entering the watercourses is lost during conveyance to the fields. To reduce losses a number of watercourse improvement techniques were developed and tested. Of the techniques tested earthen improvement, with provision of pacca control structures, is the most economically feasible for adoption on a large scale. However, earthen improvements require engineering assistance and capital cost for purchase of construction material for water control structures. As present neither engineering staff nor money resources are available for the improvement of Pakistan's 80,000 watercourses; even with adequate resources it will require a long time period. As an alternative to improve watercourse conveyance efficiency, cleaning and maintenance techniques which do not require engineering skill nor capital cost in any form, were developed and tested at the Mona Project. They include the removal of sediment and vegetation from watercourse channels, strengthening and compaction of banks, provision of freeboard, straightening of the sections as far as possible, and reshaping of the cross sections to safely convey the authorized discharge.

The farmers of nine watercourses were motivated to utilize this program to reduce conveyance losses. Under the supervision of the extension staff, eight watercourses were cleaned and maintained by the farmers and work is in progress on the 9th watercourse. Intensive extension efforts were invested for motivating and organizing the water users for this program. Except for the water users own labor no other expenditure was involved. Labor time utilized on watercourse cleaning and maintenance was about 50% of that spent on earthen improvement; an average of 6 feet of channel were cleaned and maintained in one hour. Cleaning and maintenance reduced losses from 10.4% per 1000 ft to 3.3% per 1000 ft. This program can be implemented wherever earthen improvement is feasible without engineering assistance or financial implications and using only the water users' labor. It must be emphasized that cleaning and maintenance is equally essential on earthen improved watercourses to maintain conveyance efficiencies at improved levels. To provide physical evidence in support of requirements for cleaning and maintenance of earthen improved watercourses, five watercourses improved before the start of this study were included in this program. The conveyance loss data before and after cleaning and maintenance of these improved watercourses testifies to the necessity and benefits of the program.

s. Effects Of Cleaning A Watercourse On Rates Of Water Loss

A major portion of the farmer's water is being lost from his watercourses before it reaches his fields. The rate of loss is highly dependent on the elevation of the water surface in the watercourse. On the average, the rate of water loss is approximately doubled for each five centimeter increase in the level of the watercourse. This observation, coupled with observations by Mohammad Afzal and Mohammad Akram, of the Mona Reclamation Experimental Project, and Thomas Trout of the CSU Field Party that the water level in watercourses commonly dropped from 7 to 10 centimeters when farmers cleaned their watercourse led to the tentative conclusion that the primary mechanism by which cleaning and maintenance reduced watercourse losses was by lowering the operational level. However, a complete set of data had not been available showing the water levels before and after cleaning, the shape of the watercourse before and after cleaning, and the rates of loss before and after cleaning. The purpose of this study is to provide such a set of data.

Past relationships with farmers indicate that he responds logically to facts which give him a better understanding of his potential resources. Consequently, we recommend that the data reported herein and the information being gained from the watercourse cleaning study at the Mona Reclamation Experimental Project be developed in simplified visual form with first an English text and then an Urdu text which can be discussed by extension field assistants with farmers. Perhaps a version of this could be introduced to the farmers through the school system and their children who are in school. To gain the interest of the audience, these materials should be made entertaining as well as informative and motivational.

The visual aids to help the farmer understand the benefits of cleaning and maintenance should be accompanied by some means to help him recognize when his water level has risen above the designed operational level. Painted aluminum plates for this purpose were installed in the Mona Reclamation Experimental Project cleaning and maintenance study. These plates showed the approximate designed operational level and successively higher levels with Urdu script stating the fact that much more loss was occurring when the water reached these levels. These plates appeared to be relatively effective, but unfortunately they were sufficiently attractive so as to be stolen frequently, and their installation in a manner such as to prevent their loss was expensive so that making and installing these plates approached 150 rupees. A simpler marker is proposed using a simple reinforced concrete post about 60 cm long and 10 cm in diameter. At the top of this post is a 5 cm long neck about 6 cm in diameter and extending above this another 5 cm is the bare 13 mm diameter reinforcing bar. It should be possible to build these for about 10 rupees and they are sufficiently small that they can be carried and installed by one man. They would have little value for another purpose and consequently should be fairly immune from theft.

Extension personnel should be taught why and how to use the simple pictorial booklets and the markers (which would be installed toward the head of the watercourse and/or the head of the branch watercourses in cases where the branches needed special attention). The effectiveness with which the extension personnel are able to motivate the farmers to properly clean and maintain their watercourses should then be evaluated, feedback should be obtained from them, and the methods for most effectively utilizing this information to help the farmers should be developed.

Another factor which this and other data illustrate is that when water levels in the watercourse are kept near the level of the adjacent fields, or below that level, the loss from the watercourses are substantially reduced. One way in which to make practical use of this fact is to lower the designed operational level of the watercourse by digging the watercourse deeper into the ground and then constructing water control structures which can raise the level of the water to the level essential to cover the adjacent land surface at the point where the water is needed. Of course there will be a raise in the water level upstream from that point, but generally this necessary raising of the water will extend over only a fraction of the total length of the watercourse to the mogha. Consequently, there will be considerable savings of water. This type of a lowered watercourse was designed and installed at Tubewell 81L watercourse in the Mona Reclamation Experimental Project. It did reduce the seepage damage along the upper reaches of the watercourse and increased the delivery efficiency to the lower reaches. Some of the farmers in the head reaches of the watercourse complained of having to fill the deeper watercourse. Had they been forced to control the water with earthen bunds built that much higher, it is unlikely they would have accepted this design. However, new check structures made of concrete which allowed them to check the water to the necessary level without expensive shovel work were developed and installed for them and the farmers appear to be accepting this new design.

t. Potential For Building And Utilizing Fresh Water Reservoirs In Saline Aquifers

The SCARP tubewell program was designed to lower the water table, provide additional water for irrigation, stop salinization and reclaim salinized land. This program has accomplished at least part of these objectives in many areas. The excellent aquifer has proven to be the best storage site available in the Indus Basin except where the saline water has been pushed up near the surface by hydrologic factors.

Recharge to the aquifer from the rivers has pushed salt water to the centers of the doabs and the layers of fresh water in the centers of these doabs are often so thin that pumping for irrigation use is not feasible. This is an aggravating problem because lack of pumping in these areas leaves the water table high, so when monsoon rains come, there is little room in the aquifer for this good fresh rain water. It accumulates on the surface, causing flood conditions and runs off slowly through the available drains. The net effect is loss of this good water to the sea, retention of saline water in the aquifer and a negligible increase in thickness of the layer of fresh water.

Recent studies of effects of pumping wells on saline-fresh water interfaces indicate the possibility of creating and maintaining 'fresh water reservoirs" in the saline aquifers of the mid-doab areas of Pakistan. The fresh water to fill these fresh water reservoirs would come from localized zones of overirrigation, seepage from watercourses and monsoon rains, which will probably average only about one acre-foot per acre per year at the well. The water in these reservoirs could be pumped to provide water during critical need periods. Consequently, although its volume would be low, the value of the water would be high.

Preliminary estimates of costs indicate that this type of storage would cost less than 10% of the cost of surface storage reservoirs. Preliminary estimates of potential benefits indicate a benefits-to-cost ratio of greater than 2. The deep well-skimming well combination, required to extract the saline and fresh water for reservoir building and irrigation respectively, could provide the needed assistance to farmers who are most severely afflicted by salinization and waterlogging, and are not being assisted by SCARP programs. Considerable additional information regarding the mixing of fresh and saline water during rise and fall of the interface, effects of recharge and pumping timing on the extension of the fresh water reservoir, etc. is needed before an optimized development program can be initiated.

u. Utilizing Irrigation Seepage For Groundwater Storage

In order to maximize agricultural production from the scarce water resources in the Indus Basin, it is necessary to redistribute the naturally occurring surface flows from periods of high flow to periods of peak crop requirements. Large scale surface storage can help in this regard, but appropriate sites in Pakistan are limited and their development is extremely expensive. The effectiveness of this approach is also limited by the capacity of the conveyance system to distribute the increased supplies when needed. Therefore, the fresh water aquifer underlying extensive areas in the basin is being exploited by groundwater pumpage to augment supplies during peak demand. This aquifer is recharged by a combination of percolation from rainfall, rivers, canals, watercourses, and fields under irrigation.

Recent efforts to improve the efficiency of the irrigation system at the farm level through watercourse improvement programs have prompted concern that the recharge of this aquifer would thereby be diminished, thus interfering with pumping programs and their potential for redistribution of fresh water supplies over time. This brief analysis addresses the question of the probable effect of watercourse improvement programs on groundwater recharge. Simplifying assumptions are harsh, as they must be for any analysis short of the construction of a detailed hydrologic model. However, we believe the assumptions overall are conservative in their estimation of recharge rates and the analysis is mathematically accurate within the assumptions. The results of this brief analysis indicate:

(1) Large scale programs of earthen reconstruction of watercourses are unlikely to reduce recharge of the fresh water aquifer to the point that it interferes with the use of this aquifer as a storage reservoir during periods of high demand; and

(2) Reducing conveyance losses is particularly important when a single tubewell source serves a complete watercourse.

v. The Economics Of Precision Land Leveling In Pakistan

This study identifies the economic and physical benefits attributable to precision land leveling. While the work is specific to Pakistan, the implications are relevant for other arid areas of the world where irrigation is practiced.

Two sets of fields were selected, one set that had been precision leveled and another set that had been leveled using traditional techniques. These fields were resurveyed and then the farmers were interviewed every month during the winter crop season. Cutting samples were taken on all the fields during harvest. The average yield of the precision leveled fields was 24.60 maunds per acre and the yield for traditional leveled was 18.18 maunds per acre. This difference is significant at the .001 level. In addition, the mean time to irrigate an acre field was 1.13 hours for precision leveled and 2.12 hours for traditional leveled. Again this is significantly different at the .001 level. The change in yield attributable solely to precision land leveling was calculated by regression analysis at 2.7 maunds per 0.1 foot change in max-min range. The remaining difference in yields was attributable to increased use of nitrogen and phosphorus fertilizers on the precision leveled fields over the traditional leveled fields.

The economic analysis of precision land leveling, assuming a life of ten years, is positive but not above the two or three to one return that is usually required to persuade subsistent farmers to invest in a new technology. However, the precision land leveling clearly acts as a catalyst and increases the efficiency of the other associated inputs and hence is a more valuable investment than is indicated by simple economic analysis.

w. Cropping Intensity And Water Shortages: The Response Of the Punjabi Farmer

Pakistan's canal system was originally designed to support a cropping intensity of 75%. However, on most canal systems today the average cropping intensity is around 100% and often as high as 125% in some areas. The object of this study was to analyze the water management techniques used by the Punjabi farmer to obtain these higher cropping intensities. A linear programming (LP) model is developed for a typical 500 acre watercourse on a perennial canal in the Sargodha area. The available water is varied to determine the farmers' optimum response to different levels of available water. The second part of this study applies sensitivity analysis to determine the value of additional water during the rabi (winter) and kharif (summer) seasons.

Crop yields in Pakistan are very low compared to other areas of the world with similar agro-climatic conditions. The results of this model explain these low yields as a rational economic response of the farmers to an insufficient water supply. The farmers obtain more return for the first increment of water than he obtains for additional increments and hence it is to his advantage to increase cropping intensity first and then to increase his yields. In order to increase the per acre yields in Pakistan, it is necessary to provide additional water during the critical times. This water can come from increased canal supplies, from increased pumpage of private or public tubewells (in sweet water areas) and/or from increased system efficiency. An increase in either the delivery efficiency and/or the application efficiency will provide additional water at the root zone. Since the canal water supplies in most areas are over allocated and the groundwater is often of hazardous quality, the only viable source of additional water supply for many areas is an improvement in overall watercourse system efficiency. An alternative method to improve crop yields is to develop crop varieties and crop production techniques that spread out the demand for water. For example, if part of the wheat crop could be planted and irrigated in January when water demand is small, this would relieve some of the pressure that now exists in October-November.

x. Water Management As Affected By Size Of Holding And Cropping Systems

As widespread attention is focused on the problems of matching food production to an expanding world population, the problems of on-farm water management have become increasingly apparent. Many developing nations depend on irrigated agriculture for a major portion of their food supplies, and while ineffecient use of water is found in both developed and lesser developed countries, the problem assumes particular urgency where populations threaten to outstrip food supplies. The relationships of these problems to size of holding and cropping systems is not necessarily obvious, and in fact may differ markedly in different areas of the world. The bulk of the authors' experience in the systematic study of on-farm water management problems has been in Pakistan, and this paper deals largely with our perception of these problems on the Indus plain. While aspects of the problem may be different in other areas, it seems likely that many components may be common to the irrigated areas of the developing world.

Size of operational units and field size significantly affect the amount of watercourse channels required to deliver water to the field. In Pakistan total delivery channels generally exceed 200 ft/acre (150 meters/hectare). Due to the flat topography and poor condition this extensive distribution system typically operates at between 50 and 60% efficiency. If field size could be increased to 2.8 acres (1.3 hectares) at least half of this system could be eliminated. Improved water management will require better watercourse maintenance and more effective organization to achieve this at the village or watercourse level. Research and extension programs designed to determine the most effective organization and to promote awareness of the need for better organization and maintenance should be a high priority item. Even though cropping systems have evolved and adapted over a long time, we still find that cropping intensities and production are limited by water availability at critical periods. Water saved through good management is extremely valuable at these times.

y. Proposed Applied Research For The On-Farm Water Management Project In Punjab Province

In the establishment of the On-Farm Water Management Development Project for Punjab Province, provision was made for research and training in areas related to water management. Such research and training will be conducted at two training centers: one to be established with the University of Agriculture, Lyallpur (now Faisalabad) and the other at the training demonstration farm near Lahore.

The Training and Research Center, Niaz Beg, near Lahore will be established on a farm of 50-70 acres. This farm will have, in addition to training personnel and trainees, an established labor force and equipment to satisfy the needs of both applied research and training. The ultimate purpose of the applied research component is to develop and introduce on a large scale the most appropriate water management techniques for the province. Included would be problem identification, development, and implementation stages of research.

While previous research efforts primarily concerned watercourse improvement, the forthcoming program will in addition include agronomic, soils, irrigation, and land leveling and other subjects relating to water management. Applied research can also serve as a good demonstration, and in this respect all research will be organized to gain maximum demonstration benefit.

z. First Training Course For Water Management Extension Officers At University Of Agriculture, Faisalabad

Under the On-Farm Water Management Pilot Project, Colorado State University has the responsibility to serve as advisors for the training of Water Management Extension Officers (WMEO). The Pilot Project is called the On-Farm Water Management Development Project in each of the four provinces. Under the provincial programs, each Field Team consists of a team leader called the Water Management Specialist, two Watercourse Development Officers (WDO), five Land Development Officers (LDO), and one Water Management Extension Officer (Agricultural Officer).

The University of Agriculture, Lyallpur (UAL), which became the University of Agriculture, Faisalabad (UAF) in September 1977, was assigned the responsibility for training the WMEO's. Mr. Qurban Ali Awan of the Department of Irrigation and Drainage was named to be course coordinator to be assisted by seven other trainers representing six academic departments in the University. Dr. Alan C. Early and Dr. Max K. Lowdermilk, in cooperation with UAF faculty, developed the initial course content.

Upon the departure of Dr. Early in May 1977, Dr. Kemper took responsibility for CSU in assisting the trainers in getting this first course underway. Mr. Norman S. Illsley went to Pakistan on TDY from April-September 1977 to assist in this training course. Because of political unrest in Pakistan, the University was closed and the initiation of the course was delayed until June 10, 1977. Professor Skogerboe was stationed in Faisalabad during September and October to serve as adviser until completion of the course. Graduation ceremonies were held October 20, 1977. Sixteen persons graduated from the first training course. They represented all four provinces in Pakistan, with two from the North West Frontier, two from Baluchistan, four from the Sind, and eight from the Punjab.

During the time period November 1977 through March 1978 considerable effort was made on-campus to revise the course curriculum and develop appropriate training materials. The faculty trainers at UAF had developed many ideas for improving the course. Since Dr. Dwayne G. Westfall was to have primary advisory responsibility for the second training course, which was to begin in March 1978 (actually this second course got underway in April 1978), he spent most of his time prior to departure for Pakistan in late February in developing a revised curriculum and reviewing training materials.

aa. Organizing Farmers To Improve Irrigation Water Delivery--The Problem and Prospects for Solutions In Pakistan

Data from ten districts in the Punjab and Sind reveal that about half of the irrigation water entering poorly constructed and maintained sample watercourses is lost before reaching farmers' fields. This water is not only lost to crop production, but also contributes to waterlogging and salinity. One of the most important things which can be done to increase water supplies to farmers' fields--reduce waterlogging and salinity, and increase the productivity of fertilizer, pesticides, and improved seed varieties--is to undertake a program of watercourse reconstruction and maintenance. Data is presented revealing the extent and significance of water losses, discusses options for organizing farmers to undertake and maintain the watercourse improvements, and suggests guidelines for evaluation of organizing efforts.

One of the most important constraints to increasing agricultural production is the limited water supply. The productivity of improved seeds and fertilizers which have constituted much of the "green revolution" is centrally dependent upon adequate supplies of irrigation water. Given an inadequate supply of irrigation water, the farmer must reduce the level of all of this "modern," and relatively costly, inputs. Farmers must accept reduced output and profits in order to decrease chances of loss. Fertilizer is relatively costly and return from its application depends on the delivery of water in adequate amounts and at the proper time. The rational farmer with inadequate irrigation water supplies will apply fertilizer at low levels in order to insure that his marginal costs do not exceed his marginal returns--a most rational response, but one which sacrifices productivity. One of the most important things that can be done to increase water supplies, as well as to reduce waterlogging and salinity, is to reconstruct poor watercourses which, overall, lose over fifty percent of the water between the mogha and the field outlet. But to reconstruct watercourses and to maintain the improvements, farmers must be organized. This paper has addressed some of the major considerations relevant to that organizing effort.

Water losses of major magnitude are occurring due to poorly constructed watercourses, such losses can be reduced in major ways at great savings to the national economy, and to accomplish the objective of improving watercourses, farmers must be organized to effectively provide themselves with an important collective good--a well-designed, well constructed watercourse which will reduce seepage damage at the head of the channel, and which will increase needed water supplies for the farmers located at the tail.

At present, three organizational alternatives are available for establishing the necessary water users associations--the informal, the authority of the Companies Act, and the authority of the Cooperatives Act. Farmers may elect to organize in any of the three ways, but it is essential to carefully evaluate the outcomes of their efforts before major policy commitments are made.

bb. Farmer Organization To Improve And Maintain Watercourses

Since there are commonly from 30 to 100 farmers on a watercourse, it is impossible to give detailed guidance to each farmer. Moreover, they need an Executive Committee of fellow farmers which they will support and which can make the many decisions necessary in initiating, carrying out, and maintaining the benefits of a development program. Consequently, one of the first responsibilities of the On-Farm Water Management Field Team is to help the farmers understand the need for, and responsibilities of, such a committee.

The farmers know the capacities of their neighbors for decision making and leadership. When they understand the functions which the Executive Committee members must perform, the farmers themselves are best able to select the men for this job. Experience at Mona indicates that three strong and active committee members are sufficient to provide the necessary supervision of the construction, plan the program and carry out the other committee assignments. If the farmers feel that acceptance of the program requires appointment of an influential person to the committee, whom they know will not be active, they should expand the committee so there are always at least three active members.

The three basic ingredients for success of a development program are:

(1) The program is physically sound and has potential for returning high benefits compared to costs.

(2) That the farmers be given what they cannot provide (information, technical services, capital, etc.) and <u>no more</u>.

(3) That the farmers understand from the beginning that the development program is theirs - and

> that while there are limits and regulations governing the extent of government participation, within those limits the farmers are in charge and the success or failure of the program is their responsibility.

Successful development of the third ingredient requires considerable thought and planning on the part of the government employees working with the farmers, so that they are guiding rather than pushing the farmers. The On-Farm Water Management Field Team must let the farmers know that they respect their wisdom and judgement in all matters and are available, at their request, to give them technical guidance on their watercourse improvement program.

cc. Farm Water Management: Past, Present And Future In Pakistan

It has been my pleasure to work with a team of water management specialists from CSU here in Pakistan during the past few years. It has been our privilege to cooperate with many Pakistani engineers, scientists and administrators in the rediscovery of Pakistan's potential for improvement in water management. As I leave your country and have been asked to write this paper, the temptation arises to dwell on the successes of the programs on which we have worked together, and to imply that we have done the hard work, accomplished all the important objectives, set a good example and that progress will be easy from now on. Such a paper could give us a temporary feeling of accomplishment and goodwill toward each other, but would be basically untruthful and would tend to lull us into the sense of complacency and inaction that has characterized farm water management in the past.

Consequently, this paper will emphasize our potentials for improvement more than past successes. It will imply that we as individuals, and the organizational systems within which we work, have a potential for improvement. Water management in Pakistan will improve as we strive to achieve these personal and organizational potentials.

The Indus Basin contains over 33 million acres of irrigable land, received about 140 million acre feet of good quality river water each year, and has a climate which allows year-round production of crops. One of the world's biggest and best canal systems delivers this water to the potentially rich agricultural areas. The basin is underlain by a permeable sandy aquifer which allows storage of water for pumping as needed for irrigation. This tremendous storage reservoir is commonly within 50 feet of the plants which need the water. Extensive public and private tubewells have been constructed to make this water available to the crops. A manpower resource, involving over 50 million people, is available with common labor costing less than Rs. 1 per hour.

In spite of the availability of the components for one of the world's greatest food machines, in the average season only about 15 million acres of this land is producing and the average yields are low with wheat at about 20 maunds per acre, maize at 13 maunds per acre and rice at 20 maunds per acre. Yields from other countries with similar climates and on Research Stations in Pakistan indicate that these three crops should have yields up around 60, 80 and 80 maunds per acre respectively.

This low productivity is a result of several factors including small farm size and inability of most farmers to afford the implements and power requirement to do a first class job of farming. The farmers are commonly illiterate which makes most of them inaccessible to new technology via the printed word. The extension program is under-financed, poorly equipped and the extension training program does not provide field experiences which give the trainee the ability to develop credibility with the farmers. Many of the farmers, and particularly the smaller farmers, are poor managers, partially because they do not know or are not able to afford a large portion of the management alternatives.

Poor water management is probably the primary constraint on crop production in the Indus Basin. The designers of the irrigation system recognized that there was more land available than could be irrigated with the available water supply. Consequently, they designed the irrigation system to supply about 1 cusec per 300 acres and hoped that the farmers would develop optimum management techniques which would maximize the economic return from the water available. The majority of the farmers have not developed this water management ability and, in the past years, no Government Agency has been assigned to help them do so.

dd. Improving Irrigation Water Management In The Indus Basin

Over half of the water delivered from the canal system to the watercourses managed by the farmers is not made available to the farmers' crops in Pakistan. Most of this water loss is due to loss of water through the banks of the watercourses. Lack of maintaining these banks and lack of cleaning the watercourse is a result of inadequate organization of the 10 to 150 farmers who use the watercourse, and a deficiency of knowledge concerning the amount of their water which is being lost.

Various methods of watercourse improvement have been evaluated including concrete and masonry linings and simple earthen improvements of the ditches with concrete control structures, junctions and turnouts. With the cost of labor low in Pakistan, the earthen improvements with concrete structures appear to be the best investment.

Farm water management improvement programs have been implemented in most of the provinces which include this type of watercourse improvement, land leveling and advice to the farmers on how and when to irrigate his crops to optimize his production. The rate at which personnel can be trained to help the farmers implement these improved water management practices is limiting the rate of implementation.

ee. Land And Water Development And Use: Farm Water Management

Dissemination of the knowledge and potential benefits to be derived from improved water management practices will require a greatly expanded and better equipped and trained extension service. Many of the best practices are practiced by some of the better farmers. However the good practices spread very slowly due to a deficiency of publicity, well organized field days, demonstrations, and printed guidelines.

The role of the better farmers acting as demonstrators is essential to the rapid spread of these practices. Helping the small and inefficient farmer is one of Pakistan's goals, but it must not be done at the expense of failure to achieve self sufficiency in food production through avoidance of the good managers who eagerly accept, utilize and demonstrate new technology. Efforts to help the small farmer should include variants of all new technologies which are adapted to his resources, and opportunities to share or rent equipment which he cannot afford to own.

The role of the better managers is particularly essential in watercourse improvement and maintenance which requires an organized group effort. Fortunately, when farmers elect the officers of their watercourse improvement committee, they usually select these good managers as their leaders.

ff. Social And Organizational Factors For Farm Irrigation Improvements: A Case Study

Farmers and their local organizations are not only the end receivers in the technology transfer process but are also a means of effective horizontal transfer of technologies to other farmers. Farmer organizations are a requisite for the maintenance of many improved technologies which require collective action. The Pakistan case study describes the importance of this concept and the need for irrigation specialists to understand and utilize local farm organizations for water management improvement programs. The unique research-development process developed by Colorado State University in Pakistan has built-in mechanisms for the transfer and maintenance of technologies.

gg. Research And Linkages Needed To Support The Provincial Farm Water Management Improvement Program

Recent survey and research studies in Pakistan have shown that only about half the water leaving the distributaries and SCARP tubewells is reaching the farmers fields. Studies of elevations within bunded areas show that it is common for low portions of a bunded unit to receive over twice as much irrigation water as the high portions. Data on maize and cotton show that the yields on the low areas of bunded units are about half of the yields on the high areas in a SCARP project area. Watercourse survey data also show that both under- and overirrigation occurs at various times of the year, which varies in different parts of the country.

Underirrigation, overirrigation and the surface flooding method of irrigation and associated sealing and crusting of the soil surface are primary factors in the poor stands and low yields, particularly of kharif crops, in the Indus Basin. Inadequate water, particularly at planting time is a primary constraint or the acreage of wheat that can be planted. Watercourse improvement programs by farmers have increased delivery efficiencies from 50% to 75%, which increased the amount of water available at the farmers fields to 150% of previous deliveries. The payoff in such a development program will occur only if the saved water is used effectively through improved irrigation and agronomic practices.

A listing of research and action agencies which can contribute to improved water management practices shows the existence of several agencies which are, or could be, contributing to the needed research. In the past, the farmers have received little guidance in how to use the water more effectively. The Provincial On-Farm Water Management Development Projects will provide some farmers with such help and the Provincial Extension Services could also give the farmers guidance. These action agencies now have few personnel trained in water management. To allow them to place their primary emphasis on implementation of improved water management, it is suggested that they do not develop major research efforts of their own. To help them draw on relevant research from other agencies to improve their implementation program and to allow the action agencies to help the research agencies focus on the farmers most pressing needs, the following "linkages" are proposed:

(1) Establish a Research and Development Coordination Committee and construct test watercourses on which promising new innovations will be evaluated;

(2) Appoint Research Focus and Implementation Coordinators in each of the Provincial On-Farm Water Management Development Projects;

(3) Conduct annual reviews of recommendations for various crops;

(4) Train Water Management Specialists in the Provincial Agriculture Extension Programs; and

(5) Provide additional linkages as needed.

Maintenance of these linkages should allow the researchers and implementers to become effective specialists in their jobs and still provide the interchange of information essential to use of research information and improving the relevancy of research.

hh. Sociological Analysis For Irrigation Water Management--A Perspective And Some Analytical Approaches To Assist Decision-Making

Irrigation water is sociological because people must organize collectively to secure it, transport it, divide it into usable shares, enforce rules for its application, pay for it, and dispose of unused portions. The kinds of social organizations, the patterns of power, decision-making, conflict, and cooperation which people create and maintain for the social control of water intimately affects the productivity of its use. Attempting to comprehend physical and agronomic problems of irrigation without probing into surrounding social organizational webs is like attempting to understand deficiencies in plant growth without reference to conditions of climate. When water moves efficiently from rivers, through a network of canals, to plant root zones, it is because people have effectively organized a decision system capable of enforcing technically sound rules for pursuing the collective interest. Defects in the delivery and application of irrigation water are typically associated with deficiencies in social organization.

The multi-faceted process of organization building and reform so central to the transfer of improved irrigation technology encompasses a range of crucial tasks such as:

(1) Mapping strategic variables accounting for behavior associated with poor irrigation efficiencies in existing systems, including identification of central constraints;

(2) Identification and testing of potential alternative socio-technical "solutions" for relaxing constraints;

(3) Verification of "optimum" organizational-technical "packages" through systematic adaptive research;

(4) Pilot project design and implementation;

(5) Project evaluation with "feedback" to policy makers and practitioners;

(6) Diffusion of the "improved" organizational-technical "packages" with focus on communication and supporting services thereby altering the strategic factors identified in step one.

Two implications must be noted about such a listing. First, no single discipline can adequately deal with any specific area mentioned above. Interdisciplinary efforts are essential in all phases of water management improvement programs and the term interdisciplinary is stressed rather than multidisciplinary efforts. Second, each item requires extensive analysis--no paper of modest length can adequately comprehend the complex interdependent problems, the available tools, and the many uses and limits of potential analytic approaches for all six tasks even within a single discipline.

This study contends that:

(1) The role of sociology in water management has been unclear to both decision-makers and researchers. There is a high probability that decision makers will obtain sociological research inappropriate to the type of water management problem with which they are faced.

(2) Water management problems can be broken into six major varieties based upon two properties of water management related technology--its divisibility and its private-collective nature.

(3) For some types of problems, the task of building or modifying small scale local level organizations is central--water management improvement programs will stall without effective local organization building and/or reform so as to allow acceptance, utilization and maintenance of improved technology.

(4) Organization-building and reform is centrally affected by environmental conditions--specifically in the social environment, the degree of conflict polarization, the proportion of member-clients who enjoy high

centrality in the network, and the extent to which power/influence is in the hands of a few are hypothesized to significantly affect the prospects of successfully organizing farmers for adopting, utilizing, and maintaining improved water management technologies.

(5) In order to identify those social units most conducive to successful organization building, it is hypothesized that those units characterized by low conflict polarization, high centrality, and low concentration of power influence have the greatest potential.

ii. A Research-Development Process For Improvement Of On-Farm Water Management

A research-development process for rapid improvement of on-farm water management through technology transfer is described. The process focuses on systematic research to identify problems, develop and assess solutions, and implement development programs at the farm level. An interdisciplinary team executes the research-development process with farmers.

The technology transfer process consists of four interrelated phases as follows:

I. Priority Problem Identification
II. Search for Problem Solution
III. Assessment of Solutions
IV. Pilot Project Implementation

Problem identification consists of the combination of an interdisciplinary approach with farmer participation to achieve an understanding of system operation. This results in an objective, quantitative definition of priority problems. The interdisciplinary team combines knowledge and experience with systematic research in Phase II to develop direct acceptable solutions to priority problems. Applied, adaptive, and evaluative research methods are used under farmer conditions in Phase III for the assessment of solutions. These results are used to redefine problems and improve solutions. In Phase IV an institutionalized development program evolves as a pilot project. Trained personnel use the carefully designed technological package to work directly with farmers to solve their problems.

jj. Apparent Investment Potentials For Increasing Food Production Through Improved Water Management In Sri Lanka

The land and water resources of Sri Lanka are excellent and the basic engineering schemes to bring the water to where it is needed are basically sound. Apparently, funding is available for these projects. The basic problem is inefficiency of the system and "lack of discipline" among the public and private sector. How to instill the needed discipline in the system is of paramount importance. The farmer's response and willingness to work hard, when he can see the benefits to be derived, lead to the conclusion that the needed discipline should be instilled primarily via an education program. We do not yet know all the answers as to the best procedures the farmers should follow on these soils, so considerable research will be needed. However, sufficient information on water-course losses and how to reduce them and other basic water management practices exists which can furnish the basis for a productive Water Management Extension Program.

Currently the Irrigation Department is proposing hiring of a new classification of employees who would be called "Irrigators" or "Water Distributors." They would work with all the farmers on about eight field channels to help them to regulate and distribute their water properly. At this intensity there would be over twice as many of these "irrigators" as extension agents in the irrigated areas.

Since the Irrigation Department has the responsibility for "enforcing maintenance" of the field channel by the farmers it appears logical to have these men trained to help the farmers do the maintenance and cleaning in a proper and efficient manner. Mixing of regulatory and assistance functions is generally discouraged. However, staff members at the Agricultural Research and Training Institute who have been taking surveys among these farmers believe that the regulatory powers of these "water distributors" may give them status which will allow them to be more effective as change agents with the farmers without resorting to undue coercion.

The basic components of a program for improvement in water management and crop production would include:

(1) Education of the farmers in water management principles and procedures which would:

  (a) Allow them to measure flow in their channels and know when they were losing a substantial portion of the water.

  (b) Provide them with a program of known benefit for cleaning and maintaining their field channel to increase its delivery efficiency.

  (c) Allow them to make quantitative estimates of the amount of water needed by their crops and apply the proper amount, based on rainfall, stream flow and evaporation or some of the procedures based on climatic data.

(2) Training of the "Water Distributor" in the techniques of and benefits to be derived from proper cleaning of field channels and proper application of water, and in how to be a positive change agent with farmers. This training should be done by Water Management Specialists in the Irrigation Department and would be primarily in the field. Sufficient "Specialists" should be employed to allow them to complete the training of all irrigators in two years by which time research will have adapted, developed and tested water management technology for a second round of the training program.

(3) Water Management Specialists should be trained by Irrigation Department personnel from the Maintenance and Land Use Divisions using assistance from expatriates as needed. Colorado State University's Water Management Project, funded by USAID, could probably provide some of the training materials for this program.

(4) Research on improved irrigation methods should be supported to identify methods which will increase crop production and decrease the labor requirements. The work at Vanathivillu, Jaffna, Maha Illupallama and at Kala Wewa (USAID supported) should provide many of the answers needed. If more work is needed, strengthening these institutions and projects would be preferable rather than beginning new locations. However, outstation studies with farmers on irrigation projects should be encouraged to bring the "farmer factor" into realistic consideration.

Irrigation and Drainage methods which would help upland crops avoid damage from poor aeration, particularly during the monsoon seasons, are needed to productively use the Red-Brown Earth soils.

(5) In conjunction with No. 4 upland crops which would fill needs for domestic consumption or foreign exchange should be evaluated. When identified, along with the proper culture, irrigation and other inputs, a program should be developed to stabilize the

price for the product as has been done with rice. If this is a "new" plant such as soybeans, this will also require processing plants and a program to introduce and popularize the food products derived from the crop.

(6) Maintenance of the canals and their structures should be improved. This will require an increase in maintenance allowance. The Irrigation Department presently feels this could be achieved at an annual rate of Rs. 110/acre served. It would also involve setting firm standards for maintenance, intensive field training of staff in maintenance procedures, allocation of supervisor's time for checking maintenance and promotion or dismissal of personnel based on observed performance.

Since the Irrigation Department supervises the farmers in maintenance of the field channels training in how to use and maintain the structures on these channels should be provided. Many of the structures are poorly designed and should be replaced.

The program should include measurement of water flow rate throughout the distribution system, including the canals, field channels and private channels out to the farmer's fields so that reaches of high loss can be identified, the benefits and costs of lining estimated and the best investments made. The UNDP modernization project is supposed to do many of these things. Effects of these procedures on that project should be monitored with measurements. This may require investments in flumes, current meters, portable weirs and other devices which are not currently funded. On equipment such as current meters, maintenance is extremely important and it may be necessary to send a person overseas on a short term training course to assure that the data is factual.

F. Dissemination and Utilization of Research Results

Throughout the year in keeping with program objectives, special efforts have been made which have resulted in wide dissemination and utilization of research results. As credibility with the Government of Pakistan has been increased as a result of a wide range of project activities, interest in Pakistan from farmers to government officials has accelerated. The major results of project efforts described in more detail

below are: 1) implementation of the comprehensive On-Farm Water Management Pilot Project; 2) the training of a large number of host country personnel for research and development activities; 3) the institutionalization of water management research activities at research stations and with other organizations; 4) assistance to WAPDA Master Planning, the University of Agriculture, Faisalabad (UAF), and other institutions in action oriented research and development activities; 5) focus on the need to improve water laws and codes and the provision of incentives for farmers to organize for improving their farm irrigation systems; 6) increase linkages with international organizations active in Pakistan and elsewhere with a concern and focus for on-farm irrigation problems; and 7) utilization of project personnel for reconnaissance surveys to irrigated projects in other low income nations.

In May of 1976, USAID Washington approved an AID Mission to Pakistan proposal for a loan of over $10 million to help Pakistan launch a comprehensive On-Farm Water Management Pilot Project (referred to by the provincial governments as the "On-Farm Water Management Development Project"). This five year project will cover 1500 watercourse command areas totaling about 600,000 acres of land and involving about 60,000 farmers. The major components of this Pilot Project (costing an estimated $40 million) include watercourse rehabilitation, precision land leveling, and water management advisory services. The research data of the CSU program, and the particular vehicles by which these were transferred to farmer and official audiences, convinced both the GOP and the USAID Mission that such a pilot project was both needed and feasible. This program has been actively underway during this report year with the first watercourses being completed in September 1977. Now, the World Bank and the governments of Canada and the United Kingdom have developed watercourse improvement projects to be implemented soon in Pakistan.

A training program has evolved for farm level extension personnel as a result of both the Pilot Project and the concern of provincial agricultural departments. It has been realized that saving water through reducing conveyance losses is only half the job; the farmer must also receive help to utilize his water more effectively for increased crop production possibilities. The first training course for Water Management Extension Officers was given June 10-October 20, 1977. The graduating class consisted of 16 participants representing all four provinces.

As improved models of the panel water control structures have been designed, they have been immediately adopted by the On-Farm Water Management Development Project in the Punjab, where this program is moving ahead rapidly. Several sources indicate that the successful performance of these control structures is a major factor in motivation of farmers to enter into the watercourse improvement program. This technology will be transferred to the other provinces in the very near future.

Determination of the functional relationship between water level in the watercourse and water loss led to the prediction that "low operational level" watercourses would lose much less water than the normal watercourses existing in Pakistan. This "low operational level" design was utilized in the reconstruction of a full scale watercourse in the Mona Project area and the resulting watercourse losses were less than half as much as the average of the other improved watercourses. This is undoubtedly just the beginning of the use of this design for watercourse improvement in Pakistan and elsewhere. It will probably be one of the primary design factors considered in watercourse reconstruction in the On-Farm Water Management Pilot Project in the future.

The finding that good cleaning and maintenance of watercourses increases delivery of water to the fields by about 50% is being incorporated into the training materials for the Water Management Extension Officer Training Program at UAF so that the Agricultural Extension Officers training under this program will have the faith and visual aids necessary to convince the farmers to take this apparently mundane step which can provide them with such substantial benefits at such low cost. A common host country request is that we focus more attention on how to give existing organizations a mission and something worthwhile to do rather than conceiving new organizations. The cleaning and maintenance research which has been carried out primarily by Field Assistants (with training comparable to that of Field Assistants in the Department of Agriculture of the various provinces) indicates a real potential for carrying this message and the necessary technology to the farmers via the existing extension program. The watercourse improvement program involved in the On-Farm Water Management Pilot Project will improve only about 2% of Pakistan's watercourses and even the most ambitious proposals would require a decade or more to improve all of the watercourses in Pakistan. However, programs for giving field training to extension Field Assistants, which would allow them to lead the farmers in watercourse cleaning and maintenance projects, could be developed within a year and the training and maintenance and cleaning programs would be achieved within two or three years. Current observations indicate an alarming tendency of farmers on some of the improved watercourses to not maintain their watercourses. It is probable that both the watercourse improvement program and the proposed cleaning and maintenance program could be benefited by requiring a good cleaning and maintenance program as a prerequisite for participating in the improvement program which provides the farmers with the concrete control structures.

The findings of the cleaning and maintenance program and the low operational level design trial provide a real opportunity for reducing the water losses to about 25% of what they were prior to the improvement program. The improvement program underway in the On-Farm Water Management Pilot Project and the improved watercourses at Mona reduce losses to about 50% of what was occurring before the improvement was undertaken. However, this improvement does not persist if the watercourses are not cleaned and maintained regularly and losses tend to creep back up to 60, 70, or even 80% of their original values. Within a year or two, development of good visual aids and sound arguments to help the farmers understand the potential for increasing their water delivery to the field by cleaning, maintaining and redesigning their watercourses should play a major role in giving further emphasis to the on-farm water management programs existing in Pakistan and those which may be developed in other countries of the world.

The skimming well data from the small CARE-financed project have convinced WAPDA officials to invest their efforts in a larger related research study to determine the potential for building "fresh water reservoirs" as lenses on top of saline aquifers. This study will be funded in part by USAID at the Mona Reclamation Experimental Project (MREP).

As the pilot watercourse improvement program has evolved at Mona, a steady stream of at least 1000 visitors annually from the provincial and federal government, USAID, FAO, the World Bank and several other countries have visited the projects, talked to the farmers and seen the improvements. This on-site inspection has been reported as a major factor helping bring about the acceptance of the water management program by various agencies in the Government of Pakistan.

The results concerning conveyance efficiency in watercourses have had a major impact on Pakistan's future planning and on programs presently being developed. Previously, plans for water related projects assumed 90% of the water delivered to canal outlets or by public tubewells was delivered to the fields. Presently, the Federal Planning Commission is assuming that 60% is delivered. Our measurements suggest this value is still about 7% high, but it is certainly much more realistic than previous assumptions. New SCARP programs on the drawing boards are including plans for rebuilding of watercourses as part of the SCARP program. International funding agencics such as IBRD (World Bank), SIDA, and Canadian Aid are interested in funding water management related programs. Agencies such as the Punjab Agriculture Department and the WAPDA Master Planning and Survey Division are using our results in the planning process as a basis for new programs. Unfortunately, key personnel in the Irrigation Department in the Punjab still maintain that watercourse conveyance efficiencies are in the 85 to 60% range and that action to improve watercourses is unnecessary. Repeated invitations to visit our work sites and see the program results first hand have been accepted initially, but cancelled at the last minute. We are, however, attempting to develop some small cooperative programs with the Irrigation Department and hopefully these will result in improved communications.

In November of 1977 Esso Pakistan sponsored a Water Management Seminar in Lahore. Previous Esso seminars have been based on the production of specific crops (i.e., wheat, cotton and rice). Researchers and officials from agriculturally related agencies and institutions in Pakistan were invited and papers read varying from pest control to policy. Production recommendations were then developed by committees. These crop seminars each attracted 50 to 70 participants. By contrast, the Water Management Seminar attracted over 150 registered, while attendance at individual sessions exceeded 200. Top officials such as the Vice Chancellor of the University of Agriculture, Chairman of WAPDA, and the Chief of the Water Resources Division of the Planning Commission attended and actively participated. This unprecedented participation and attendance indicates the level of awareness of the need for improved water management in Pakistan. Previously, water management had been considered largely in terms of storage, canal conveyance, or waterlogging and salinity, with associated tubewell supplies and vertical drainage. Farm water management is now a major issue in Pakistan.

The undergirding philosophy of the CSU Water Management Research Project from its inception has been the clear objective of building up host country capabilities in the water management related fields. All research and other program activities involve host country personnel--ranging from extension workers, engineers, agronomists, social scientists, as well as officials in applied field training. The problem identification surveys in the Punjab and Sind Provinces alone resulted in field training of a group of about 30 individuals from disciplines including agronomy, economics, extension and engineering. This state of the art study was done in cooperation with the WAPDA Master Planning group and all trained personnel have been employed by WAPDA for an intensive survey of 60 command areas (UNDP and World Bank funding), which is now nearing completion. This same trained staff will be used in the near future for the "Monitoring and Evaluation of the On-Farm Water Management Pilot Project."

Formal graduate training at the CSU campus was undertaken during this report year by Mr. Barkat Ali (Agricultural Economics), Mr. M. Hanif (Agronomy), Mr. M.A.R. Farooqi (Agronomy), Mr. Mohsin Wahla (Agricultural Extension) and Mr. Muhammad Akram (Agricultural Engineering). An important innovation in this formal training is the requirement that after successful completion of course work, the candidate for a degree will return to Pakistan and conduct his thesis research on a relevant problem area in his respective field. The field research, data analysis, writing of the thesis, and final examination are all completed in-country under the guidance of the CSU Field Party. Mr. Siddique Shafique has successfully complete his M.Sc. in Agricultural Engineering and is presently active in research at Mona. Mr. Mushtaq Gill completed his masters thesis in Agricultural Engineering and is very active as Deputy Director, Training and Research Center, Punjab On-Farm Water Management Development Project. The research of both of these gentlemen was conducted on actual watercourse commands and resulted in findings that advanced technical and organizational procedures for water management improvement activities of farmers. Mr. Nur Din Ahmad, who is a senior official of the Land and Water Reclamation Directorate in Lahore, has completed his M.Sc. in Agronomy and course work for a Ph.D. and is presently doing his research. Both Mr. Ghulam Hussain and Mr. Khalid Gill have completed course work at the Ph.D. level in Agronomy and returned to important research positions at the WAPDA-Mona Reclamation Experimental Project (MREP) and at the Punjab Agricultural Research Institute (PARI). They will complete the requirements for the Ph.D. degrees in soils at their respective institutes under CSU staff guidance.

Realizing the worldwide demand for expertise in on-farm irrigation related fields, the project has provided an opportunity for two stateside graduates to conduct field research in Pakistan. Mr. Tom Trout is a Ph.D. candidate in Agricultural Engineering and his research will result in a comprehensive technical design manual for improvement of farm water conveyance systems. Mr. Larry Nelson, who returned to campus in December 1977, conducted his research at MREP related to the problem of kharif season (summer) high soil temperatures and the germination and emergence of maize and cotton. Both candidates received much orientation at CSU prior to their research tour in Pakistan. They are expected to complete their work in 1979.

While not directly related to or sponsored by the CSU project, Field Party members have helped arrange research sites and provided guidance for two social anthropologists from the University of Pennsylvania and one economist from the University of Wisconsin. These three Ph.D. candidates are conducting their research on subjects relevant to Pakistan's irrigation problems. One of the social anthropologists became a member of the CSU Field Party in April 1978.

Beginning in June 1977, Mr. Ramchand Oad, a Ph.D. student in Agricultural Engineering at Cornell University, has been receiving special training at CSU in irrigation engineering and the interdisciplinary aspects of on-farm water management. He will return to Cornell University in September 1978 and will then undertake his dissertation work in Indonesia shortly afterwards as part of an AID funded irrigation research program in Asia. Later, Mr. Oad will return as a faculty member in the Mehran University of Engineering and Technology located in the Sind at Nawabshah.

Expertise developed in the research and surveys conducted in Pakistan is providing a substantial springboard for the water management project in Egypt where aspects of the problem identification surveys found effective in Pakistan are proceeding at an accelerated pace in Egypt because they have been able to avoid some of our mistakes and because Pakistan Field Party members who have returned to campus are available to give support and on-the-spot guidance to the Egyptian Program.

The relative success of the farm water management research in Pakistan in helping develop a viable national water management improvement program has led to a continuing stream of requests for information concerning how the research programs were conducted and the available findings. Two slide shows titled "Pakistan: Land of Promise" and "Investments in Water Management" have been developed to tell these experiences. A half hour movie on "Watercourse Improvement" is also available for this purpose. However, one of the primary means of transferring this information to other programs is for project members to consult with individuals involved in water management in other countries and international programs. These consultations have involved TDY trips of Clyma to Chile, Bowers and Kemper to Sri Lanka and Reuss to Thailand in the near future. The World Bank has shown strong interest in the program and has at various times asked for consultations with Clyma, Kemper, Lowdermilk, Radosevich, Freeman and Skogerboe. The Food and Agriculture Organization of the United Nations has also shown a strong interest in the program asking for a paper on the history of the project and asking Kemper to spend three weeks in the near future with them writing a position paper on how water management research should be organized and coordinated with development programs in developing countries.

Dr. Doral Kemper participated in an agricultural sector review in Sri Lanka during March 1978. USAID representatives from the Asia Bureau in Washington, D.C., Pakistan and Sri Lanka participated in this review. The role of Dr. Kemper was to look at investments in improved water management that would result in increased food production for Sri Lanka.

G. Work Plan (April 1, 1978 through March 31, 1979)

The complete Work Plan for this second contract year is available upon request to the Contractor.

1. Mona Reclamation Experimental Project

The research work at Mona has provided significant results on watercourse improvement that is now being utilized in the On-Farm Water Management Pilot Project. A new five year research proposal has been prepared consisting of six components (see Tables 1, 2 and 4). The rupee funding is expected to be received by early fall of 1978. Portions of this research program will be undertaken in July 1978.

2. On-Farm Water Management Pilot Project

The second training program for Water Management Extension Officers will be undertaken in April 1978, with the third course scheduled to begin in January 1979. Eight faculty members representing six departments of the University of Agriculture, Faisalabad (UAF) are serving as trainers. Considerable effort will be required in developing more comprehensive training materials.

A research program is now underway on organizational arrangements for farmers to improve their irrigation water management practices. Professor Ashfaq Mirza, Department of Rural Sociology, UAF, is serving as principal investigator. Mr. Douglas Merrey of the CSU Field Party has been stationed in Faisalabad and is officed with Professor Mirza. The two will work together in this field research program.

The Master Planning and Survey Division of WAPDA has prepared a proposal for "Monitoring and Evaluation of the On-Farm Water Management Pilot Project." This proposal is expected to be funded during late summer of 1978.

The CSU Field Party is providing some assistance to the Training and Research Center of the Punjab On-Farm Water Management Development Project. This Center provides training for watercourse engineers, precision land leveling and Field Assistants. Some training materials will be provided to this Center to assist in their training programs.

3. Water Management Research Program for Rural Development

The faculty of the University of Agriculture, Faisalabad, completed a research proposal for a water management research program in October 1977. The eight components of this research program are:

a. Crop production as affected by irrigation methods and practices, depth to groundwater and fertility.

b. Utilizing saline water for the production of salt-tolerant crops and lowering the water table in mid-doab areas.

Table 1. Summary of activity support.

	Second year support (April, 1978 thru March, 1979)					Activity	
	CSU man months			Local support			
	Field	Campus		Man		Initiation	Expected
		TDY	Backup	Mos.	Rupees	date	termination date
I. Mona Recl. Exp. Proj.							
a. Watercourses	4		1	99	640,000	July 72	June 83
b. Soils, Agronomy	4		1	153	330,000	Sept. 72	June 83
c. Extension	4		1	144	308,000	Dec. 75	June 83
d. Economics	3	0.5	0.5	36	172,000	Dec. 75	June 83
e. Groundwater Management	2	1		81	845,000	July 78	June 83
f. Tubewell Oper. & Maint.	2			54	880,000 12.5m/5 yr.	July 78	June 83
II. On-Farm WM Pilot Proj.							
a. Training	11.5		9.5	18	180,000	March 77	June 82
b. Water Users Assoc.	7	1	4	75	300,000 .52m/2 yr	Dec. 77	March 80
c. Monitoring & Eval.	10			396	16.1m/4 yr	July 78	June 82
d. Training and Res. Center	5		2	CSU advisory only		July 76	March 83
III. WM Res. Proj. for Rural Dev.	13.5			156	7.6m/5 yr	Oct. 78	Sept. 83
IV. Research Institutions	5	2		CSU advisory only		July 72	March 80
V. Regional Analysis	6	2	1	Logistical support only		continuing	
VI. World Utilization			56	"	" "	Oct. 76	March 80
VII. Tech. Assistance	1	3		"	" "	Apr. 77	March 80
VIII. Administration	6	1	6			July 70	March 83
	84	10.5	82				

Table 2. CSU Field Party personnel requirements (man-months) for planned activities.

	Mona Reclamation Experimental Project						On-Farm Water Management and Pilot Project										
	Ia	Ib	Ic	Id	Ie	If	IIa	IIb	IIc	IId	III	IV	V	VI			
	Water-courses	Soils, Crops	Extension	Economics	Ground-water	Tube-wells	Trng Water Mngmt Advisors	Water Users Assn's	Monitor. and Eval'n.	Trng & Res Ctr.	WMR Prog for Rural Dev.	Res. Instns.	Reg. Anal.	World Utilization	Int. Tech. Assist.	Admin.	Total
Field Party																	
Chief of Party		1									1	1	2		1	6	12
Ag. Eng. (Irr.)	1				2		0.5		3		2.5	2	1				12
Ag. Eng. (Equip.)		1	1			2	2			5	1						12
Soil Scientist	3		2						2		3	1	1				12
Agronomy		2					6		1		2	1					12
Ag. Econ.				3			1	1	3		2		2				12
Social Anthro.			1				2	6	1		2						12
Field Party Totals	4	4	4	3	2	2	11.5	7	10	5	13.5	5	6	0	1	6	84
Campus																	
Agronomy		1					3			1					?	.5	
Agric. Eng.	1						4.5					2 TDY	1.5 TDY .5 backup	27.5	?	5.5	
Economics				.5 TDY .5				1 TDY					.5 TDY .5 backup	6.5	?	.5	
Sociology			1					4 backup						14	?	.5	
Other							2			1				3	?		
Campus Totals	1	1	1	1.0	1	0	9.5	5	0	2		2	3	56	3	7	92.5
Water Mgt. Res. Proj. Totals	5	5	5	4	3	2	21	12	10	7	13.5	7	9	56	4	13	176.5

Table 3. Plan for filling personnel requirements.

Present		End of Contract Year	
Name	Position	Name	Location
Reuss	Chief-of-Party (Agronomist)	Reuss	Lahore
Trout	Agricultural Engineer (Irrigation)	Konrad	Lahore
Illsley	Agricultural Engineer (Equipment)	Illsley	Lahore
Bowers	Soil Scientist	Bowers ?	Lahore
Westfall	Agronomist	Westfall	Lahore
Holje	Agricultural Economist	Holje	Lahore
Merrey	Social Anthropologist	Merrey	Faisalabad

Table 4. Estimated completion dates for each activity and necessary rupee 204 or Mondale fund support.

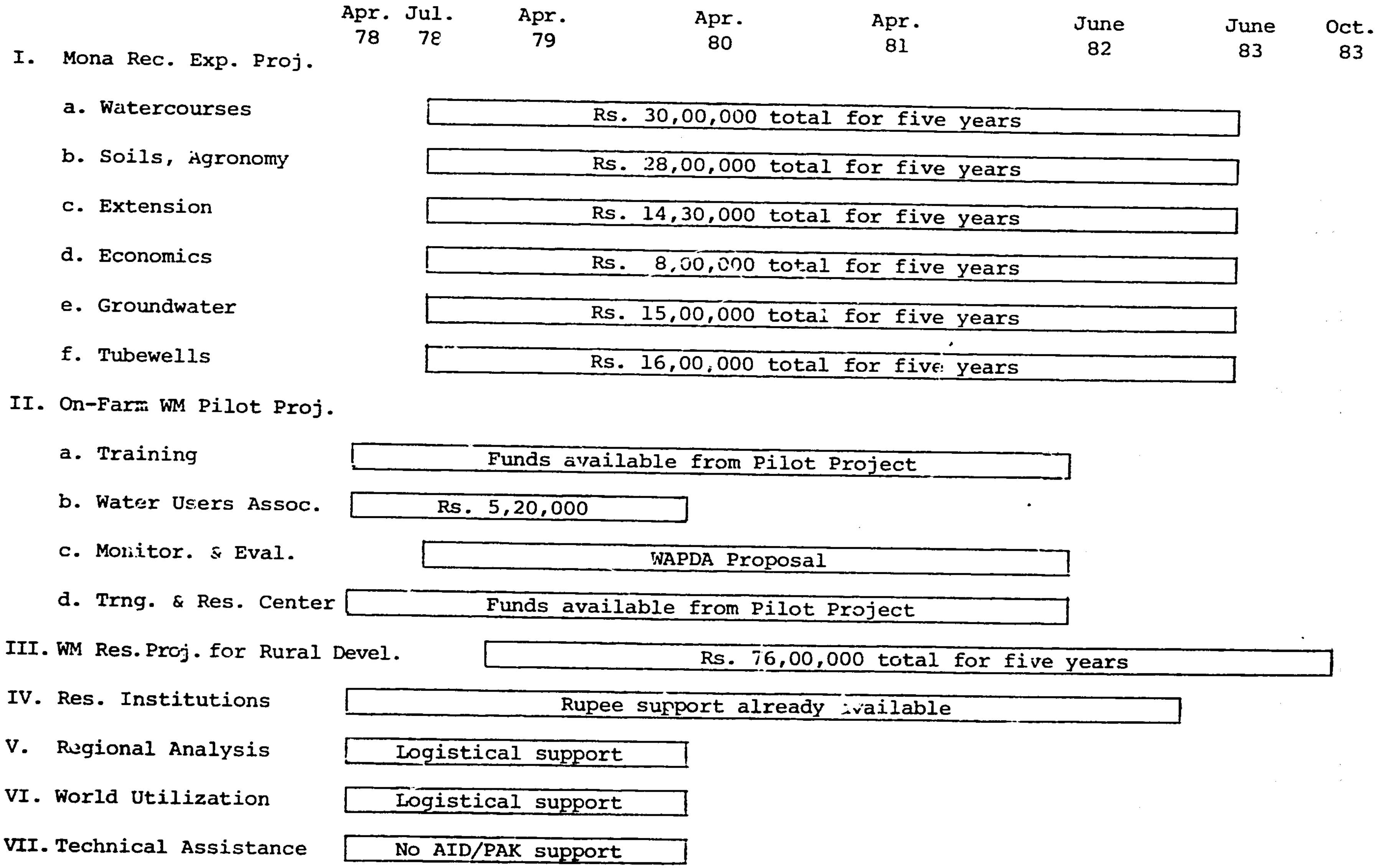

Table 5. Schedule for completion of manuals and reports.

	Apr 78				Apr 79				Apr 80
Transfer Process									
Transfer Process Report	1						2 R	Pu	
Problem Identification Manual		1	2				R	Pu	
Solutions Development Manual			P		1		2 R	Pu	
Implementation Manual			P	1			2 R	Pu	
Technical Manuals									
Water Users Associations			P			1	2 R	Pu	
Watercourse Improvement				P	1		2	R	Pu
Diagnosis and Improvement of Farmer Water Management Problems				P		1	2	R	Pu
Evaluation and Improvement of Basin Irrigation			1		2	R	Pu		
Small Irrigation Structures				P			1	2 R	Pu
Cutthroat Flumes					1	2	R	Pu	
Skimming Wells					P		1	2 R	Pu

P - Completion of planning outline for manual.
1 - Completion of first draft.
2 - Completion of second draft
R - Completion of review draft for AID
Pu - Publication of manual or report.

c. Improved methods for rehabilitating watercourses.

d. Optimizing the farm irrigation application system.

e. Impact of improved technologies on surface and subsurface hydrology and salt balance of watercourse command areas.

f. Farm management plans and farm consultancy service.

g. Organizing and testing Water Users Associations and their federation, and other organizational arrangements, as self sustaining enterprises in the Thikriwala Markaz.

h. Development of effective extension methods for motivating farmers to adopt improved on-farm water management practices.

Hopefully, this research program will be funded in the fall of 1973.

4. Research Institutions

There has been a continuing program of providing cooperative assistance to a number of research institutions in Pakistan. Two of the new activities for this year will be: (a) the development of a water management program for the Province of Baluchistan; and (b) the preparation of a research proposal that would provide rupee funding for the design and installation of lined watercourses (including flow measurement devices and control structures) at four research institutions in Pakistan.

5. Regional Analysis

In order to examine a watercourse command area as a complete system, it is proposed that CSU, with the help of local cooperators, construct a dynamic simulation model that will simulate the flow of water in a watercourse command area of the type commonly found in Pakistan. The simulation model will be developed to analyze the interaction of the many physical and biological variables involved in crop production. The output produced by this model, coupled with economic coefficients of input costs, will be used to determine the optimum economic relationships that will maximize the direct and indirect benefits from the watercourse improvement program. It is planned at this time to develop a linear programming model to determine those optimum economic relationships.

6. Worldwide Utilization

Several manuals will be prepared during the next two years. These will be of high quality print, highly illustrative, written in a general manner (nonsite specific) and in nontechnical language. The purpose of these is to describe the results in language which can be used by donor agencies and planners within LDC governments.

a. Transfer Process

At this time, it is planned that the entire transfer process will be developed in four manuals: (a) Transfer Process; (b) Problem Identification; (c) Development of Solutions; and (d) Implementation. The June 1977 edition of the Transfer Process has been published. During the second year of this contract only a very limited amount of time will be spent on this manual to incorporate the thinking of the staff. Additional improvements will be undertaken during the summer of 1979 (third contract year).

The first complete draft of the Problem Identification Manual is nearing completion. This manual will be used this summer (1978) in the campus training program for the Egyptians. During the summer training program, and immediately afterwards, the manual should be strengthened and the second draft completed by August 1978.

The planning for the Development of Solutions Manual and Implementation Manual, which includes the development of detailed manual outlines, should be undertaken during this summer and completed by August 31, 1978. The first complete draft of the Development of Solutions Manual should be completed by March 31, 1979, and the first draft of the Implementation Manual should be completed by December 31, 1978.

During the third contract year, and more specifically the summer of 1979, all four manuals will be completed in final form for final review by AID. Summer project facilities will be sought that will allow all of the staff to work together in one location in order to interact on a day-to-day basis. A number of staff members have agreed to spend full time during the summer of 1979 on completing these manuals. In addition, a full-time illustrator will be employed for the summer.

b. Preparation of Manuals

Radosevich and Layton will undertake the preparation of a general report for worldwide utilization on Water Users Associations. This report will draw upon the previous work of Radosevich, but instead of citing case studies in various countries, general principles will be developed.

When Tom Trout returns to campus in September he will work with Kemper in developing a Watercourse Improvement (or Watercourse Rehabilitation?) Manual for Pakistan. The first draft of this manual should be completed by March 31, 1979. In addition, Kemper will also take leadership in developing a manual on Diagnosis and Improvement of Farmer Water Management Problems. During the third contract year, these materials will be rewritten for worldwide utilization.

Peri and Skogerboe will be working together in developing a manual on evaluation and improvement of basin irrigation, which will be suitable for worldwide utilization. The first draft of this manual will be completed by September 30, 1978. A manual on Small Irrigation Structures will be undertaken by Aust and Skogerboe, which will be completed during the third contract year. In addition, Skogerboe will prepare an up-dated and more complete manual on Cutthroat Flumes and v-notch weirs, with the first draft being completed by March 31, 1979.

McWhorter is not available this contract year to work on the Skimming Well Manual, but he has agreed to undertake the preparation of this manual during the summer of 1979.

An international seminar consisting of a conference and field demonstration of all on-farm water management activities in Pakistan will be planned. This will be principally reporting of the transfer process, implementation of the On-Farm Water Management Pilot Project in Pakistan and field trip inspection of the research and operation activities. It will be presented for LDC planners, researchers or administrators, who are in a position to influence the direction of similar type programs in their countries. The activity would not exceed 10 days and would not be aimed at a technical audience.

7. International Technical Assistance

Various USAID Missions and LDCs may want to develop on-farm water management projects similar to those progressing in Pakistan. The equivalent of four man-months of contract funds will be used for this purpose.

H. Involvement of Minority Personnel and Women

A project was developed jointly with CSU and USAID to determine the effective role of rural women in deciding priorities in investment, especially for agricultural and water improvement projects. Dr. Sam Johnson previously was in charge of coordinating this project with Mrs. Emily Datta, a graduate student from the University of California, Berkeley, to do the actual field work. This project was funded by USAID/Islamabad with the end result to be a report to USAID describing the role of rural women in decision making and recommending steps to be taken to better reach this segment of the population. The project gathered data in the villages in the Mona and Faisalabad areas. The final report is presently being written.

I. List of Publications

1. Water Management Technical Reports

a. Watercourse Improvement in Pakistan: Pilot Study in Cooperation With Farmers at Tubewell 56L, by CSU Water Management Field Party and Mona Reclamation Project Staff. Water Management Technical Report No. 45. May 1977.

Abstract

Over half the water supplied to the watercourse at Tubewell 56L was lost before it reached the farmers' fields. This loss was primarily through the upper porous portions of the banks and in the vicinity of junctions where banks were thin.

The 35 farmers in the 900-acre area served by this watercourse were motivated to organize themselves to rebuild their own earthen improved watercourse (28,000 feet), according to design specifications drawn up by young Pakistani engineers. Low cost concrete diversion structures were developed and installed at junctions to eliminate continued borrowing of soil and degradation of banks near the junctions. The improvements reduced losses to about one-half their previous values and increased deliveries to the fields by over 50 percent. The cost was about Rs. 2/foot (Rs. 10 = $1.00 U.S.) of watercourse improved, including farmers' labor. These costs included costs of experimentation and training and could be decreased to less than Rs. 1.5 per foot in a developmental program.

The benefits/cost ratio is based on increased deliveries to the field, on the value assumed for water, and on the interest rate assumed for capital. Additional benefits from reductions in seepage damage to crops and reduced labor at junctions are obvious, but more difficult to evaluate. Maintaining the benefits will require the investment of about 10-man hours of labor per acre foot of water saved. This is some of the least expensive water available in countries where rural labor has a low value during some seasons.

This watercourse improvement appears to be an ideal component for a development program designed to increase crop production. However, farmers require further information on how to use this water and other inputs to optimize crop production if they are to obtain full benefits from this extra water.

b. Planning and Implementing Procedures for Contracting Agricultural-Related Research Programs in Low Income Nations, by Max K. Lowdermilk, Wayne Clyma, W. Doral Kemper and Sidney A. Bowers, Water Management Technical Report No. 46. January 1978.

Abstract

Procedures and guidelines are presented for research contractors and international donor agencies in establishing research projects in low income nations. The major assumptions are: 1) an international donor agency and a specified host country have reached a tentative agreement for a research program related to agricultural development; 2) the donor agency will request a contractor with proven capabilities, technical competence, and experience to consider a contract for the project; and 3) the host country project will be in cooperation with the donor agency mission located in the host country (or a nearby country) with at least administrative approval for initiation of the project. The process is conceptualized in three phases: 1) preliminary contract discussion and tentative agreements; 2) preliminary field investigations; and 3) decision to accept contract and subsequent project planning.

Also, procedures and guidelines are described for implementing an agricultural-related research project in a low income nation. The implementation procedures are described under the three phases: 1) selection and organization of administrators and the research team; 2) formal project implementation; and 3) evaluation of program activities.

c. A research-Development Process for Improvement of On-Farm Water Management by Wayne Clyma, Max K. Lowdermilk and Gilbert L. Corey, Water Management Technical Report No. 47. June 1977.

Abstract

A research-development process for rapid improvement of on-farm water management through technology transfer is described. The process focuses on systematic research to identify problems, develop and assess solutions, and implement development programs at the farm level. An interdisciplinary team executes the research-development process with farmers.

The technology transfer process consists of four interrelated phases as follows:

I. Priority Problem Identification
II. Search for Problem Solution
III. Assessment of Solutions
IV. Program Implementation

Problem identification consists of the combination of an interdisciplinary approach with farmer participation to achieve an understanding of system operation. This results in an objective, quantitative definition of priority problems. The interdisciplinary team combines knowledge and experience with systematic research in Phase II to develop direct acceptable

solutions to priority problems. Applied, adaptive, and evaluative research methods are used under farmer conditions in Phase III for the assessment of solutions. These results are used to redefine problems and improve solutions. In Phase IV an institutionalized development program is implemented. Trained personnel use the carefully designed technological package to work directly with farmers to solve farm problems.

2. Field Party Reports

a. Operational Conveyance Losses on Tubewell 81-R Watercourse, by Tom Trout, S. A. Bowers, Mohsin Wahla, Hayat Ullah Khan, Mohd. Yasin and M. Iqbal, Water Management Research Field Report No. 7. July 1977.

b. Fertilizer Water Interaction Experiment on Wheat, by S. A. Qureshi, Noor Mohd. Chaudhry, and J. O. Reuss, Water Management Research Field Report No. 8. June 1977.

c. Watercourse Conveyance Losses in the Mona Reclamation Experimental Project Area, by Tom Trout and Mohammad Munir, Water Management Research Progress Report No. 10. February 1977.

3. Theses

a. Land Leveling and Watercourse Improvements for Pakistan, by Muhammad Siddique Shafique. M.S. thesis. Spring 1977.

Abstract

Despite the intensified efforts and the technological advancement in agriculture over the past three decades, Pakistan is still faced with the challenge to produce enough food to feed her people. The problems posed by this challenge are further compounded by the fact that often there are both economic and trained manpower constraints on irrigated agricultural development.

An intensive irrigation network was built in Pakistan to provide an increased water supply. While the network brought more areas under cultivation and increased crop production, it later created the twin menace of waterlogging and salinity. At this stage a viable, effective, and economical alternative which should be considered is the improved on-farm water management for efficient use of water. Better on-farm water management provides improved delivery and application efficiencies and minimizes the dangers of waterlogging, salinity, and short water supplies.

In this study, the research was conducted on the benefits of land leveling and watercourse improvements. For this purpose the Kanjra watercourse command area, near Lahore, was selected. Necessary surveys were made to collect the required information. About 20 percent of the area was precisely leveled to determine the seasonal impact of land leveling on application efficiencies. The average seasonal application efficiencies were found to range from 81-90 percent on leveled fields to 49-50 percent on unleveled fields. The cost data for precision land leveling was collected from the watercourse command area as well as from the other parts of the country. The average operational cost was Rs. 2.5 per cubic yard. The benefit/cost ratios always exceeded unity against three selected rates of return. For better on-farm water management, economical "katcha" watercourse improvement alternatives were also undertaken. Water measurements were made with Cutthroat flumes to determine the differences in delivery efficiency before and after improvement. The average delivery efficiency of a four branch watercourse system at the before and after stages were 70 and 90 percent, respectively. The benefit/cost analysis, with alternatives consisting of renovation of branches A and D, essential improvement of branch B, and cleaning of branch C, gave highly acceptable ratios. Had the improvement activity stopped at intermediate stage of branches A and B, the cost per unit of water saved would have been more attractive. The average improvement cost per linear foot for the four branch watercourse was a little more than Rs. 0.50.

The role of water user associations for implementation and efficient use of water was discussed. At the end, recommendations were made for a package of land leveling and watercourse improvements for Pakistan.

b. Irrigation Scheduling in Pakistan, by Mushtaq Ahmad Gill. M.S. thesis. Fall 1977.

Abstract

Water, being the "life blood" of both plants and animals is a limiting factor in the agricultural economy of most of the late developing countries. Pakistan is no exception. Where water is plentiful, it is often wasted. This wastage often results in waterlogging. Where there is a limited supply of water, wastage leads to decreased yields and salinity problems. Efficient use of limited irrigation water supplies in Pakistan has become more important since the demand for irrigation water has increased and new sources of supply are becoming harder to develop. To get the most out of each unit of water one must know how much water to apply, when to apply, where to apply and how to apply water to crops. Present on-farm water management practices are the major constraint on food production in Pakistan.

In spite of limited irrigation water supplies, over-irrigation is a common practice in Pakistan due to

unleveled fields and lack of knowledge of plants' water requirements. Tremendous delivery losses have been measured by others in badly managed earthen watercourses. Extensive measurements on farmers' fields indicated substantial field irrigation application losses.

To determine the proper amount and timing of irrigation, different methods of determining crops peak water use were compared. Water use as estimated from pan evaporation was more closely correlated to actual water use under the conditions of the study than were estimates using the empirical equations. Consequently, estimates of water use based on pan evaporation are recommended for use in this area.

The need for an irrigation extension advisory service to provide scientific irrigation scheduling services to Pakistani farmers has been recognized. Accordingly, scientific irrigation schedules were prepared for a maize crop. Recommendations were made regarding reorganizing the existing institutional infrastructure both in public and private sectors to implement on-farm water management in Pakistan with irrigation scheduling as its basic component.

4. Journal Articles

a. Water and Nutrient Response of Semi-Dwarf Wheat Under Improved Management in Pakistan: Agronomic and Economic Implications by J. B. Eckert, N. M. Chaudhry and S. A. Qureshi. Agronomy Journal, Volume 70, pp 77-80, January-February 1978.

Abstract

Chenab-70 cultivar of semi-dwarf wheat (Triticum aestivum L.) was grown under improved management conditions with several levels of N, P and irrigations. An incomplete factorial design included N levels of 0, 56, 112, 168, and 224 kg/ha and 1, 2, 3, 4, 5 and 6 irrigations. Each irrigation consisted of 7.6 cm applied water. Irrigations were optimally sequenced with crop growth stages as indicated by prior research in India and Pakistan. The resulting quadratic production functions indicate that yield levels now obtained by the best farmers can be obtained with one-third to one-half of the water currently being applied if irrigations are timed and controlled appropriately. Fertilizer response also exceeded that obtained by progressive farmers. Economically optimum application rates for water and N were rather restrictive with little opportunity for substitution. Finally, soil moisture measurements coupled with concurrent physiological and morphological observations are used to rationalize the persistence of indigenous cultural practices and to suggest new cultural practices to further enhance irrigation efficiency.

b. Water Problems in the Indus Food Machine, by Sam H. Johnson III, Alan C. Early and Max K. Lowdermilk, Water Resources Bulletin, Volume 13, No. 6. December 1977.

Abstract

Examples are drawn from the Indus Basin to explain why on-farm water management problems restrict the output of agricultural products in many LDC's. Data is presented to illustrate the low level of water management knowledge of both the farmers and the current extension agents. Examples of the level of corruption and its effect on the operating system are illustrated. Several requirements that must be met before a large-scale irrigation scheme will actually increase the welfare of LDC's farmers are presented.

c. Planning Procedures for Research Programs in Low Income Nations, by Wayne Clyma, Max K. Lowdermilk, Sidney A. Bowers and W. Doral Kemper, Journal of the Society of Research Administrators. January 1978.

Abstract

Procedures and guidelines are presented for research contractors and international donor agencies in establishing research projects in low income nations. The major assumptions are: 1) an international donor agency and a specified host country have reached a tentative agreement for a research program related to agricultural development; 2) the donor agency will request a contractor with proven capabilities, technical competence, and experience to consider a contract for the project; and 3) the host country project will be in cooperation with the donor agency mission located in the host country (or a nearby country) with at least administrative approval for initiation of the project. The process is conceptualized in three phases: 1) preliminary contract discussion and tentative agreements; 2) preliminary field investigations; and 3) decision to accept contract and subsequent project planning.

d. Implementing Procedures for Research Programs in Low Income Nations, by Max K. Lowdermilk, Wayne Clyma, W. Doral Kemper and Sidney A. Bowers, Journal of the Society of Research Administrators. April 1978.

Abstract

Procedures and guidelines are described for implementing an agricultural-related research project in a low income nation, which presupposes that a decision has already been made to enter into a contract based upon preliminary contract discussions, some agreement on tentative arrangements, and preliminary field investigations. The implementation procedures are described under the three phases: 1) selection and organization of administrators and the research team; 2) formal project implementation; and 3) evaluation of program activities.

5. Slide Show

a. Pakistan: Land of Promise, by Max K. Lowdermilk, George Bargsten and Richard L. Aust.

APPENDIX 1

FERTILIZER WATER INTERACTION EXPERIMENT ON WHEAT

S. A. Quereshi, Noor Mohd. Chaudhry and J. O. Reuss[1]

INTRODUCTION

Experiments involving fertilizer and irrigation variables on wheat have been conducted at Punjab Agricultural Research Institute (Cereal Section) for several years. Results have shown that maximum or near maximum yields can be obtained with three or at most four irrigations after emergence rather than the five to seven previously thought to be optimum, and that fertilizer responses generally were attained both under conditions of moderate stress and where optimum water was applied. Results of these trials have resulted in reduction of the number of irrigations and increasing rates of phosphorus in the recommendations made to farmers. Such trials need to be continued to provide a larger sample of years and environmental conditions for the testing and refinement of recommendations. One of the next logical steps is to determine both the effect of fertilizer on the plant's need for water and its ability to extract water from the soil. Therefore, the 1975-76 trial was designed to include measurements of the effect of fertilizer on root development and soil moisture extraction as well as on yield.

The objectives of the study were:

1. To determine the effect of nitrogen and phosphorus fertilization on the irrigation requirements of wheat in the Punjab.

2. To determine the effect of nitrogen and phosphorus fertilization on rooting patterns and extraction of soil water by wheat.

3. To develop effective methods of root sampling.

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[1] 1/Director, and Assistant Wheat Botanist, Wheat Research Institute, Lyallpur; and Agronomist, CSU Water Management Research Project respectively.

PROCEDURE

Field Operations

The treatments consisted of three levels each of irrigation, nitrogen and phosphorus. The irrigation treatments I-1, I-2 and I-3 received 1, 3 and 5 irrigations after planting respectively (Table 1). Nitrogen rates were 30, 90 and 150 lbs N/acre and phosphorus rates were 0, 75 and 150 lbs P_2O_5/acre. All fertilizer was applied just before sowing and worked into the soil surface by tillage during final seedbed preparation.

Irrigated main plots were approximately 72 x 45 feet, each of which was split into three nitrogen plots of 72 x 15 feet. Before sowing it was decided to bund each of these N plots separately so that they in fact became separate irrigation plots. Phosphorus treatments were applied across all three nitrogen plots within an irrigation treatment in a direction normal to the nitrogen split. A field plot diagram is shown in the Appendix (Figure A1). The plot arrangement used applies some restriction to the randomization which must be considered in the selection of error terms for the analysis of variance. The degrees of freedom breakdown for the overall analysis of variance used for yield and yield components is also shown in the Appendix (Table A1).

Final subplot size was 15' x 24' and the net area harvested for grain yield was 10' x 11'. Plots were planted in "wattar" condition on November 26. Due to the late planting date Sandal variety was used. Row spacing was 12 inches. Plants emerged on December 2 and were harvested during the April 16-19 period. Irrigation water was applied by siphon tubes. Using a measured head and calibrated siphon tube system, 3 inches of water were applied at each irrigation.

Additional data taken included lodging, tillers/meter, 1000 kernel weight, and grains per head. Lodging data include: date of lodging, percent of plot lodged, and angle of lodging. Angle of lodging was recorded on a scale of 4 where 1 represents approximately 22.5 degrees from vertical, 2 represents approximately 45 degrees, 3 represents 67.5 degrees, and 4 represents 90 degrees from vertical. The product of percent of plot times the scaled angle of lodging divided by 40 gives a convenient scale on which 0 is no lodging and 10 is the complete plot lodged to 90 degrees. The headed tillers per meter were counted at harvest on 1 meter of row randomly selected. The 1000 kernel weight was calculated from a 500 kernel sample of the plot grains counted and weighed, broken grains were excluded. The number of grains per head are the average of 20 heads selected at random.

Table 1. Irrigation treatments and dates of sampling of fertilizer-water interaction experiment at PARI 1975-76.

Treatment	Number of irrigations	Dap[1]	Dates		
			Irrigation	Sampling[2]	
All				26/11	(seeding)
I-1	1	24	20/12	18/12	(P)
				30/12	(A)
				8/2	
				24/3	
				19/4	(AH)
I-2	3	24	20/12	18/12	(P)
				30/12	(A)
		76	10/2	8/2	(P)
				16/2	(A)
		101	6/3	4/3	(P)
				20/3	(A)
				19/4	(AH)
I-3	5	24	20/12	18/12	(P)
				30/12	(A)
		76	10/2	8/2	(P)
				16/2	(A)
		93	26/2	25/2	(P)
				4/3	(A)
		108	13/3	12/3	(P)
				24/3	(A)
		122	28/3	27/3	(P)
				not sampled	(A)
				19/4	(AH)

[1] Dap = Days after planting

[2] (P) = Prior to irrigation, (A) = After irrigation, (AH) = After harvest.

Root Sampling Studies

Root samples were taken at three times during the season: 54 days after planting (January 20), 90 days after planting (February 25) and after harvest (April 19). The first sampling was taken to a depth of nine (9) inches. A block of soil one foot long, 6 inches wide and 9 inches deep centered on the wheat row was excavated from each plot sampled. This block was placed on a screen and gently washed with water until all soil had washed through the screen. The plants with roots attached remained on the screen. The root and plants were then rewashed in clean water, the roots detached from the tops and dried and weighed.

The second and third root samplings were taken with a specially constructed core sampler 3-1/2 inches in diameter. These cores were taken directly over the wheat row and were taken by one foot depth increments to a depth of three feet. Each one foot depth increment of core was placed on a wire web screen and water gently sprayed on the soil until the soil was washed through the screen. The roots were then collected from the screen, rewashed, dried and weighed. Due to the lengthy procedure involved only the following eight treatments were sampled for root weight:

I-1	I-3
30-0	30-0
30-150	30-150
150-0	150-0
150-150	150-150

Two replications were sampled 54 days after planting and three replications at the later sampling dates.

The treatment set for root samplings actually represents a 2^3 factorial. At the first sampling date there are no differences in irrigation treatments so each irrigation treatment is considered a replication. The field plot layout again would technically require a breakdown of error components of the type used in the yield analysis, but after careful examination of the error structure it was decided to use a pooled error term to test all treatment effects.

Soil Moisture Sampling

A schedule of soil moisture sampling was designed to allow evaluation of the soil water stored at each irrigation, the evapotranspiration between irrigations, and water use on the single irrigation treatment after irrigation had been discontinued.

Soil moisture sampling was limited to the same four fertility treatments that were sampled for roots. Sampling depths were 0-6, 6-12, 12-24, 24-36 and 36-48 inches.

Before planting eight cores were taken from each replication. Before and after the first irrigation all irrigation treatments were in fact identical so a set of plots was selected for sampling that included two of each fertility treatment from each replication for a total of 32 plots. After the first irrigation the design called for irrigation treatment I-2 and I-3 to be sampled before and after each irrigation, with I-1 to be sampled at the same time as the before irrigation sampling of I-2. All irrigation treatments would then be sampled at harvest. Rainfall and other operational difficulties caused some deviation in this schedule. Actual sampling dates of each treatment in relation to the irrigation are shown in Table 1.

The statistical analysis of the soil moisture samples required careful consideration. As no irrigation variable had been applied prior to February 2, the pattern of plots selected for the first sampling allowed the use of an analysis appropriate to two plots of each treatment randomly distributed within each replication. Later analyses were generally performed within irrigation treatments as irrigation treatments were sampled at different times. Here again different error components could be used to test certain effects, but a careful evaluation failed to show any particular components consistently higher or lower than others so the final tests of significance were made with the various components pooled within a sampling date and irrigation treatment.

Water Use Calculations

Volumetric soil water percentages were estimated from gravimetric percentages by using the average bulk density of 1.40. During periods of water extraction consumptive use for treatments I-1 and I-2 per day was calculated simply by the loss of soil water during the period, plus rainfall divided by the number of days. The use that occurred between irrigation and the sampling following irrigations was assumed to be equal to pan evaporation for that period, as the soil surface would remain wet. It was necessary to use a slightly different procedure for estimating the use on treatment I-3 after February 26. Due to delays in sampling after irrigation and the resulting very short use periods, plus one missed sampling date, it appeared more precise to assume a field capacity of 12.80 inches per 4 ft. occurring 2 days after irrigation. The amount of water found prior to irrigation was then subtracted from 12.80 to arrive at the consumptive use during the period. The 12.80 inch field capacity was the mean for the December 31 sampling date. Use during the two days immediately after irrigation was taken from pan evaporation.

RESULTS

Root Sampling Studies

The first root samples were taken 54 days after planting and at this time a very pronounced growth response due to phosphorus was apparent. Shoot weight on plots to which phosphorus was applied was two to three times that on the no phosphorus plots (Table 2). This growth response to phosphorus was also noted in the root development at that time. Root weight per foot of row averaged 2.84 grams (g) without phosphorus and 4.09 g where 150 lbs P_2O_5/acre were applied. This effect was significant at the .05 probability level, but on these samples of only 1 foot of row the number of plants was quite variable. When calculated on the basis of g roots per plant the effect of phosphorus was highly significant ($P \leq .01$).[2] Thus, there seems little doubt that root growth at this stage was increased by phosphorus application. Even so this increased root growth was relatively less than the shoot growth response so the shoot/root ratio was increased by phosphorus application.

The effects at the later sampling dates were less clear. The root weight in the 0-12 inch layer was largely affected by crowns and no treatment difference could be discerned at that depth at either the 90 days or the post harvest sampling. The weights of roots in the 12-24 inch depth and 24-36 inch depths were combined since treatment differences that could not be detected in either depth alone appeared significant in the total of the 12-36 inch depth. Nitrogen appeared to decrease the root weight for these combined depths with the 30 lb rate averaging 0.173 g/core, while the 150 lb rate averaged 0.124. At 90 days the I-3 treatment had received two irrigations compared to the one irrigation on the I-1 treatment and this additional irrigation apparently depressed the total root weight from 12-36 inches to 0.121 g/core from 0.176. No effect of phosphorus application on root development could be detected at this stage. At the post harvest sampling no effect of either fertility treatment or irrigation treatment could be detected. The root washing technique appeared to lose some effectiveness later in the season as the more mature roots became more brittle and tended to break up and pass through the screen.

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[2] 2/Probabilities in this paper are expressed in terms of the probability of committing a type I error. The null hypothesis is that the means are equal and $P \leq .01$ means that the probability that this is rejected when the means are in fact equal is less than .01.

Table 2. Effect of fertilizer treatment on wheat roots and shoots measured 54 days after planting.

Fertilizer treatment	Number of[1] plants	Shoot[2] weight(g)	Root[3] weight(g)	Roots per Plant(g)	Shoot/root ratio
30-0-0	20.8	4.02	2.50	.48	1.65
30-150-0	27.5	12.09	4.48	.66	2.76
150-0-0	26.5	4.14	3.18	.50	1.38
150-150-0	20.2	9.44	3.70	.75	2.55
$s\ e_{\bar{y}}$[4]	3.2	1.21	0.44	0.016	0.17
Significance					
N	NS	NS	NS	NS	NS
P	NS	**	*	**	**
NXP	NS	NS	NS	NS	NS

1/Plants per foot of row.
2/Shoot weight per foot of row.
3/Roots per foot of row to 9 inch depth and 3 inches to each side.
4/$s\ e_{\bar{y}}$ is the standard error of the treatment mean.

*$P \leq .05$
**$P \leq .01$
NS Not significant

Table 3. Effect of irrigation and fertility treatments on root development 90 days after planting.

Fertilizer treatment	0-12 inch depth		12-36 inch depth	
	I-1*	I-3*	I-1	I-3
		g root/core		
30-0-0	0.84	0.96	0.17	0.14
30-150-0	1.22	1.07	0.27	0.15
150-0-0	0.81	1.16	0.16	0.07
150-150-0	0.87	1.07	0.15	0.13
s e $_{\bar{y}}$		0.11		0.032
Significant effects		none	N1	0.173**
			N3	0.124
			I-1	0.176**
			I-3	0.121

*At this sampling data one irrigation had been applied to I-1 and 2 irrigations to I-3.
**P ≤ .01

Table 4. Mean roots recovered from irrigation and fertility treatments at post harvest sampling.

Fertilizer treatment	0-12 inch depth		12-36 inch depth	
	I-1	I-3	I-1	I-3
		g/core		
30-0-0	1.01	1.16	.96	.12
30-150-0	1.61	1.22	.16	.10
150-0-0	1.07	1.13	.08	.09
150-150-0	1.10	1.03	.11	.11
s e $_{\bar{y}}$		.17		.021
No significant differences				

Yield Effects

Grain yields in maunds per acre (1 md = 82.29 lbs) are given in Table 5. Yields ranged from 27.1 to 42.1 maunds per acre. Significant treatment effects at .01 or greater probability levels were found due to nitrogen and phosphorus. A nitrogen x phosphorus x irrigation interaction was detected at the 0.95 level. While interpretation of main effects in the presence of significant interaction is subject to limitations, in this case the main effects were relatively large. The average effects of nitrogen and phosphorus were very similar. Average yields of the 90 lb N/acre treatment exceeded those of the 30 lb treatment by 3.98 maunds/acre, while average yields of the 75 lbs/acre P_2O_5 treatment exceeded the 0 P_2O_5 treatment by 4.36 mds/acre. The 150 N treatment averaged slightly less than the 90 N treatment and the 150 P_2O_5 treatment slightly less than the 75 P_2O_5. This depression of yields was due largely to lodging at the higher fertility levels.

The N x P x I interaction is complex. The observed factor which is responsible for the apparent significance of this interaction is the tendency for I-2 to give lower yields than I-3 at the 150 lbs N level, a tendency that does not occur in the other fertility treatments except perhaps the 90 N - 75 P_2O_5 level.

The major factor limiting the yields at high fertility levels was lodging. The mean composite indexes of lodging are given in Table 6. A mean of 0 would indicate no lodging while a score of 10 would mean all plots were 100 percent lodged to a 90° angle. Due to the nature of the index no statistical analysis was performed on these indices but the effect of nitrogen, phosphorus, and irrigation treatments are all obvious. The nitrogen effects are common and probably need no further explanation. Phosphorus effects of this type are unusual. The growth response to phosphorus was evident at a very early stage while nitrogen effects appeared minor until mid-season. The early vegetative response to phosphorus resulted in more severe lodging where phosphorus was applied. Lodging commonly results when rain or wind occurs at a time when the soil is saturated from irrigation. Virtually all lodging, regardless of irrigation treatment, occurred on March 9, when 0.33 inches of rain were recorded. These showers commonly occur in conjunction with winds of greater than normal velocity. Irrigation treatment I-2 was irrigated on March 6, and apparently was much more susceptible to lodging on that date than was treatment I-3 which had not been irrigated since February 26. An additional factor that must be considered is the possibility of the irrigation treatment affecting lodging by means of changing the fertility. The I-3 treatment supplied water in excess of the evapotranspirative demand, a condition conducive to

Table 5. Effect of fertilizer and irrigation treatment on the yield of Sandal wheat.

Fertilizer		I-1	I-2	I-3
lb N/A	lb P_2O_5/A	(1 irrig.)	(3 irrig.)	(5 irrig.)
		md/a	md/a	md/a
30	0	28.4	27.1	30.5
30	75	29.9	33.0	31.6
30	150	32.9	33.4	33.9
90	0	30.2	34.3	32.8
90	75	35.5	36.4	40.7
90	150	36.1	37.4	33.7
150	0	31.6	30.3	34.1
150	75	36.6	32.7	42.1
150	150	32.8	35.2	37.3

Main effect means:

30 N 31.19**	0 P_2O_5 31.03***	I-1 32.7 NS
90 N 35.17	75 P_2O_5 35.39	I-2 33.3
150 N 34.74	150 P_2O_5 34.74	I-3 35.2

Significant interaction:

N x P x I*

*** Probability ≤ .001
** Probability ≤ .01
* Probability ≤ .05

Table 6. Mean composite lodging indices as affected by fertilizer and irrigation treatment.

Fertilizer		I-1	I-2	I-3
lb N/A	lb P_2O_5/A	(1 irrig.)	(3 irrig.)	(5 irrig.)
30	0	0	1.25	0
30	75	.63	1.88	0
30	150	.03	3.65	.03
90	0	0	2.20	0
90	75	.75	5.38	.47
90	150	2.75	8.38	3.56
150	0	0	4. 8	0
150	75	2.83	8.13	1.75
150	150	6.25	10.00	8.13

Table 7. The effect of irrigation and fertility treatment on number of headed tillers per meter of row.

Fertilizer		I-1	I-2	I-3
lb N/A	lb P_2O_5/A	(1 irrig.)	(3 irrig.)	(5 irrig.)
30	0	81.8	79.3	80.0
30	75	91.8	98.8	91.2
30	150	96.0	88.2	92.2
90	0	79.3	83.0	80.0
90	75	95.3	110.3	87.5
90	150	99.8	109.3	116.0
150	0	83.0	80.0	88.3
150	75	93.8	112.3	103.3
150	150	100.8	112.5	107.8

Significant mean effects:

N_1	88.7**	P_1	81.6***	I_1	91.2*
N_2	95.6	P_2	98.1	I_2	97.0
N_3	97.9	P_3	102.5	I_3	94.0

Interactions:

N x I*
P x I*
N x P*

*** Probability ≤ .001
** Probability ≤ .01
* Probability ≤ .05

leaching part of the nitrate nitrogen from the root zone. Thus, it is feasible that nitrogen loss from treatment I-3 lowered the N levels, which decreased lodging in this treatment compared to I-2.

The major effect of phosphorus on yield components was an increase in the number of headed tillers per meter of row (Table 7). Seventy-five lbs P_2O_5/A increased tillers from an average of 81.6 to 98.1/meter. While a significant main effect due to N was noted, this was in fact largely due to NP interaction, as the increase due to phosphorus was more pronounced at the higher N levels. Irrigation also affected the number of headed tillers. The I-1 treatment averaged 91.2 tillers per meter with the I-2 and I-3 averaging 97.0 and 94.0 respectively. The tillers were probably formed prior to any irrigation differences being applied in the field so apparently the irrigation treatments affected the number of tillers that successfully formed heads. Interaction effects with irrigation were also present, with fertility effects on tillering more pronounced on the three and five irrigation treatments than where only one irrigation was applied.

The nitrogen fertilizer increased the average number of grains per head from 35.4 at 30 lbs N/acre to 41.7 and 42.5 at the 90 and 150 lb rates respectively (Table 8). Phosphorus depressed grains per head slightly with main effect mean of 41.1, 40.3 and 38.2 for 0, 75, and 150 lbs P_2O_5/acre ratio respectively. This may have been due to greater competition for sunlight in the high P treatments where there were 20 percent more tillers per unit area.

The effect on kernel weight is shown in Table 9. Nitrogen depressed kernel weight from 44.9 g/1000 kernels at the 0 rate to 43.1 at 75 lbs N/acre, and 41.9 g/1000 kernels at the 150 lbs N rate. This depression was slightly more pronounced in the presence of phosphorus fertilizer.

The general pattern seems to be that the large early response to phosphorus resulted in many more tillers. Increases in headed tillers due to nitrogen at the higher phosphorus levels were probably due to a large percentage of the tillers successfully producing heads as nitrogen effects were much more noticeable in late season. Increases due to irrigation were undoubtedly due to a high percentage of tillers heading as there was no difference in irrigation treatments until after February 8. The later season effect of nitrogen was also manifested in increased grains per head. The effect of increased tillers and kernel numbers at the higher N and P levels was partially cancelled by a depression of grain weight, probably due to lodging. While the increase of headed tillers due to irrigation was clear, the effect of irrigation on the other two parameters tended to be either small or inconsistent due to lodging.

Table 8. Effect of irrigation and fertility treatments on the number of grains per head.

Fertilizer		I-1	I-2	I-3
lb N/A	lb P_2O_5/A	(1 irrig.)	(3 irrig.)	(5 irrig.)
30	0	38.8	33.7	39.6
30	75	37.4	32.7	34.5
30	150	34.8	31.8	35.5
90	0	42.6	44.9	41.1
90	75	41.5	43.1	43.1
90	150	41.0	37.6	40.8
150	0	43.0	44.9	41.8
150	75	45.5	39.2	45.6
150	150	40.6	38.8	42.8

Significant effects:

N_1	35.41***	P_1	41.1**
N_2	41.9	P_2	40.3
N_3	42.5	P_3	38.2

*** Probability ≤ .001

** Probability ≤ .01

Table 9. Effect of irrigation and fertility treatments on the weight of 1000 kernels.

Fertilizer		I-1	I-2	I-3
lb N/A	lb P_2O_5/A	(1 irrig.)	(3 irrig.)	(5 irrig.)
			g/1000 kernels	
30	0	45.3	44.5	43.6
30	75	45.4	45.3	44.4
30	150	45.5	44.8	44.9
90	0	43.9	42.3	42.7
90	75	44.5	43.2	43.7
90	150	44.0	42.1	42.1
150	0	42.7	42.0	43.2
150	75	42.5	41.2	42.6
150	150	41.0	41.0	40.5

Significant main effects:

N_1	44.9***	I-1	43.8*
N_2	43.1	I-2	42.9
N_3	41.9	I-3	43.1

Significant interactions:

N x P**

***Probability $\leq$ .001
**Probability $\leq$ .01
*Probability $\leq$ .05

WATER USE MEASUREMENTS

Due to the large amount of work involved, water use measurements were made on only four of the nine fertility treatments, i.e. N_1P_1, N_1P_3, N_3P_1, and N_3P_3. Detailed water use tables by irrigation and fertility treatment are shown in the Appendix. Prior to February 8, all irrigation treatments were identical and fertility effects on water use were nonexistent or at least minor, so at the early sampling dates all fertility and irrigation treatments were combined.

A summary of consumptive use and water supplied is shown in Table 10. Total water utilized from seeding to harvest ranged from 8.80 to 10.31 inches for I-1, depending on fertility. The increased water use at high fertility levels was generally significant and a more detailed discussion of the precision involved is given in the next section. The I-1 results are important. Yields in excess of 30 mds/acre were obtained with only one irrigation after planting and a total water use of 9-10 inches, including 2.34 inches of rainfall. A most important point is that the fertilized plots were able to extract about 1.4 inches more water from this soil than were the unfertilized plots. Some of the I-1 plots that were not sampled yielded in excess of 35 maunds per acre and fertilizer responses were evident even under this stress situation (Table 5).

Total water used by the crop on the I-2 treatments ranged from 11.23 inches up to 12.26 inches from seeding to harvest, with the high use values again found on the high fertility plots. The two additional irrigations furnished about 6 inches more water than was applied to I-1, some of which remained in the profile. The total supply is the amount of irrigation plus rainfall, plus the change in soil water between seeding and harvest. If the total supply exceeds the sum of the calculated use, the assumption is that the difference represents leaching through the profile. This loss averaged 2.02 inches on treatment I-2.

The total evapotranspiration for treatment I-3 ranged from 12.84 to 16.11 inches with the highest use again measured at the highest fertility level. Averaged over fertility levels the use was 14.66 inches or 5.27 inches greater than the average for I-1 and 3.15 inches more than I-2. The estimated leaching on this treatment averages 3.93 inches. While some water normally should pass through the profile for salinity control, this amount is in excess of normal leaving requirements and will probably result in excessive loss of nutrients.

A plot of bi-weekly mean evapotranspiration values upon which consumptive use values for the various irrigation

Table 10. Summary of total water used and applied by irrigation and fertility treatments.

		Consumptive use	Total supplied*	Estimated leaching
I-1	N_1P_1	8.95	8.95	0
	N_1P_3	8.80	8.80	0
	N_3P_1	9.49	9.49	0
	N_3P_3	10.31	10.31	0
I-2	N_1P_1	11.23	13.41	2.18
	N_1P_3	10.31	12.81	2.50
	N_3P_1	12.23	14.04	1.81
	N_3P_3	12.26	13.83	1.57
I-3	N_1P_1	12.84	17.76	4.92
	N_1P_3	13.84	17.95	4.11
	N_3P_1	15.84	19.12	3.28
	N_3P_3	16.11	19.50	3.39

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*Total supply = applied + rain + change in soil water.

treatments have been superimposed as shown in Figure 1. Some care should be taken in interpreting these figures as the length of time included in the various consumptive use points may vary. The data do show, however, that by mid-January the ET is very close to the pan evaporation and in the I-3 treatment, the ET values remain very close to the pan evaporation except for the April period when maturation was in progress. The ET on the I-1 treatment dropped well below pan evaporation in late season with the I-2 intermediate. It appears that the actual use by the well watered crop may be closely approximated by pan evaporation after full cover has been established.

The pattern of extraction by depth is also of interest. The amount of water utilized between the final irrigation and harvest is shown by irrigation and nitrogen treatments in Figure 2. As more irrigations were applied, the final irrigations were applied later, so the water used between final irrigation and harvest became less. Where only one irrigation was applied the surface one foot became quite dry by harvest regardless of fertility level. However, extraction from the second and third foot layers was definitely increased by nitrogen fertilization. On the I-2 and I-3 treatments the increased use by the high N treatments was apparently drawn from the first, second, and third foot layers. The use from the fourth foot was small and no increase in use from this layer due to fertility effects could be detected. These data are also shown in more detail in Table A6 in the Appendix.

The tendency for increased extraction of water during the late season by the high nitrogen treatments appears to be somewhat inconsistent with the root data. As mentioned above, nitrogen appeared to depress root development in the one to three foot depth layer as measured 90 days after harvest. We might, therefore, expect nitrogen to depress water use during mid or late season. In fact the opposite occurred. Nitrogen consistently increased late season water extraction between one and three feet. The reasons for this apparent inconsistency are not known. Perhaps the effect of N on root development was in fact only a random error, or the nitrogen may have tended to keep those roots present more active in late season.

PRECISION OF MEASUREMENT

The question of the precision of the measurements of soil and water and the separation of treatment effects from random variation is complex and by no means trivial. Complexities arise as a result of combining of depth measurement and the fact that different treatments are sampled at different times. The problem can be approached in several

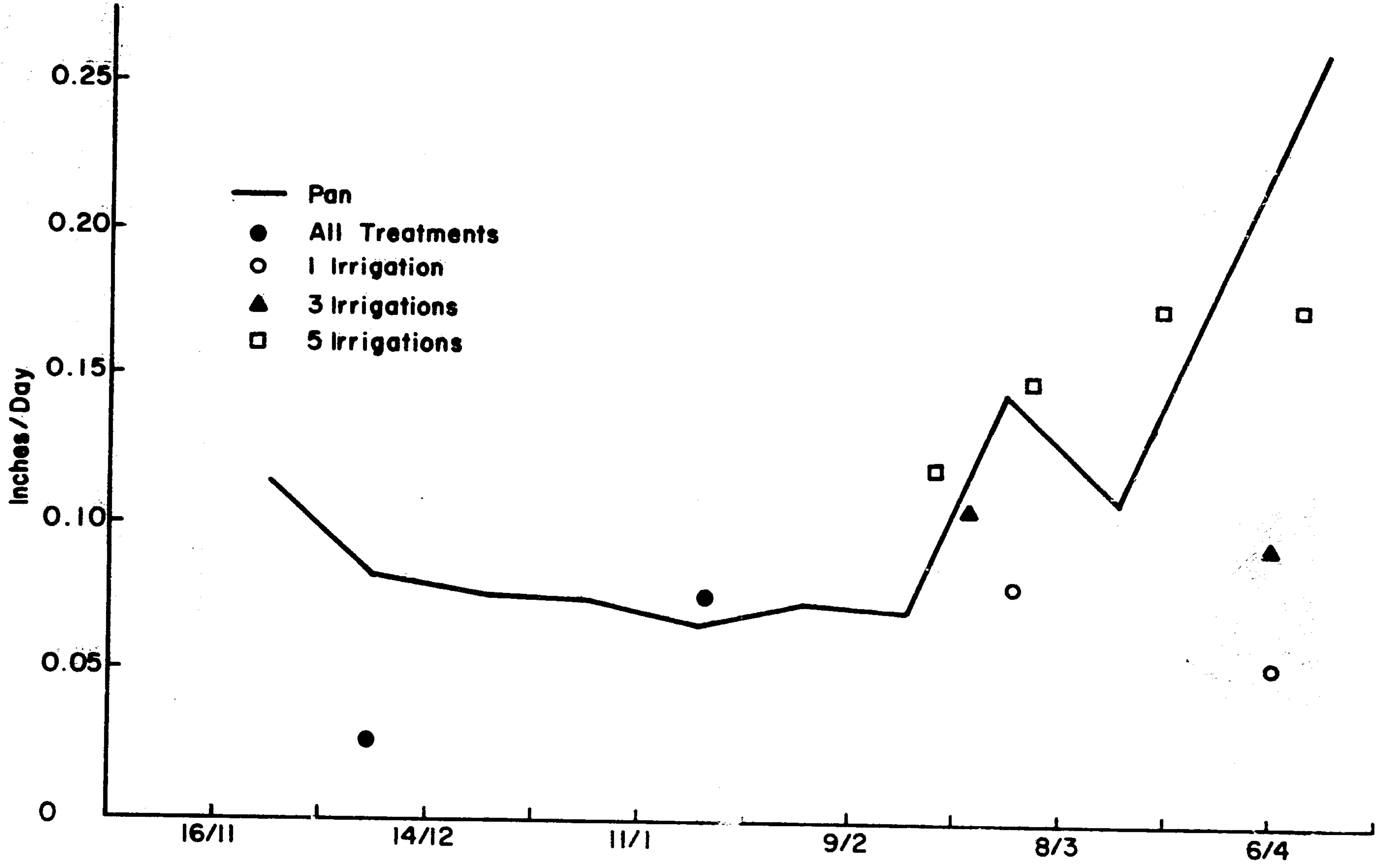

Figure 1. Comparison of soil water use by the various irrigation treatments with bi-weekly mean pan evaporation values.

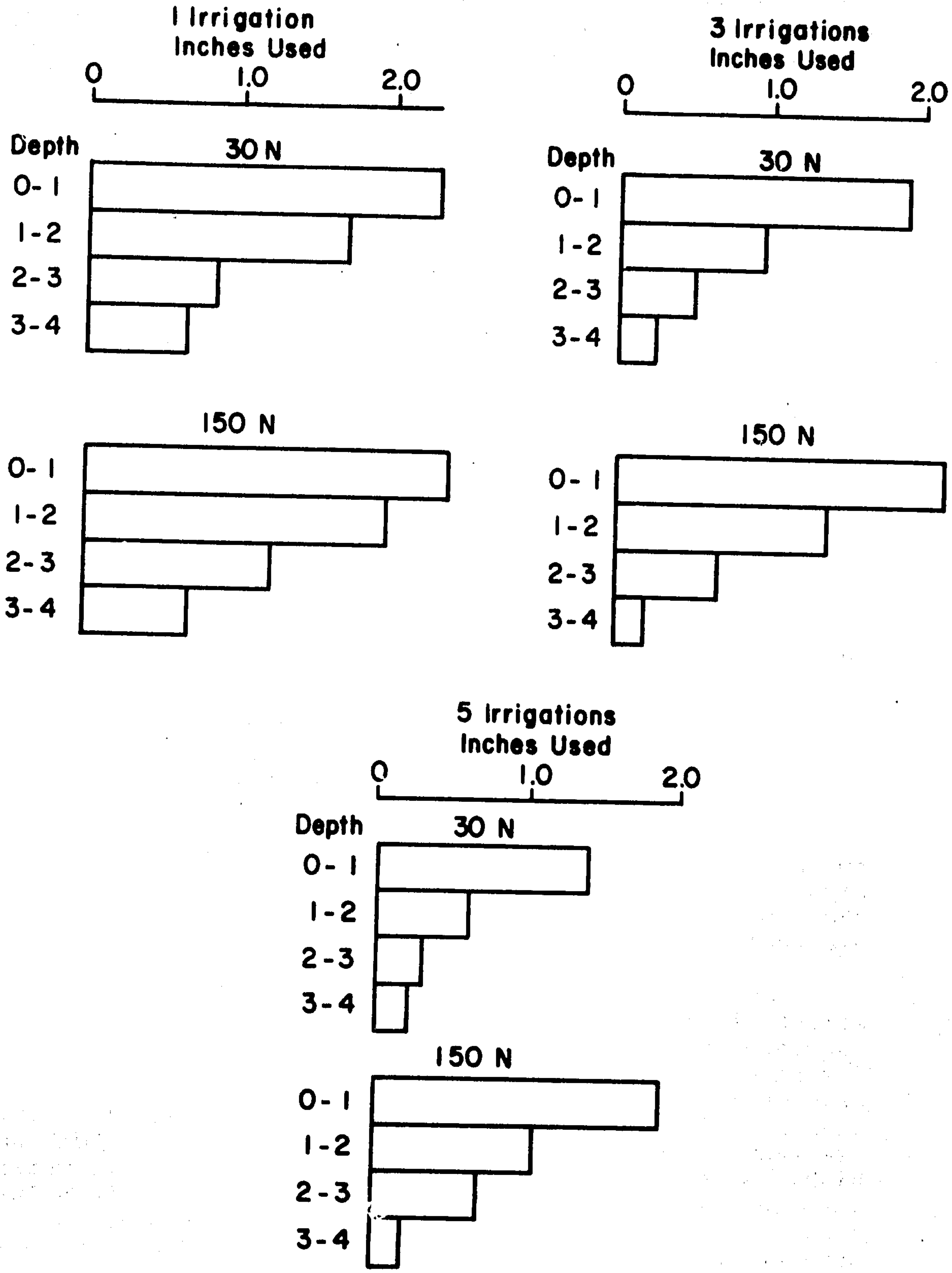

Figure 2. Amount of water extracted from the different soil depths by the 30 and 150 lb N/acre treatments between the final irrigation and harvest.

different ways depending on the initial assumptions. First we may assume that after irrigation all fertility treatments within an irrigation treatment have reached field capacity, or at least that the soil moisture levels after irrigation are not different under the various fertility treatments. If this assumption is valid then any differences in soil water detected prior to the next irrigation must be due to treatment differences in water use. This assumption allows us to evaluate treatment differences from a single moisture sampling.

A second approach is to test the treatment effect of the difference between two samplings. Whether or not this is a more precise procedure depends on the conditions. If there is no intercorrelation between the two samplings the variance of the difference between two samplings will be equal to the sum of the variance of the two individual samplings and the precision of measurement of the difference will be less than the precision of the single sampling. However, the variance of the difference will be reduced by positive intercorrelation, i.e., if there is a tendency for plots that were wetter than average at the initial sampling to also be wetter at the final sampling.

In order to evaluate the effect of different assumptions the two mean square summaries shown in Tables 11 and 12 were prepared. Table 11 shows the mean squares for each of the individual samplings performed.

First, note in Table 12 that the error mean square at seeding was 0.796, much larger than found for any of the other samplings. The reasons for this large error are not known for certain, but may be related to the fact that the soaking dose irrigation was applied before the area was divided into plots and the resulting irrigation may have been nonuniform due to field elevation differences. The error mean squares for the after harvest samples also tend to be higher than for most of the other sampling dates for reasons that are unclear.

Some care must be taken in interpreting significant effects from these tables as the mean squares in Table 11 represent some 60 separate F tests and the probability of a few random effects showing up as significant is quite large, especially at the .05 probability level. Note, however, that treatment I-1 on March 23 had highly significant ($P \leq .01$) treatment effects and that treatments I-1 and I-3 both showed highly significant treatment effects after harvest, while I-2 was significant at the .05 level at this time. The values shown for the tree irrigation treatments represent independent samples at that time and all three effects were in the same direction, i.e. increased use of water at the high N level. With three independent measurements, two of which are significant at the .01, and one at the .05 level,

Table 11. Mean square summary for changes in soil water (inches to 4 ft) found in individual plots by a single core sample taken at the start and end of the period.

Period	Irrigation treatment	Average sources of variations and degrees of freedom ( )							
		Change in.	Reps (3 df)	Fertilizer (3 df)	N (1 df)	P (1 df)	NXP (1 df)	Error	
18/12-24/12	All	+2.34	.967	.162	.002	.480	.003	.120	(25)
30/12-8/2	All	-2.65	.485	.291	.296	.098	.480*	.091	(21)
8/2-24/3	I-1	-2.09	.349	.242	.605	.121	.000	.150	(9)
8/2-19/4	I-1	-3.16	1.394	.832	3.891*	.104	.187	.338	(9)
8/2-16/2	I-3	+1.72	.522	.267	.720*	.007	.075	.153	(9)
16/2-4/3	I-2	-1.88	.247	.418	1.067*	.104	.082	.196	(21)
4/3-20/3	I-2	+1.18	.167	.283	.487	.006	.357	.113	(9)
20/3-19/4	I-2	-2.44	.090	1.486*	3.320**	1.044*	.093	.161	(9)
16/2-25/2	I-3	-1.00	.153	.067	.179	.014	.010	.061	(9)
25/2-4/3	I-3	+ .65	.768	.022	.034	.023	.010	.208	(9)
4/3-12/3	I-3	- .33	.071	.359	.898	.029	.150	.190	(9)
12/3-24/3	I-3	+ .63	.068	.141	.002	.245	.178	.215	(9)
24/3-27/3	I-3	- .42	.271	.394	.011	.593	.577	.345	(9)

**P ≤ .01
*P ≤ .05

Table 12. Mean square summary for total profile water (inches/4 ft) found in individual plots by a single core sampling. All error components are pooled.

Date sampled		Irrigation treatment	Source of variations and degrees of freedom ( )							
			Mean	Reps	Fertilizer	N	P	NXP	Error	
			in.	(3 df)	(3 df)	(1 df)	(1 df)	(1 df)		
26/11	(B)[1]	All	11.05						.796	(15)
8/12	(P)[2]	All	10.45	.440	.002	.003	.000	.046	.113	(25)
30/12	(A)[3]	All	12.79	.175	.192	.010	.496*	.071	.072	(25)
8/2	(P)	All	10.12	.098	.204	.028	.359*	.225	.085	(30)
16/2	(A)	I-2 I-3	11.93	.711	.295	.474	.174	.236	.139	(21)
25/2	(P)	I-3	10.87	.238	.026	.018	.045	.016	.147	(9)
4/3	(P)	I-2	10.12	1.021	.664*	.126	.027	.511	.133	(9)
4/3	(A)	I-3	11.52	1.370	.023	.003	.004	.064	.228	(9)
12/3	(P)	I-3	11.19	.822	.315	.810*	.126	.009	.121	(9)
20/3	(A)	I-2	11.30	.246	.065	.100	.075	.019	.098	(9)
24/3	(B)	I-1	8.01	.400	1.012**	1.375**	.985*	.674*	.079	(9)
24/3	(A)	I-3	11.82	.775	.562*	.885*	.723*	.079	.084	(9)
27/3	(B)	I-3	11.40	1.579	.453	.558	.006	.794*	.124	(9)
19/4	(AH)[4]	I-1	7.02	2.666	1.871**	4.213**	.446	.954	.263	(9)
19/4	(AH)	I-2	8.87	.314	1.195*	2.716*	.653	.155	.298	(9)
19/4	(AH)	I-3	9.74	.427	2.954**	8.497**	.325	.040	.330	(9)

1/ (B) Between irrigations
2/ (P) Prior to irrigation
3/ (A) After irrigation
4/ (AH) After harvest
*P ≤ .05
**P ≤ .01

all showing increased water use by the nitrogen treated plots, we can be sure the effect of fertility is real and not a random error effect.

The pattern shown by the changes between samplings is similar, but significance levels are less obvious. This arises for two reasons. The pooled error mean square for the difference between two samplings is 0.1682 as compared to 0.1362 for the single sampling. There is apparently some intercorrelation as otherwise we would expect the error term of the difference to be about twice that of the single sampling. This tells us that there is a tendency for low moisture plots at the start of the period to be associated with low moisture plots at the end. Even so, this increased mean square resulting from the difference measurement decreases the sensitivity so that we detect less of the actual treatment differences. In addition, due to one missed sampling on the I-3 treatment, one of the periods for which we would expect significant differences could not be calculated and included in Table 12.

Another important point concerning Table 12 is that many of the changes measured, particularly in treatment I-3, were small, often less than 1.00 inches. Typically, we would have four observations of each fertility treatment within an irrigation treatment, or eight observations for each N and P level. We can calculate the differences we could expect to detect at the .05 probability level.

For the paired change or the single measurement by the formula:

$$\text{difference} = t_{.05} \left(\frac{\text{Mean Square}}{n}\right)^{\frac{1}{2}}$$

Thus, for any number of observations n we can calculate the difference we should have to encounter before we would expect statistical significance by using the pooled error variances given above. These have been calculated for various numbers of samples and a plot of expected precision as a function of number of samples is shown in Figure 3. For eight observations within a fertility level we would require a difference of about 0.27 inches between treatments. If the total use between the two samples was one inch, we could only expect to detect a fertility effect that was 27 percent of the total use, while if the use was 2.0 inches we could detect perhaps 13 percent difference. If design allows 20 observations of any effect we may expect to detect differences of the order of ± 0.16 inches. These values must be considered a minimum as they would require a relatively large number of degrees of freedom. Also, our previous experience indicates that most gravimetric sampling data sets have a higher error variance than encountered here.

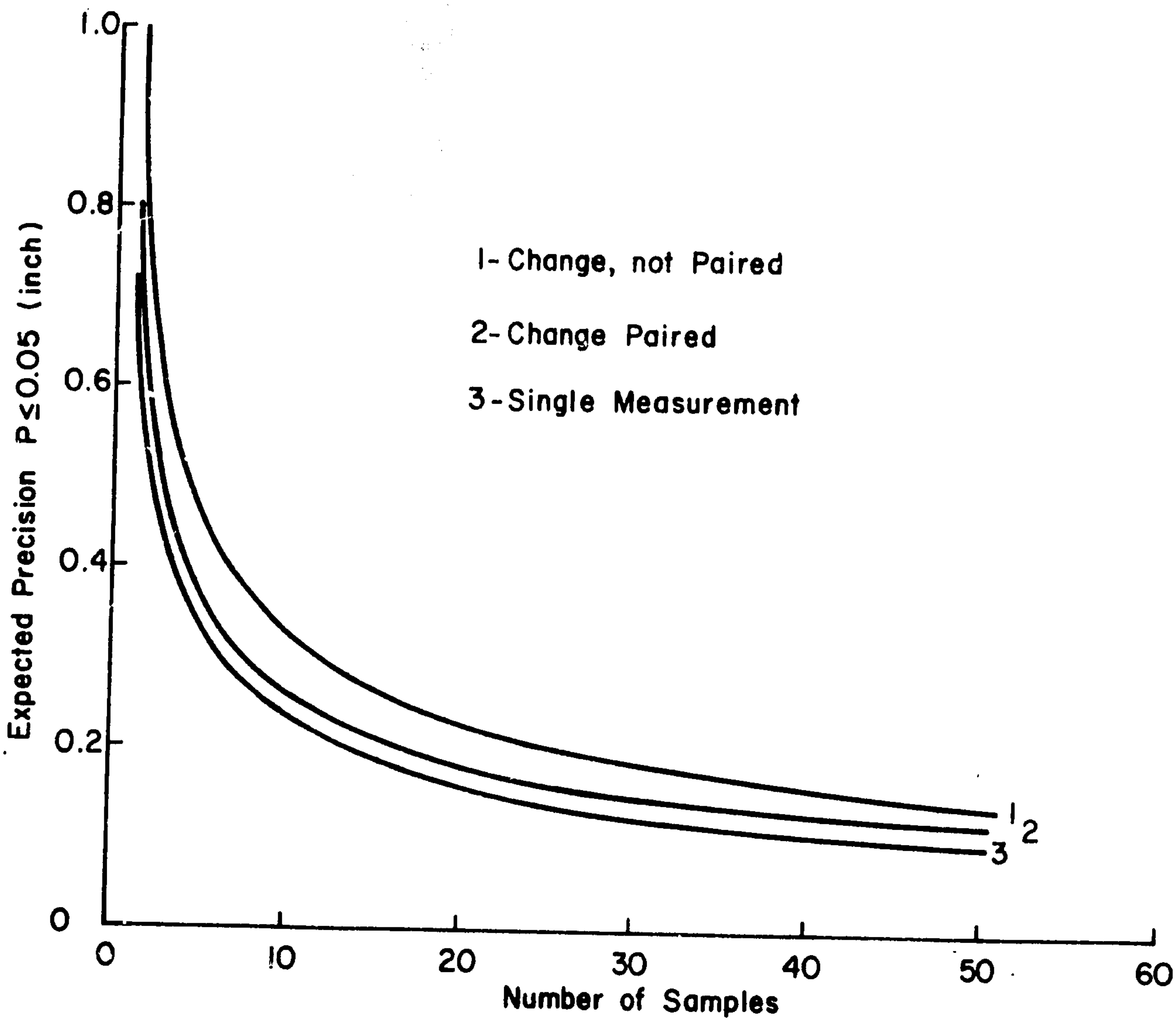

Figure 3. Expected precision at the .05 porbability level in inches of water to a 4 ft. depth as a function of number of samples for a single measurement and for the change in soil water between measurements using paired or unapired sampling.

SUMMARY AND CONCLUSIONS

An experiment was conducted at PARI near Lyallpur during the 1975-76 rabi season in which the effect of nitrogen, phosphorus and irrigation treatments on root development, yield components, and water use by the Sandal variety of wheat was investigated. Early season root and shoot development were both increased by phosphorus fertilizer. Mid season root development between the 1 and 3 foot depths was depressed by high levels of N and increased irrigation.

Yields of more than 35 maunds per acre or more were attained by some fertility treatments with only one irrigation after planting, applied on December 20, plus 2.34 inches of rainfall. Maximum yield was obtained using 5 irrigations but the advantage over 3 irrigations was generally small and would probably be nil except for the effect of increased lodging with 3 irrigations caused by adverse weather at the time the final irrigation was applied to the three irrigation treatment.

Yield responses to both N and P fertilization were obtained at all irrigation levels. Water use, particularly in the 1 to 3 foot depth region, was increased by nitrogen fertilizer, an effect that appeared inconsistent with the rooting data. This was largely a late season phenomenon and was found at all irrigation levels. This increased use totaled about 1.5 inches for the season. The increased use of water by the fertilizer treatments, however, does not support the contention that fertilizer should not be applied unless extra water is available, as yield responses were obtained from fertilizer even with only 1 irrigation.

Another important aspect was the fact that acceptable yields could be obtained with a total use of only 9-10 inches of water used between seeding and harvest, including stored soil moisture, rainfall, and irrigations applied well below the amount often considered necessary for wheat production. Well watered wheat used 13 to 16 inches depending on fertility treatment, and amount consistent with open pan evaporation of 16.8 inches during the growing season.

Table A1. Analysis of variance used for yield and yield components.

Source	Degree of freedom
Total	109
Reps	3
Irrigation	2
Erros A (R x I)	6
Nitrogen	2
N x I	4
Error B (N x R plus N x I x R)	18
Phosphorus	2
P x I	4
Error C	18
N x P	4
N x P x I	8
Error D (N x P x R plus N x P x I x R)	30

Table A2. Water use summary for irrigation treatment I-1 (one irrigation).

Period	Fertilizer treatment	Days	Soil water			Rain	Total use	ET	Accumulated use	Pan evaporation
			Initial in.	Final in.	Change in.	in.	in.	in/day	in.	in/day
26/11-18/12	All	22	11.05	10.45	-0.60	0.0	0.60	.027	.60	.0838
19/12-30/12	All	12	10.45	12.50	+2.45	0.08	0.75 (est.)	.063	1.35	.0700
31/12-8/2	N_1P_1	40	12.80	10.25	-2.55	0.40	2.95	.074	4.30	.0694
	N_1P_3	40	12.80	10.21	-2.59	0.40	2.99	.075	4.34	
	N_3P_1	40	12.80	10.34	-2.46	0.40	2.86	.072	4.21	
	N_3P_3	40	12.80	10.03	-2.77	0.40	3.17	.079	4.50	
9/2-24/3	N_1P_1	45	10.25	8.35	-1.90	1.44	3.34	.074	7.64	.1181
	N_1P_3	45	10.21	8.26	-1.95	1.44	3.39	.075	7.73	
	N_3P_1	45	10.34	8.14	-2.20	1.44	3.64	.081	7.85	
	N_3P_3	45	10.03	7.27	-2.76	1.44	4.20	.093	8.72	
25/3-19/4	N_1P_1	26	8.35	7.46	-0.89	0.42	1.31	.050	8.95	.2340
	N_1P_3	26	8.26	7.61	-0.65	0.42	1.07	.041	8.80	
	N_3P_1	26	8.14	6.92	-1.22	0.42	1.64	.063	9.49	
	N_3P_3	26	7.27	6.10	-1.17	0.42	1.59	.061	10.31	
								Total Pan Evaporation		16.85

Table A3. Water use summary for irrigation treatment I-2 (three irrigations).

Period	Fertilizer treatment	Days	Soil water Initial	Soil water Final	Soil water Change	Rain	Total use	ET	Accumulated use	Pan evaporation
			in.	in.	in.	in.	in.	in/day	in.	in/day
26/11-18/12	All	22	11.05	10.44	-0.60	0.0	0.60	.027	0.60	.0838
19/12-30/12	All	12	10.45	12.80	+2.45	0.08	0.75*	.063*	1.35	.0700
31/12-8/2	N_1P_1	40	12.80	10.25	-2.55	0.40	2.95	.074	4.30	.0694
	N_1P_3	40	12.80	10.21	-2.59	0.40	2.86	.072	4.21	
	N_3P_1	40	12.80	10.34	-2.46	0.40	2.86	.072	4.21	
	N_3P_3	40	12.80	10.03	-2.77	0.40	3.17	.079	4.52	
9/2-16/2	N_1P_1	8	10.25	11.80	+1.55	0.02	0.60*	.075*	4.90	.0743
	N_1P_3	8	10.21	11.82	+1.51	0.03	0.60*	.075*	4.91	
	N_3P_1	8	10.34	12.21	+1.87	0.02	0.60*	.075*	4.81	
	N_3P_3	8	10.03	11.90	+1.87	0.02	0.60*	.075*	5.12	
17/2-4/3	N_1P_1	17	11.80	10.07	-1.73	0.0	1.73	.102	6.63	.1214
	N_1P_3	17	11.82	10.35	-1.47	0.0	1.47	.086	6.61	
	N_3P_1	17	12.21	10.25	-1.96	0.0	1.96	.115	6.77	
	N_3P_3	17	11.90	9.81	-2.09	0.0	2.09	.123	7.21	
5/3-20/3	N_1P_1	16	10.07	11.25	+1.18	1.42	1.91*	.120*	8.54	.1216
	N_1P_3	16	10.35	11.18	+0.83	1.42	1.91*	.120*	8.32	
	N_3P_1	16	10.25	11.48	+1.23	1.42	1.91*	.120*	8.68	
	N_3P_3	16	9.81	11.28	+1.47	1.42	1.91*	.120*	9.12	
21/3-19/4	N_1P_1	30	11.25	8.98	-2.27	0.42	2.69	.090	11.23	.2265
	N_1P_3	30	11.18	9.58	-1.60	0.42	2.02	.067	10.34	
	N_3P_1	30	11.48	8.35	-3.13	0.42	3.55	.118	12.23	
	N_3P_3	30	11.28	8.56	-2.72	0.42	3.14	.105	12.26	
									Total Pan Evaporation	16.85

*Estimated

Table A4. Mean soil water values for treatment I-3 (five irrigations). Prior to 17/2 treatment I-3 was identical to I-2 as shown in Table A3.

Period	Fertilizer treatment	Days	Soil water			
			Initial in.	Final in.	Changes in.	Rain in.
17/2-25/2	N_1P_1	9	11.80	10.92	-0.88	0
	N_1P_3		11.82	10.89	-0.93	
	N_3P_1		12.21	10.93	-1.28	
	N_3P_3		11.90	10.75	-1.15	
25/2-4/3	N_1P_1	8	10.92	11.46	+0.54	0
	N_1P_3		10.89	11.55	+0.66	
	N_3P_1		10.93	11.61	+0.68	
	N_3P_3		10.75	11.45	+0.70	
5/3-12/3	N_1P_1	8	11.46	11.53	+0.07	.33
	N_1P_3		11.55	11.29	-0.26	
	N_3P_1		11.61	11.02	-0.59	
	N_3P_3		11.45	10.91	-0.54	
13/3-24/3	N_1P_1	12	11.53	12.20	+0.67	1.09
	N_1P_3		11.29	12.20	+0.63	
	N_3P_1		11.02	11.87	+0.85	
	N_3P_3		10.91	11.30	+0.39	
25/3-27/3	N_1P_1	3	12.20	11.83	-0.37	0
	N_1P_3		11.92	11.35	-0.57	
	N_3P_1		11.87	11.01	-0.86	
	N_3P_3		11.30	11.41	+0.11	
28/3-29/3	N_1P_1	2	11.83	Not sampled		0
	N_1P_3		11.35			
	N_3P_1		11.01			
	N_3P_3		11.41			
30/3-19/4	N_1P_1	2	N.S.	10.63		.42
	N_1P_3			10.44		
	N_3P_1			9.27		
	N_3P_3			8.89		

Table A5. Water use by treatment I-3 (five irrigations) after 17 February 1976.*

Period	Fertilizer treatment	Days	Total use**	ET	Accumulated use	Pan evaporation
			in.	in/day	in.	in/day
17/2-25/2	N_1P_1	9	.88	.098	5.78	.0754
	N_1P_3		.93	1.04	5.87	
	N_3P_1		1.28	1.42	6.09	
	N_3P_3		1.15	.128	6.27	
26/3-28/2	All	3	.43***	.144***		.1570
28/2-12/3	N_1P_1	13	1.60	.123	7.81	.1686
	N_1P_3		1.84	.141	8.14	
	N_3P_1		2.11	.162	8.63	
	N_3P_3		2.22	.171	8.92	
13/3-15/3	All	3	.17***	.058***		.0577
16/3-27/3	N_1P_1	12	1.68	.140	9.66	.1395
	N_1P_3		2.16	.180	10.47	
	N_3P_1		2.50	.208	11.30	
	N_3P_3		2.10	.175	11.19	
28/3-30/3	All	3	.59***	.197***		.2080
31/3-19/4	N_1P_1	20	2.59	.148	12.84	.2497
	N_1P_3		2.78	.139	13.84	
	N_3P_1		3.95	.198	15.84	
	N_3P_3		4.33	.217	16.11	

Total pan evaporation 16.85 in.

*Prior to 17-2 - the I-2 and I-3 treatments were identical and results are shown in Table A3 above.

**After 25/2 the use between irrigation was calculated by assuming a field capacity moisture of 12.80 in 2 days after irrigation. Total use is the difference between this value and the soil water found prior to irrigation plus rainfall.

***Estimated.

Table A6. Inches of water utilized from the four depth layers between final irrigation and harvest.

Irrigation treatment	Depth	N_1P_1	N_1P_3	N_3P_1	N_3P_3	Average	Significant effects		(Totals)
							N	P	N x P
	ft.	in.	in.	in.	in.				
I-1	0 - 1	2.14	2.38	2.35	2.39	2.31			
Final	1 - 2	1.55	1.58	1.84	2.11	1.77			
Irrigation	2 - 3	.82	.81	1.10	1.39	1.03			
20/12/76	3 - 4	.79	.50	.58	.80	.67			
	Total	5.30	5.27	5.87	6.69	5.78	**	*	*
I-2	0 - 1	1.95	1.81	2.06	2.24	2.02			
Final	1 - 2	.97	.88	1.50	1.26	1.15			
Irrigation	2 - 3	.56	.38	.59	.57	.53			
6/3/77	3 - 4	.32	.13	.28	.15	.22			
	Total	3.80	3.20	4.43	4.22	3.92	*		
I-3	0 - 1	1.31	1.45	1.79	2.05	1.65			
Final	1 - 2	.60	.50	.97	1.06	.78			
Irrigation	2 - 3	.31	.29	.59	.66	.46			
28/3/77	3 - 4	.19	.12	.16	.13	.15			
	Total	2.41	2.36	3.51	3.90	3.01	**		

** $P \leq .99$
* $P \leq .95$

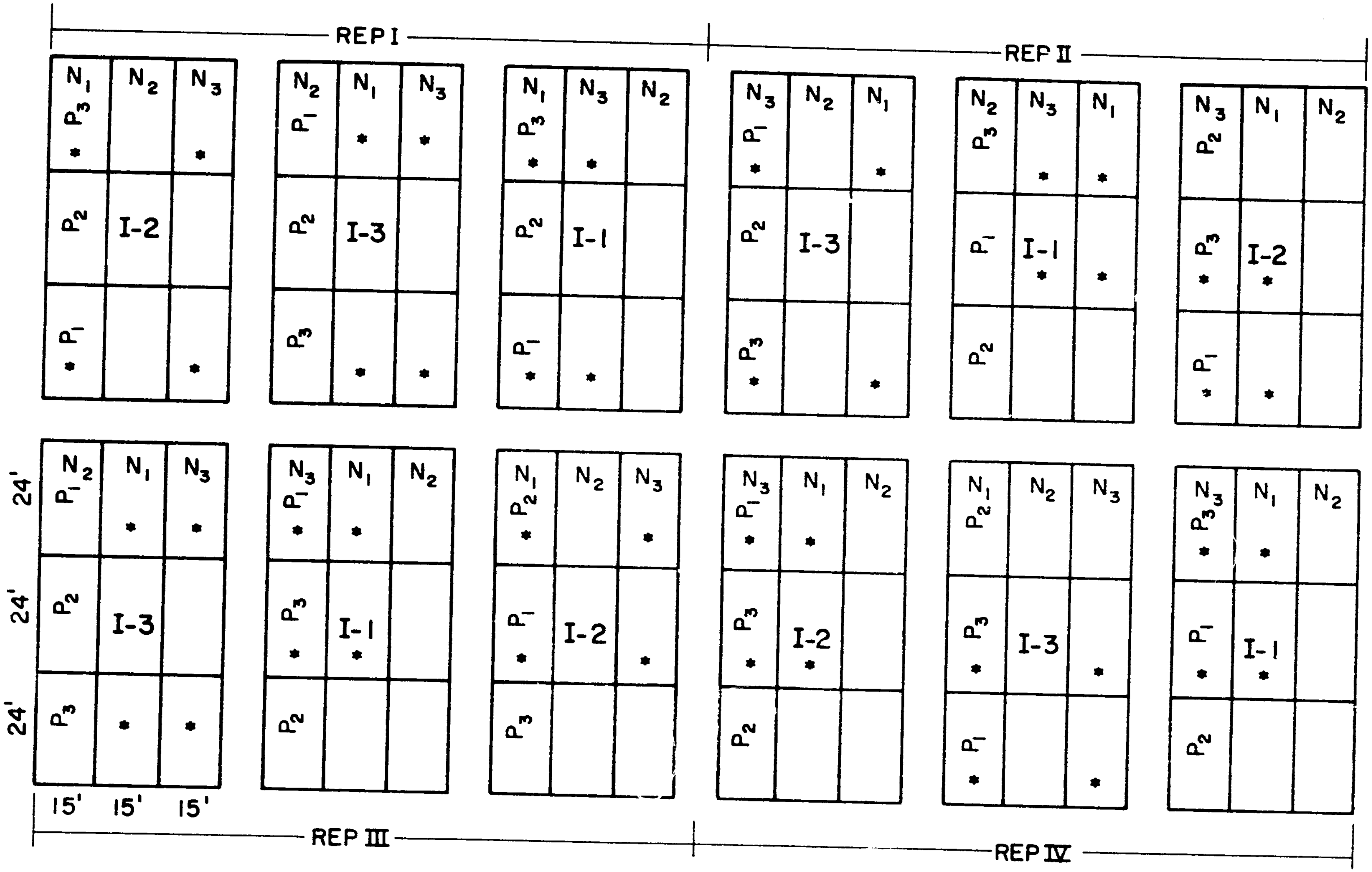

Figure A1. Field plot layout, fertility x water interaction experiment. PARI 1975-76.

APPENDIX 2

REPORT

INFLUENCE OF WATER LEVEL AND SOIL PUDDLING ON YIELD OF BASMATI RICE[1]

by

S. A. Bowers, Siddique Shafique, and M. Yasin[2]

For irrigated agriculture Pakistan's yields are among the world's lowest. While the causes are multiple certainly poor water management practices are a contributing factor. Interacting to produce low yields is a shortage of water plus the tendency of many farmers to over irrigate. The latter partially results from a "fixed turn" irrigation schedule.

Rice is one of Pakistan's major crops. However, the necessity for maintaining flooded paddies has been questioned. Naghia (2) showed that rice planted on a saturated nonpuddled clay soil, used 25 percent less water than on a puddled, flooded soil; its yield was reduced only 10 percent; flooding was primarily responsible for this difference in water use.

Paddy rice, by virtue of its flooded management, uses considerable water. One of the assumed benefits of soil puddling is that it reduces the permeability of the plow zone, and thus decreases deep percolation. Based on cited literature, it appears that by accepting yield reductions, water utilization could be reduced by not flooding rice paddies. This not only reduces head contributing to increased permeability but also reduces surface evaporation. This experiment was initiated to test the effects of various water and soil treatments on water consumption and to determine the effect of reduced water application on yield.

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[1] Cooperative study undertaken by Colorado State University and the "On-Farm Water Management Development Project" of the Punjab Province Department of Agriculture.

[2] Soil Scientist, CSU, Assistant Agriculture Engineer, Punjab Department of Agriculture, Assistant Agriculture Engineer, CSU.

PROCEDURE

The soil and water treatments were as follows:

P_o - nonpuddled soil
P_1 - puddled soil
M_1 - 5 cm water depth
M_2 - Soil saturated
M_3 - Soil at field capacity

The experimental design was a randomized complete block with three replications. The treatments when applied in factorial combination resulted in six individual treatments; the total number of plots were 18. Plot size was 5 m x 5 m. All plots were leveled and bunded with 50 cm wide compacted bunds. P_1 plots were puddled by hand, using a kusi, to an approximate 10 cm depth.

Basmati, a local aromatic variety, was transplanted on July 18, 1976 at a 25 cm x 25 cm plant spacing. Fertilizer applications to all plants were split. The basal dressing, broadcast and incorporated into all treatments prior to puddling, was 50 kg N/ha and 40 kg P_2O_5/ha and consisted of a combination of DAP and Urea. On both August 31 and October 1, 1976 25 kg N/ha (Urea) were broadcast on all plots.

Water was added to each plot by means of a hose attached to a plastered brick reservoir (Figure 1). The crossectional area of the reservoir ($2.5m^2$) was 1/10 the individual plot areas. The water added to each plot was calculated from the change in water level as read from a manometer attached to the reservoir. Because of the 10:1 area ratio between plots and tank, the change in tank water level read in cm was numerically equal to the millimeters applied to the plots. Thus depth of water applied could be measured to 0.1 mm.

On each M_1 plot a stake was driven into the soil until it protruded 5 cm above the mean plot surface level. Daily, water was added until the stakes were just barely submerged. For the saturated plots, M_2, small, open ended, perforated cans were buried in the soil with 1/2 inch protruding above the soil surface. Within the can a steel pin was driven into the soil until the sharpened upper end was just at soil surface level. Water was then added to the plot until the rising water in the can covered the pin. For the field capacity M_3 treatments the surface 15 cm were sampled every 2-3 days and, if required, sufficient water added to restore the soil to FC. The field capacity percentage was 19 percent. Following the frequent heavy rains all water remained on the plot; no surface drainage was attempted. During the first week after transplanting all plots were continuously flooded to facilitate plant establishment.

Data collected included yields (mt/ha), plant heights, tillers/10 plants, grains/2 plants, wt/1000 grains, straw weight, rainfall, and water applied. All data were analyzed according to a two way, factorial, analysis of variance and the associated "F" test. Where significant differences were found treatment means were separated using Duncans Multiple Range test.

RESULTS AND DISCUSSION

Table 1 shows the amount and distribution of rainfall received during the experimental period. Because of this heavy rainfall it was impossible to maintain the selected moisture treatment. Treatments M_2 (saturated) and M_3 (field capacity) frequently and for extended periods exceeded their set treatment limitations. This total rainfall was 705.22 mm. Table 2 shows the monthly totals of irrigation water added to each plot. The seasonal averages for each moisture treatment were as follows:

	M_1 (5cm head)	M_2 (Saturated)	M_3 (Field Capacity)
Irrigation	1335mm	869 mm	540 mm
Irrigation and Rainfall	.2040mm	1574 mm	1245 mm

Unfortunately, puddling had no significant effect on water retention. Either the puddling treatment was inadequate or possibly, during the transplanting process the nonpuddled plots became puddled. The average water applied to puddled and nonpuddled plots were as follows:

P_o (nonpuddled)	P_1 (puddled)
910 mm	920 mm

From the analysis of variance a significant difference (0.01 level, $F_{2, 10} = 8.05$) was detected in grain yields. Table 3 shows that the M_1 treatment, which yielded 3.01 MT/ha, significantly increased grain yields 0.67 MT/ha and 0.74 MT/ha more than the M_2 and M_3 treatments respectively. The M_2 and M_3 treatments did not significantly differ.

On the basis of rainfall and total applied water the M_1 treatments produced 1.48 kg grain/ha mm H_2O; the M_2 treatment produced 1.49 kg grain/ha mm H_2O; and the M_3 treatment

Table 1. Rainfall distribution and amount July 14-Oct. 5, 1977

DATE	Rain (mm)	Cumulative Rain (mm)
July 14	27.94	27.94
15	1.27	29.21
17	2.54	31.75
20	74.47	109.22
21	1.27	110.49
22	5.80	116.29
24	5.08	121.37
28	3.81	125.13
30	29.21	154.49
31	219.71	374.10
Monthly Total	374.10	
Aug. 1	19.56	393.66
3	2.54	396.20
4	3.81	400.01
5	10.16	410.17
6	22.85	433.02
7	38.51	471.53
8	9.65	481.18
12	20.32	501.50
16	8.89	510.39
20	13.21	523.60
24	63.50	587.10
Monthly Total	213.00	
Sept. 2	54.61	641.71
3	15.24	656.95
4	1.27	658.22
8	16.68	674.90
Monthly Total	87.80	
Oct. 3	4.51	679.41
15	25.81	705.22
Monthly Total	30.32	

Table 2. Average Irrigation Water Added to Each Treatment by Months (mm)

Month	M_1P_o	M_1P_1	M_2P_o	M_2P_1	M_3P_o	M_3P_1
July	309.23	393.32	347.82	360.29	329.67	338.09
August	369.17	335.92	177.43	132.27	41.50	40.30
September	376.60	392.30	209.50	204.63	95.60	95.63
October	284.70	241.87	156.57	150.73	64.35	75.63
TOTAL	1339.07	1363.41	891.32	847.92	531.12	549.65
Total for Moisture Treatments	1334.88		869.52		540.39	

Table 3. Rice experiment average yield data

	TREATMENT					SIGNIFICANCE LEVEL	
	M_1	M_2	M_3	P_0	P_1	"F" test	DMR test
Grain Weight MT/ha	3.01_a	2.34_b	2.27_b	-	-	0.01	0.01
Weight/1000 grains grams	21.35_a	21.10_a	20.45_b	-	-	0.01	0.01
No. grains/2 plants	-	-	-	2292_a	1808_b	0.01	0.01
Plant height cm.	1.45_a	1.41a	1.35b	1.36_b	1.44_a	0.01	0.01
Straw weight MT/ha	-	-	-	7.37_b	9.50_a	0.05	0.05

*Treatment means followed by different letters significantly differ.

produced 1.82 kg grain/ha mm H_2O. Here the M_3 treatment was 22.5 percent more efficient in grain production per unit of water than were the M_1 and M_2 treatments.

The data indicates that if irrigation water is in short supply and weeds are controlled by other methods moderate yields can still be achieved by maintaining the water at saturation or field capacity. In this experiment yields were reduced approximately 25 percent due to a 35 percent (466 mm) and 60 percent (795 mm) reduction in irrigation water to the M_2 and M_3 treatments respectively. Considering both rainfall and applied water the M_3 treatment received 39 percent less water than the M_1 treatment. Of special significance is the fact that although the M_3 treatment received 329 mm less total water (21%) than the M_2 treatment the yield reduction was only 0.07 Mt/ha (3%).

With yield of straw a significant difference (0.05 level, $F_{1,10}$ = 8.90) was detected due to soil puddling. The average straw yields for the P_o (nonpuddled) and P_1 (puddled) treatments were respectively 7.37 MT/ha and 9.50 MT/ha. It is not apparent why soil puddling increased the straw weight. Previous research indicates that greater depth of mud promotes or allows greater root growth and greater nutrient uptake (1). Presumably, this should permit greater uptake of silica which could give rise to greater straw yield. If this is true, one would anticipate that puddling should also increase grain yields through greater nutrient uptake. While the average grain yield due to puddling and nonpuddling was 2.71 MT/ha and 2.39 MT/ha respectively this increase was not signficant.

As shown in Table 3 significant differences were detected in plant height due to both moisture treatment (0.01 level, $F_{2,10}$ = 10.00) and soil treatment (0.01 level, $F_{1,10}$ = 26.86). As anticipated the higher moisture contents increased plant heights 6-10 cm and soil puddling, probably due to an expanded root system, increased the heights 8 cm.

Significant differences were also detected in the number of grains/2 plants due to soil treatment (Table 3, 0.01 level $F_{1,10}$ = 16.26. For reasons unknown soil puddling decreased the number of grains 484 grains/2 plants or 21 percent.

The weight of 1000 rice grains the M_3 moisture treatment significantly decreased the wt 0.90 grams and 0.65 grams respectively below that of the M_1 and M_2 treatments (0.01 level $F_{2,10}$ = 13.01).

No significant differences were detected in number of tillers/ 10 plants.

CONCLUSIONS

Under conditions of this experiment, decreasing the water to Basmati rice decreased the yield from a high of 3.01 MT/ha for the continuous flooded M_1 treatment to a low of 2.27 MT/ha for treatment M3 which attempted to maintain the soil water contents near field capacity. While the M_3 treatment had the lowest yield its production per unit of water was highest. Reduction of the total water by 39 percent and irrigation water by 60 percent reduced the yield by 25 percent. Thus it appears that when water is in short supply acceptable yields can still be achieved by holding the water in the paddies at moisture contents between saturation and field capacity.

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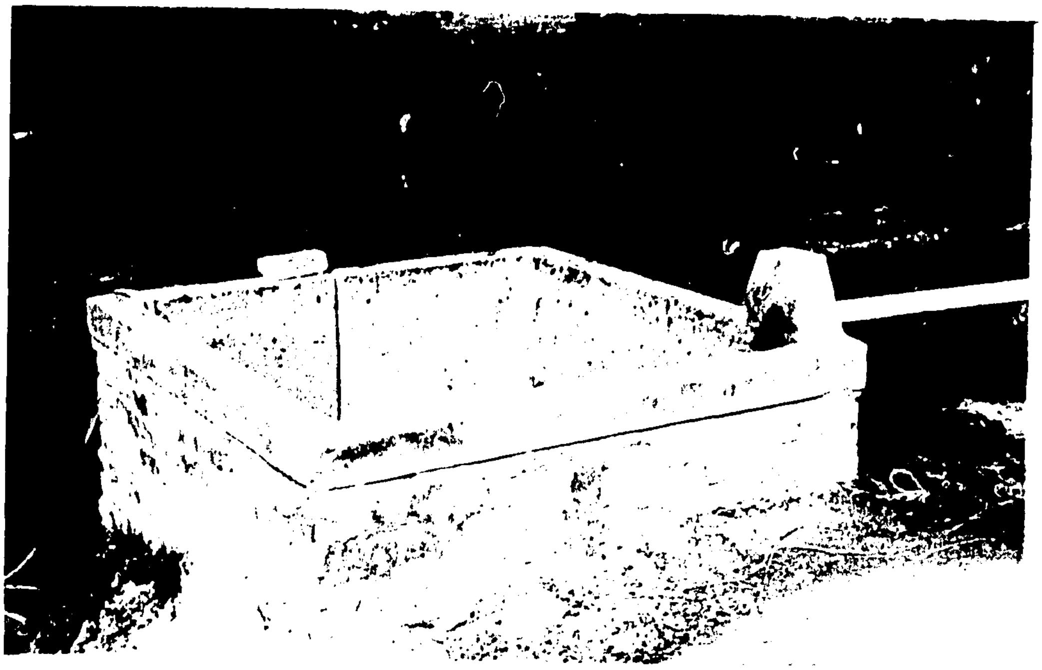

Figure 1. Reservoir tank with crossectional area 1/10 that of experimental plots

Figure 2. Basamati rice experimental plots

APPENDIX 3

DEEP WATER RICE VARIETY TRIAL

By

S.A. Bowers, M. Siddique Shafique, M. Yasin[1]

Due to annual flooding early planting of kharif crops on the Ravi River bottom lands near Lahore is hazardous. The flood generally occurs in late June or early July and may damage or destroy all crops, including paddy rice, planted on these lower lands. Usually planting is delayed until after the flood recedes.

To determine the feasibility of utilizing the full season, 70 deep water rice varieties were imported from IRRI and planted in a non-replicated trial on June 22, 1977. The varieties were direct seeded, two seeds per hill, in four meter rows, and one row per variety. The plant and row spacings were 25 cm x 25 cm.

During the first week of July five continuous days of flooding occurred. Following recession the trial was maintained in a flooded state (approximately 5 cm depth) until the latter part of October. Twenty seven varieties (including one local check) were harvested between November 8 to November 17, 1977. All varieties which had not matured by this latter date were considered unsatisfactory for this region. The varieties are listed in order of their yield/plants. The local variety provided the lowest yield of the 27 harvested varieties, while the Lab Mue Nakng - 111 variety from Thailand produced the highest yield.

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DEEP WATER VARIETIES RANKED ACCORDING YIELD/PLANTS

RANK	VARIETY	ORIGIN	Yield (gms)	No. of Plants	Yield/Plant (gms)	Tillers/ plant	Plant Height (cms)
1	Lab Mue Nakng -111	Thailand	1235	12	102.9	36	93
2	BKN 6986 - 108 - 3	Thailand	1335	16	84.4	42	102
3	B 922C - Mr - 118	Indonesia	1040	13	80.0	38	126
4	C4-63 (check)	Philippines	910	14	65.0	43	102
5	IR 5857-10-IE-1	IRRI	1215	19	64.0	51	99
6	CN-536	India	1150	18	63.9	36	98
7	HTA 7204	Thailand	1150	18	63.9	36	158
8	B1050-C-Mr-7-3	Indonesia	1075	17	63.2	47	100
9	Habigonj Oman VIII	Bangladesh	800	15	61.5	36	154
10	BKN 6987-128-2-4	Thailand	1310	22	59.5	34	94
11	BKN-6986-105P	Thailand	950	17	55.9	18	106
12	BKN-6986-108-2	Thailand	660	12	55.0	39	112
13	IR4219-35-3-3	IRRI	1135	21	34.1	42	94
14	BKN6986-147-2	Thailand	745	14	53.2	26	121
15	BKN6986-173-5	Thailand	745	14	53.2	28	123
16	CNL241	India	530	10	53.0	34	124
17	BKN6986-136-4	Thailand	100	2	50.0	26	108
18	BGD 4-7-3PE-1	Bangladesh	1000	20	50.0	36	103
19	IR5825-41-2P4	IRRI	650	16	40.6	34	89
20	Pelita-I-1	Indonesia	770	20	38.5	27	122
21	IR 5857-10-1E-2	IRRI	715	19	37.6	28	152
22	FRRS/U-3-3	WARDA	585	17	34.4	53	160
23	BKN6996-45-1	Thailand	610	19	32.1	28	109
24	BKN6987-68-14	Thailand	535	17	31.5	38	95
25	RD-1 (check)	Thailand	500	17	29.4	19	135
26	Cula	WARDA	465	20	23.2	29	98
27	Basmati (local variety)	Pakistan	125	17	7.4	15	131

APPENDIX 4

IRRIGATION EVALUATION PROCEDURE FOR FLOODED RICE CROPS

A. C. Early and Zahid Sayeed Khan[1]

INTRODUCTION

Pakistan has abundant natural resources in the form of water, soil, people and favorable climate for food production, yet the agricultural yields are far below their potential when compared with world yield statistics. There are various causes and certainly poor water management practices are a major factor in this situation. The common concern in considering low yields in Pakistan is that a shortage of water exists while field experience shows that underirrigation sometimes occurs and overirrigation frequently occurs. The objective of an irrigation evaluation is to determine the water use efficiency of the irrigation application. The concept of irrigation efficiency is not the ultimate measure of irrigation effectiveness (the crop yield is the ultimate measure) but it is a useful measure of how the water is being used and can be helpful in identifying specific problem areas where water losses may be reduced.

Rice is one of Pakistan's major cash crops. Farmers generally do not know how much water should be given to their rice fields. They just irrigate so that the fields are ponded with the full supply of water. In this way much water is wasted due to overirrigation. Accurate measurements are important to determine how much is water used in the rice fields, and how much could be saved and utilized for other crops.

This methodology paper is designed to delineate the unique considerations for lowland rice water requirements, to indicate the procedure for irrigated lowland rice water use efficiency evaluations, and to specify the equipment required to complete the evaluation. A blank data form is attached and the methodology for computation is presented.

1/Formerly Agricultural Engineer and Assistant Agricultural Engineer respectively, Colorado State University, Water Management Research Program in Pakistan; Currently Associate Agricultural Engineer, Irrigation & Water Management Department, International Rice Research Institute, Los Banos, Laguna, Philippines, and Graduate Assistant, Agricultural and Chemical Engineering Department, Colorado State University, Fort Collins, Colorado.

METHODOLOGY

Flooded (lowland) rice irrigation evaluations are unlike other (upland) crop water use determinations because the soil moisture reservoir is vastly different. In lowland rice land preparation the soil is puddled to destroy the soil structure and to decrease the moisture infiltration and transmission rates within the soil. The soil itself remains close to saturated conditions and under only rare circumstances should the moisture content fall as low as the field capacity where serious stress is imposed on the plant. Thus the only reservoir considered for the lowland rice evaluation is the water stored on the soil surface.

Since moisture movement within the soil laterally as seepage and vertically as percolation has been minimized by puddling, those further uncontrolled losses of seepage and percolation (S&P) are considered to be a soil requirement for water and a necessary part of the entire irrigation requirement for lowland rice. The general efficiency concept is the quotient of output (in this case useful water consumption as evapotranspiration, percolation and seepage) and input (rainfall and irrigation) as

$$E = \frac{\text{output}}{\text{input}} \times 100$$

For lowland flooded rice this irrigation application efficiency is generally known as the water use efficiency (WUE) and is defined as

$$\text{WUE} = \frac{\text{ET} + \text{S\&P}}{\text{RN} + \text{IR}} \times 100$$

where ET is the evapotranspiration of the crop, depth/unit time,

S&P is the seepage and percolation of the soil, depth/unit time,
RN is the rainfall depth/unit time, and
IR is the irrigation depth/unit time.

Since flooded rice is often continuously irrigated over the entire season, the time base for an irrigation evaluation is not the usual short term irrigation as for other crops. The water use efficiency is generally expressed on the minimum time period of one week to adequately represent the field conditions. More often it is expressed for the two general stages of rice growth, vegetative stage before panicle initiation and the reproductive stage of growth. It is generally not applied to the drying off stage when irrigation is stopped and drainage of fields is completed as maturation occurs.

In the case of the upland crop evaluation the unit on which measurement and results were expressed was the bunded unit. With the continuous flow irrigation method of lowland rice evaluations and frequent paddy to paddy flow occurrence with attendant difficulty in flow measurement, the basis of the irrigation evaluations is generally a larger block of land from the irrigation inlet to the drainage outlet. It can include any suitably bounded unit from 1 acre to 25 acres, depending on the flow pattern. Suitable boundaries are cultivated or uncultivated land to which flow does not occur, highway or railroad right of ways or irrigation conveyance structures. If drainage occurs to or through any of these boundaries, that flow must be measured and accounted for in the overall moisture balance.

The overall basis on which lowland flooded rice irrigation evaluations are made is the water balance or otherwise known as the continuity relationship. Stated simply, the inflow minus outflow must equal the change in storage for complete accounting.

Water supplied to lowland rice fields as irrigation (IR) and rainfall (RF) can be accounted for by evapotranspiration (ET) into the atmosphere, by surface drainage (DR) from the fields, and by seepage and percolation (S&P) into the soil plus change in water stored on the soil surface. ET cannot easily be measured in the field, but relatively accurate methods have been developed for estimating potential ET, from open pan evaporation. Evaporation, water depth change, surface drainage, rainfall, and irrigation can be readily measured. Surface drainage can be measured by use of Cutthroat flumes although usually with difficulty.

Water balance accounting allows the estimation of S&P as a residual weighted average over a larger area. Point measurements of S&P are useful in finding the effects of local soil or topographical conditions, but they are difficult to integrate into a mean value representative of large areas. Collecting data for the complete water balance, is however, very arduous and expensive, since one must account for all water entering and leaving a site. The wide and unpredictable fluctuations in flow of the many irrigation sources and drains serving typical lowland areas make these measurements difficult and inaccurate. Furthermore, S&P values are sometimes less than 5% of the total water accounted for, so that inaccuracies in the irrigation or drainage measurement could easily result in individual S&P values being too high or too low by an order of magnitude.

PROCEDURE

There are six components which must be considered in estimating the complete water balance for flooded rice crops.

1. Irrigation (IR)
2. Rain (RN)
3. Potential evapotranspiration (PET)
4. Drainage (DR)
5. Change in surface storage (ΔS)
6. Seepage and percolation (S&P)

These are considered sequentially as follows:

1. Irrigation

This can be measured by various methods. The easiest method is by the installation of Cutthroat flumes (CTF) at the field entrance of water, to measure the commonly referred to Q_{nakka} in previous irrigation evaluation procedures.

2. Rain

A nonrecording rain gauge can be used at the field site or data from a meteorological center of less than 1 mile distance can be used only in case of emergency lack of a rain gauge.

3. Potential Evapotranspiration

PET cannot easily be measured in the field, but relatively accurate methods have been developed for estimating PET from a US Weather Bureau Class A evaporation pan. This can be done by installing an evaporation pan in the field with the difference in daily readings recorded as ET, and a good estimate of PET, of a flooded rice crop, irregardless of the stage of crop growth.

4. Drainage

Drainage can be measured by installing flumes at the outlets of the rice fields, from which direct readings are taken periodically. Drainage water outflow is far more variable than the irrigation water inflow and becomes much more difficult to measure. If drainage is to be measured, hourly reading of flow should be recorded, or flumes with water level recorders should be used to provide a continuous record.

5. Change in Surface Storage

Each paddy included in the block of land should be equipped with a staff gauge for direct reading of the daily water surface elevation difference or with a suitably stabilized reference stake from which water surface elevation differences can be read using a standard hook gauge. From the daily difference and the area of the paddy the total volume and hence mean depth change of storage for the entire area can be calculated as ΔS.

6. Seepage and Percolation[2]

Methods of measuring seepage and percolation include laboratory permeability analysis and field pumping analysis to determine hydraulic conductivity, lysimeters, and field water surface level recession. This latter method requires the use of a water level recorder on a stilling well on the paddy under observation. The stilling well is generally an empty oil drum with both ends open, buried with an open end approximately 1 foot into the soil. The drum is independently supplied with water from the paddy and the surface recession is recorded continuously. This total recession includes ET, hence the pan evaporation rate must be subtracted to provide this estimate of seepage and percolation.

The major problems with the lysimeter and water recession methods are due to the discontinuities caused by the tank walls, the disturbed and unrepresentative conditions of the soil after filling the tank or permeameter and the tendency to measure only the percolation, vertical water movement to deeper depths. Seepage, the lateral movement of water in the soil, is often more important than percolation, but depends on many environmental factors which are site specific.

The most common field method of estimating seepage and percolation in irrigation evaluations is by the use of the water balance. S&P are then estimated as the residual after all other factors are accounted.

EQUIPMENT

The equipment needs for flooded rice irrigation evaluations are as follows:

1. Irrigation - as many Cutthroat flumes equipped for continuous flow recording for inflow measurement as there are inflow sites for the block of land under evaluation.

2. Rainfall - one standard nonrecording rain gauge.

3. Evaporation - one standard U.S. Weather Bureau Class A pan and hook gauge.

4. Drainage - as many Cutthroat flumes equipped for continuous flow recording for outflow measurement as there are outflow sites for the block of land under evaluation.

5. Change in surface storage - as many staff gauges for water surface elevation or hook gauge bases as there are paddies in the area being studied.

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[2] If S&P can be adequately measured by water surface recession, then drainage measurement is not necessary and can be estimated by the residual.

6. Seepage and percolation - lysimeter, water surface recession or residual as discussed earlier.

DATA RECORD

The attached data sheet provides the format for the detailed accounting of water in the moisture budget and as a weekly and fortnightly summary. All measurements are in the units of inches of water depth. The water use efficiency results are expressed as a dimensionless percentage.

Location ______________

Start Date ______________

Finish Date ______________

SUMMARY SHEET FOR FLOODED RICE IRRIGATION EVALUATION[1]
WATER BALANCE COMPONENTS IN INCHES ON AN ACRE BLOCK OF LAND

Week	Day	Depth of irrig. IR	Depth of rainfall RN	Depth of drainage DR	Initial depth of surface storage IS	Final depth of surface storage FS	Depth change of surface storage ΔS = IS-FS	Pan evaporation depth ET	Residual seepage & percolation depth residual[2] S&P	Water use efficiency[3] WUE %
1	1									
	2									
	3									
	4									
	5									
	6									
	7									
1st week summary										
	1									
	2									
	3									
	4									
	5									
	6									
	7									
2nd week summary										

1/Basic efficiency relationship

$$\text{Eff.} = \frac{\text{output}}{\text{input}} \times 100$$

2/S&P residual calculation

INFLOW - OUTFLOW = change in storage

INFLOW = IR + RN

OUTFLOW = S&P + ET + DR

CHANGE IN STORAGE = IS-FS = ΔS

IR + RN - S&P - ET - DR = ΔS

IR + RN - ET - DR - ΔS = S&P

3/Water use efficiency =

$$\left(\frac{ET+S\&P}{IR+RN}\right)100 = 100\left(\frac{-DR}{IR+RN}\right) + 100$$

APPENDIX 5

A COMPUTER PROGRAM FOR PUNJAB EVAPOTRANSPIRATION ESTIMATES

by
A. C. Early[1]

Introduction

Numerous investigators have generally accepted as fact that atmospheric demand for moisture as a function of short term meteorological factors is the primary determinant of the consumptive use of water by plants, Levine (1959). The primary forces influencing this process are solar radiation and air movement as shown by Penman (1948). Several methods of estimating evapotranspiration based on the combination of energy and aerodynamic effects of climate include the Jensen-Haise and the Penman methods.

This report provides detailed methodology for the calculation of potential evapotranspiration based on the Penman method using a digital computer program, which is found to be an appropriate method for estimation based on the data base available in Pakistan's Punjab province. Several innovations for facilitating the estimation of the potential day length, the radiation at the outer surface of the earth's atmosphere and slopes for curves in the psychrometric chart have been included.

Punjab Evapotranspiration Estimates

Generalized province-wide evapotranspiration estimates are needed in the Punjab province of Pakistan from two major standpoints. First, the need for these estimates arise at the field level where extension workers advise farmers on frequency and amount of irrigation scheduling. Secondly, improvement of system level operation of the vast Indus Basin irrigation works ultimately must rely upon water releases which are based on the demand for water. One method of predicting these demands once the crop mix, contribution of the water table and delivery and application efficiencies are known to modify these estimates, is through meteorologically

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[1] 1/Formerly Agricultural Engineer, Colorado State University, Water Management Research Program in Pakistan, currently Associate Agricultural Engineer, International Rice Research Institute, Los Baños, Laguna, Philippines.

based equations for prediction of evapotranspiration. Ultimately, the method chosen for prediction of evapotranspiration must be subjected to ground truth, soil moisture sampling experiments or lysimetric verification.

Jensen (1973) reported extensive testing and comparison of a number of equations for the prediction of evapotranspiration at a range of sites with different climatic and elevation conditions. The site most easily compared to Pakistan's Punjab is that of Brawley in the Imperial Valley of California with latitude 33°N. It is also the hottest site in the sample, making it readily comparable to Pakistan. Jensen reported that the Penman method was one of the two providing accurate estimates for inland semiarid to arid climates. The Jensen-Haise method ranked first and the Penman method ranked second among all the methods tested based on accuracy of prediction compared to lysimeter measurements at the site for the standard. Choosing a method depends on three factors: the availability of accurate meteorological data, the training and experience of the user and the general acceptance of previous estimates. In Pakistan the accurate meteorological data required for the Penman equation are much more commonly available nationwide than the accurate radiation data for the Jensen-Haise equation.

The training and experience of the user is not of major importance because the calculations are to be completed on a digital computer and tabulated for general irrigation scheduling use in the field. General work on evapotranspiration estimates has not concentrated on any one method in Pakistan, so acceptance of any one method does not appear to be an important criterion. Considering all three factors leads one to selection of the Penman method for use in the evapotranspiration estimates.

The methodology for calculation of potential evapotranspiration is presented in the following section along with the calculation of the day length and radiation available at the outer surface of the earth's atmosphere.

Procedure

The procedures for calculation of Penman estimates of evapotranspiration includes a number of steps. First is the delineation of the data available and stored on computer tape. The data used and the format are shown in Table 1. Figures 1a-d indicate the initializing and data gap routines used in the form of flow charts.

Table 1. Available Input Data and Formats Used in Coding

Variable Field	Input Data*	Columns	
I3	STA = STATION CODE	1,2,3	
I3	DAY = DAY CODE FROM OCT 1	4,5,6	
F5.2	RF = RAINFALL	7 - 11	decimal in 9
F5.2	PAN = PAN EVAPORATION	12 - 16	decimal in 14
F5.2	SS = SUNSHINE HOURS	17 - 21	decimal in 19
F5.1	WR = WINDRUN MILES	22 - 26	decimal in 25
F5.1	TEMP = MEAN TEMPERATURE	27 - 31	decimal in 30
F5.1	RH = MEAN RELATIVE HUMIDITY	32 - 36	decimal in 35
I5	IWR = INITIAL WIND READING	41 - 45	
I5	FWR = FINAL WIND READING	46 - 50	
F5.1	MXT = MAXIMUM TEMPERATURE	51 - 55	decimal in 54
F5.1	MNT = MINIMUM TEMPERATURE	56 - 60	decimal in 59
F5.1	MXRH = MAXIMUM RELATIVE HUMIDITY	61 - 65	decimal in 64
F5.1	MNRH = MINIMUM RELATIVE HUMIDITY	66 - 70	decimal in 69
	FO** = FROST OCCURRENCE	1 = FROST	
		0 = NO FROST	
	PM** = TYPE OF PREC. MEASURE	1 = millimeters	
		2 = inches	
	TM** = TYPE OF TEMP. MEASURE	1 = celsius	
		2 = fahrenheit	
	MO = MONTH CODE (1-12)	77 - 78	
	YR = YEAR CODE (14-76)	79 - 80	

*Missing data is coded as negative number
**Optional coding not available 1965-1974

Additional data is required in the form of the latitude of each station (PHI(STA))

Khanpur PHI (001) = 28.65 ; PHI (002) = 30.20 Multan
Lyallpur PHI (003) = 31.43 ; PHI (004) = 31.50 Lahore
Sargodha PHI (005) = 32.05 ; PHI (006) = 32.93 Jhelum

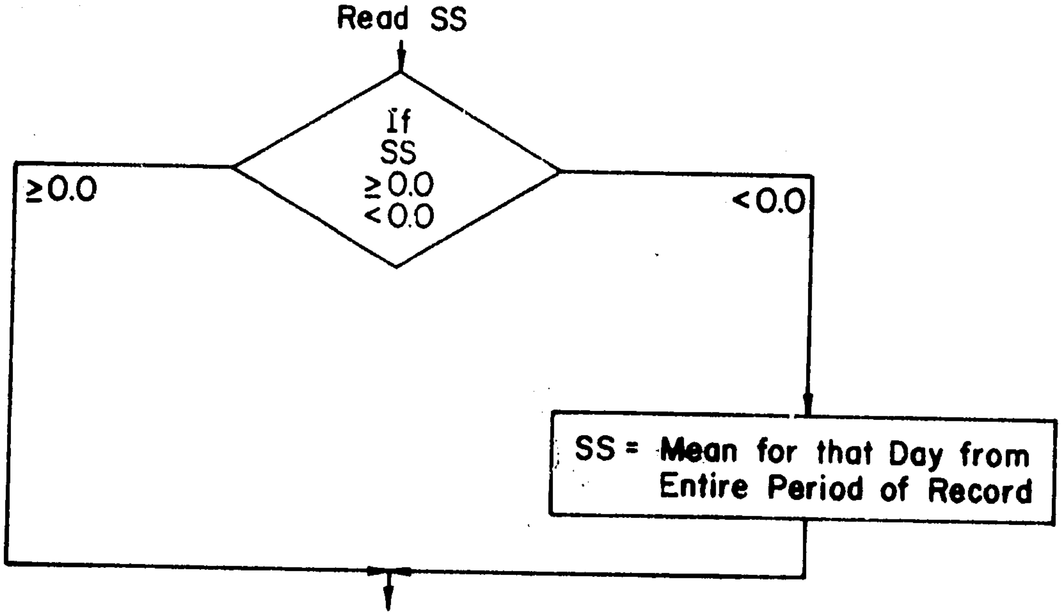

Figure 1a. Initial routine for sunshine hours determinations.

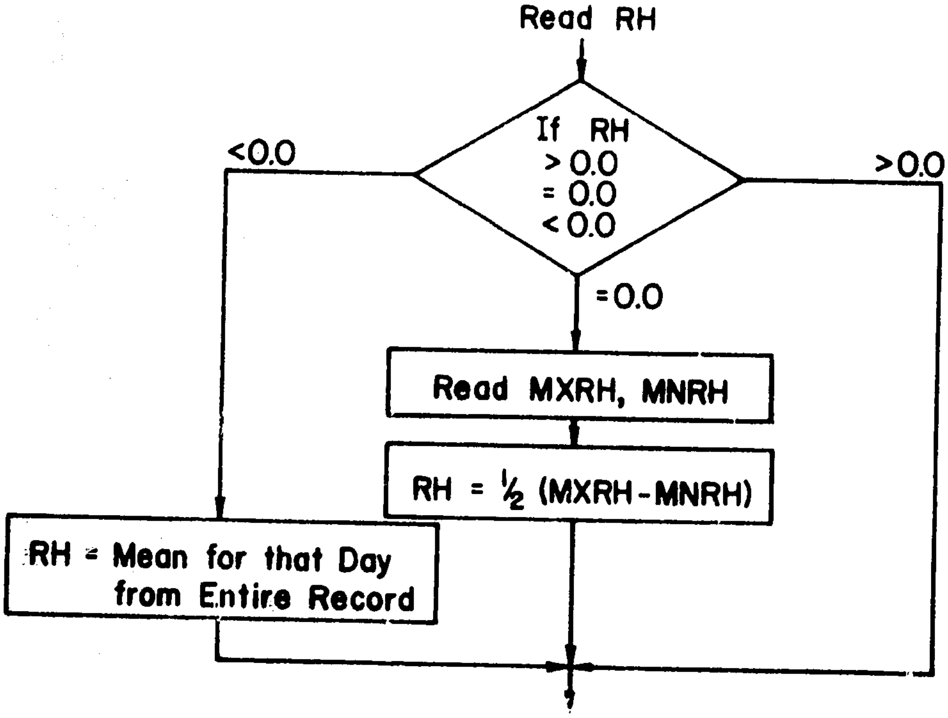

Figure 1b. Initial routine for relative humidity determinations.

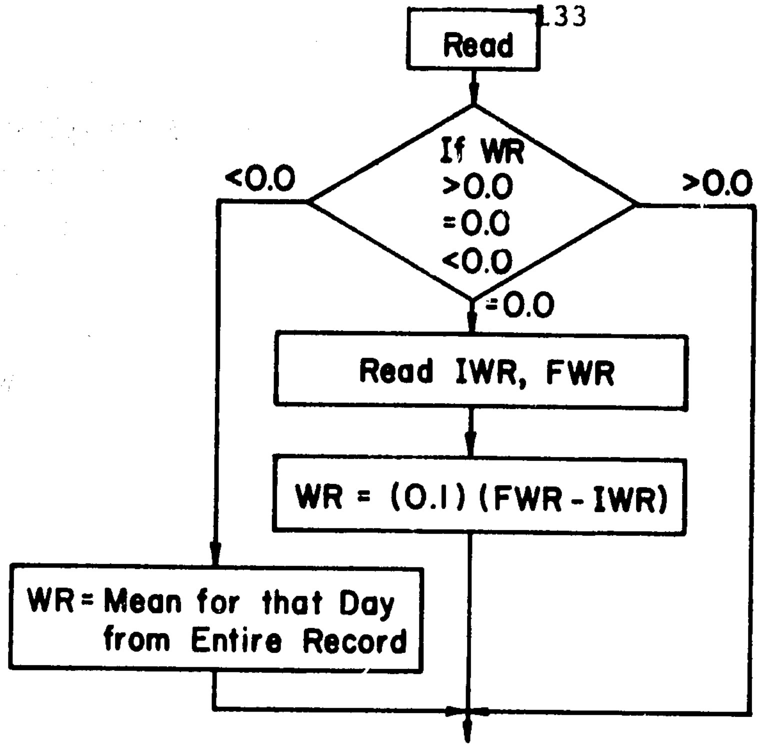

Figure 1c. Initial routine for windrun determinations.

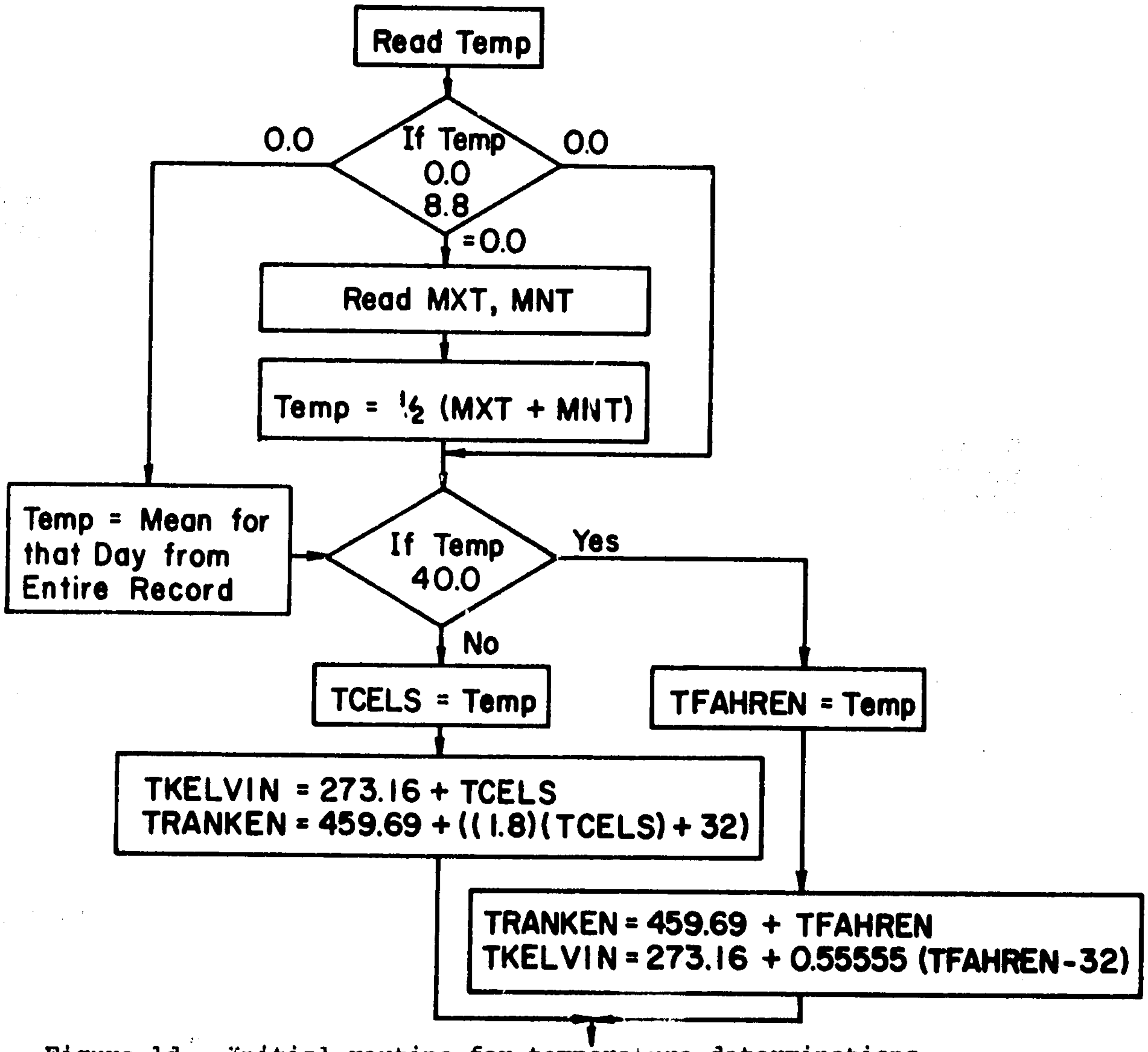

Figure 1d. Initial routine for temperature determinations.

After initial processing of the input data the following are the variables to be used:

STA
DAY
SS
WR
TCELS
TFAHREIN
TKELVIN
T RANKIN
RH
MO
YR

The next step is the computation of a number of radiation and day length variables that are dependent on the day of the year. These values are available from List (1958) in the Smithsonian Meteorological Tables. The tables can not conveniently be used in the program so the following equations are manipulated for ease of computer computation.

First is the calculation of the sinusoidal function used to convert days of the cropping year starting the rabi season with DAY = 001 on October 1 to angular measurement in radians. This is done in the following equation:

$$V = (.017214182)(DAY) - (2.960846357)$$

where V is the day of year in radians. Then the next step is the use of this single V to calculate the declination of the sun in radian depending on the season of the year. From Sellers (1965) this equation becomes

$$DEL = (0.4092\ 79710)(Sin\ (V))$$

where DEL is declination in radians.

The next set of steps is to calculate the theoretical day length or possible number of sunshine hours, based on the declination of the sun and the latitude of the station. The first step is the calculation of the latitude into radians using the conversion below

$$X = (.0174532925)(PHI\ (STA))$$

where C is the latitude in radians and PHI is the latitude of Station STA in degrees.

The second step is the calculation of an intermediate computational variable

$$Z = (\tan (x) (\tan (DEL))$$

where x and DEL are defined above.

The third step is the calculation of the predicted half day length in radians using the following relationship

$$HRAD = Tan^{-1} \left(\frac{\sqrt{1 - Z^2}}{Z} \right)$$

where HRAD is the half day length in radians.

The alternative form is HRAD = $Cos^{-1}(z)$ which, however, cannot be obtained from all computer libraries. Then the half day length is converted to degrees using

$$HDEG = \frac{HRAD}{0.0174532925}$$

where H is degrees of half day length and the predicted potential day length is

$$PDL = (0.1333333)(H)DEG)$$

where PDL is the potential day length.

The next step is for the calculation of the daily solar radiation incident on a horizontal surface at the top of the atmosphere. Sellers (1965) presented the equation in the following form.

$$Q = \frac{1440}{\pi} S_c \ (DD)^{O}(HRAD \ SIN \ (X) \ SIN(DEL) + COS(X)$$
$$COS(DEL)SIN(HRAD))$$

where

Q is the radiation in langleys per day

SC is the solar constant generally accepted to be 1.94 langleys per minute

$(DD)^{O}$ is a variable ranging from 0.9674 on July 5 to 1.0344 on January 3, accounting for tilt of the earth axis with time and estimated by a sinusoidal function of the day of the year

HRAD is the half day length in radians

X is the latitude in radians

DEL is the declination of the sun in radians.

The first step in this procedure is the calculation of the angles necessary to describe the tilt of the earth's axis in the solar radiation equation. This is obtained from the equation

$$Y = (0.017214206)(DAY)-(0.068856825)$$

where Y is the angular measure of day of the year in radians and DAY is day of the year from October 1st.

where

Then the function which is used to estimate the tilt of the earth's axis becomes

$$DD = 1.009 + (0.0335)(SIN(Y))$$

where DD ranges from 0.9674 to 1.0344.

The coefficient in the radiation equation reduces to

$$W = \frac{1440}{\pi} SC = 889.23$$

and the radiation equation becomes

$$Q = W(DD)((HRAD)(SIN(X))(SIN(DEL)) * (COS(X))(COS(DEL))$$

$$(SIN(HRAD))$$

all values of which have been previously calculated.

The solar radiation must be converted from langleys per day to equivalent depths of water units of evaporation. The latent heat of vaporization is calculated from the equation

$$L = 596 - 0.52 (TCELS)$$

where L is the latent heat of vaporization and TCELS is the water surface temperature in degrees celsius and assumed equal to the atmospheric temperature surrounding the plant.

Then the conversion becomes

$$S = \frac{(10)(Q)}{L}$$

where Q is in langleys/day

1 is in langleys/cm and

S is in millimeters/day

The form of Penman equation to be used is that presented by Levine (1959) in the following form with modifications:

$$PE = \frac{(D)(H) + (G)(E)}{D+G}$$

where PE is the potential evapotranspiration of the crop in millimeters/day

D is the slope of the saturation vapor pressure curve at the temperature of the air

H is the net gain of radiant energy at the surface where evaporation is taking place

G is the constant in the wet-bulb dry-bulb hydrometer equation and taken equal to 0.27

E is a measure of the diffusion of the air as contributing to evapotranspiration.

One can readily observe that the constant D and G are used to partition the contribution to evaporation from radiant energy and diffusion:

$$PE = \left(\frac{D}{D+G}\right) H + \left(\frac{G}{D+G}\right) E$$

The slope of the saturation vapor pressure curve D is obtained by differentiation of the equation of that curve after Dhidley (1970) with respect to temperature. The equation for that curve was given by Brooker (1967) as

$$SVP = 51.7144 \text{ e } (S4.6329 - \frac{12.301.688}{TRANKIN} - 5.16923 \text{ LN})TRANKIN$$

where SVP is the saturation vapor pressure for the mean air temperature in millimeters of mercury

TRANKIN is the mean absolute air temperature in degrees RANKIN

LN is the natural logarithm to the base e.

Differentiation with respect to TRANKIN provides

$$D = \left(\frac{1}{TRANKIN}\right) \left(\frac{12301.688}{TRANKIN} - 5.16923\right)(SVP)$$

The determination of net gain of radiant energy is obtained as the difference between the energy available for use in evaporation and the energy used to heat the air, hence sensible heat.

$$H = EE - SH$$

H = net radiant energy used in vapor

EE = gross energy avaiable for evaporation

SH = energy used on heating the air

The energy available for evaporation is obtained from

$$EE = S(1-r)(A + (B)(P))$$

where EE gross energy available for evaporation in millimeters per day equivalent

S is the solar radiation available at the outer surface of the atmosphere in millimeters per day equivalent

r is the reflection coefficient or albedo taken as 0.25 for vegetative surfaces

A&B are constants which are applied for different seasons of the year as per the following table

	Rabi[1]	Kharif[2]
A	0.30	0.18
B	0.60	0.55
	Oct 1-Mar 31	Apr 1-Sep 30

and P is the ratio of actual to potential sunshine hours calculated as

$$P = \frac{SS}{PDL}$$

where P is a decimal value between 0.0 and 1.0

SS is the number of sunshine hours/day from the meteorological record

PDL is the predicted potential day length from the astronomical calculations completed previously

The sensible heat is calculated from the equation

$$SH = \sigma(TKELVIN)^4(0.56 - 0.092(AVP)^{\frac{1}{2}}) \times (0.10 + 0.90(P))$$

where SH is the sensible heat in millimeters/day equivalent

TKELVIN is the absolute temperature in degrees Kelvin

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[1] Rabi coefficients which were found to improve Penman estimates in thesis "Irrigation Scheduling in Pakistan," by M. A. Gill (1977).

[2] Original coefficients recommended by Penman (1948).

AVP is the actual vapor pressure of the air in millimeters of mercury and

P is the ratio of actual to potential sunshine hours as previously calculated

AVP is calculated as

$$AVP = RH(SVP)/100$$

where AVP is the actual vapor pressure in millimeters of mercury

RH is the relative humidity as a percentage and

SVP is the saturation vapor pressure in millimeters of mercury

The measure of the diffusion of vapor is given by the equation

$$E = 0.35\ (SVP - AVP)(1 + 0.009842)$$

where E is the measure of vapor diffusion contribution to potential evapotranspiration in millimeters per day equivalent.

SVP is the saturation vapor pressure at the mean air temperature in millimeters of mercury

AVP is the actual vapor pressure at the mean air temperature in millimeters of mercury and U2 is the wind run in miles per day at 2 meters elevation and converted from one meter elevation as collected at meteorological stations assuming a logarithmic wind profile by the following

$$U2 = (WR)(1.04070)$$

Where U2 is wind run at 2 meters elevation

WR is wind run from the meteorological record

In concise form the equations for calculation of Penman potential evapotranspiration become (after initial routines for sunshine hours, relative humidity, wind run and temperature verification and gap filling):

1) $V = C_1(DAY) + C2$

2) $DEL = C3\ (SIN(V))$

3) $X = C4\ (PHI(STA))$

4) $Z = TAN(X)\ TAN(DEL)$

5) $HRAD = COS^{-1}(Z)$

6) HDEG = HRAD/C4

7) PDL = C5 (HDEG)

8) P = SS/PDL

9) Y = C6 (DAY) - C7

10) DD = C8 + C9 (SIN(Y))

11) Q = W (DO) (HRAD)(SIN(X)(SIN(DEL) + (COS(X))(COS(DEL)(SIN(HRAD))

12) L = C10 - C11 (TCELS)

13) S = (C12) Q/L

14) $SVP = C13_e(14 - C15/TRANKIN - C16LN(TRANKIN)$

15) $D = (\frac{1}{TRANKIN}) (\frac{C15}{TRANKIN} - C16)\ SVP$

16) AVP = (RH)(SVP)/C25

17) EE = S(1-r(A + B(P))

18) $SH = \sigma(TKELVIN)^4 (C17 - C18_2 (AVP)^{\frac{1}{2}}) \times (C19 + C20(P))$

19) H = EE - SH

20) M2 = (WR)(C21)

21) E = C22 (SVP-AVP)(C23+C24(U2))

22) PE = ((D)(H) + (G)(E))/(D+G)

C1 = 0.017214182

C2 = 2.960846357

C3 = 0.409279710

C4 = 0.0174532925

C5 = 0.133333333

C6 = 0.017214206

C7 = 0.068856825

C8 = 1.0009

C9 = 0.0335

W = 889.23

C10 = 596.

C11 = 0.52

C12 = 10

C13 = 51.7144

C14 = 54.6329

C15 = 12,301.688

C16 = 5.16923

r = 0.25

A = 0.30 for DAY = 001 - 182

= 0.18 for DAY = 183 - 365 (366)

B = 0.60 for DAY = 001 - 182

= 0.55 for DAY = 183 - 365 (366)

= 2.01 x 10^{-9} (Stefan Boltzman Constant)

C17 = 0.56

C18 = 0.092

C19 = 0.10

C20 = 0.90

G = 0.27

C21 = 1.104070

C22 = 0.35

C23 = 1.000

C24 = 0.0098

C25 = 100.0

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Appendix A.

PROGRAMME LIST

```
DOS FORTRAN IV 360N-F0-479   3-6   MAINPGM DATE 25/02/75 TIME 19.35.51 PAGE 001

C    IRRIGATION SCHEDULING  PROGRAMME  FOR  RABI  WHEAT  CROP
     REAL  P,T,D,HE,U2,EA,SE1,E2,E3,Z,ZEF,RF,PAN,SS,WR,TEMP,RH,RSMS,A,
     1B,C,X,Y,V,RD,SMSB,CSMS,PE,RR,AET,SMSF,RDBEF,INCSMS,CC,PERCNT,WATER
     2,DD,DEL,H,PHI,PDL,HRAD,VAP,TCELS,TRANK
     INTEGER   I,L,K,JJ,LL,M,MM,N,LJ,J,J1,ITEST,CTC
     DIMENSION RF (6,212),PAN (6,212), SS (6,212), WR (6,212), TEMP (6,212),
     1RH (6,212), RSMS (4), RD (4), PHI (6),   A(4), B(4), C(4), RDBEF(4)

C    INSERT INPUT DATA-METEOROLOGICAL, SOIL, CURRENT CROP DAY AND SEASON DAY
         DO 9 I=1,6,1
         DO 9 L=1, 123, 1
       9 READ(1,100) RF(I,L), PAN(I,L),SS(I,L),WR(I,L),TEMP(I,L),RH(I,L)
     100 FORMAT (6X,3F5.2,3F5.1)
         DO 99 K=1,4,1
      99 READ(1,101) RSMS(K),A(K),B(K),C(K)
     101 FORMAT (F5.2, 3F7.6)
         READ (1, 101)  JJ, LL, CTC, (PHI(I), I=1, 6)
     102 FORMAT (3I3, 6F5.2)
         WRITE (3, 105)
     105 FORMAT (1H1, 25X, 45H IRRIGATION SCHEDULING REPORT FOR RABI 1974/75.//
         1/, 39X, 16H FEBRUARY 28, 1975,////)

C    CALCULATE SOIL MOISTURE DEPLETION FOR 6 LOCATIONS AND 4 SOIL TYPES AND 9 PLANT-
       ING DATES FROM NOV. ONE TO DEC.  TWENTY SEVEN  BY ONE WEEK INCREMENTS
    1002 DO 999 I=1, 6, 1
         DO 999 K=1, 4, 1
         WRITE (3, 103)  I, K, JJ
     103 FORMAT (5X, 10H LOCATION, I3, 5X, 11H SOIL TYPE, I3,18H CURRENT CROP A 2GE, I3)
         IF (JJ.LT.20)  GO TO 999
         M=7
     888 M=M—1
         IF (M.LE.0)   GO TO 999
         MM=7—M
         L=LL—((7) *(MM))
         J=JJ—((7) *(MM))
         IF (J.LE.O) GO TO 999
         LJ=L—J
```

```
CALCULATE SOIL MOISTURE DEPLETION FOR ONE TO SIX WEEKS SINCE LAST IRRIGATION
ASSUMING THAT THE LAST IRRIGATION FILLED THE ROOT ZONE RESERVOIR
      DO 9999 N=L, LL, 1
      IF (PAN (I, N)) 555, 555, 666
 555  IF (TEMP (I, N).GE.40.) TO TO 556
      TCELS=TEMP (I, N)
      TPANK=491.69+(1.8) *(TEMP (I,N))
      T—273.16+TEMP (I,N)
      GO TO 557
 556  T=273.16+(.55555) *(TEMP (I,N)—32.)
      TCELS=-T—273.16
      TRANK=459.69+TEMP (I,N)
 557  VAP=(0.1) *595—(.545) *(TCELS))
      V=((.9863) *(N)—169.644) *(.0174532925)
      DEL=(23.45) *(SIN(V)) *(.0174532925)
      X=(PHI (I)) *(.0174532925)
      Z=—((SIN(X))/(COS(X))) *(( SIN(DEL))/(COS(DEL)))
      IF(Z) 333,334,335
 333  HRAD= 3.141592654+ATAN ((SQRT(1.—Z * *2.))/Z)
      GO TO 335
 334  Z=1.E—10
 335  HRAD=ATAN((SQRT(1.—Z * *2.))/Z)
 336  H=ABS (HRAD/(0.174532925) )
      PDL=(.1333) *H
      Y=((.9863) *(N)—3.9452) & (.0174532925)
      DD=1.0009+(.0335) *(SIN (Y))
      ZEF=(SIN (HRAD))/COS (HRAD))
      S=(916.7325) *(DD * *2.) *(HRAD-ZEF) *(SIN(X)) *(SIN(DEL))/(VAP)
      IF (SS(I,N).GE.0.0)   GO TO 223
      P=(PDL *0.7)
      GO TO 224
 223  P=(SS(I,N))/PDL
 224  EA=51.7144 *EXP(54.6329—12301.688/TRANK-5.16923 *ALOG (TRANK))
      D=(12301.688/TRANK-5.16923) *EA/TRANK
      HE=(SQRT (RH(I,N))) *EA
      U2=(WR(',L)) *(1.104070)
      E1=(2.01E-9) *(T * *4.) *(.56—.092 *(HE)) *(.1+.9+(P))
      E2=(.95) *(S)(.18+.55 *(P))
      E3=(.35) *(1.+.0098 *(US)) *(EA) *(1.—(RH(I,L))/100.)
      PE=((D) *(E2-E1)+(.27) *(E3))/((D+.27 *(25.4))
      GO TO 77
 666  PE=PAN (I, N)
  77  RR=(1.—EXP(—3. *SMSB))/(1+EXP(—3. *S—SB)—2. *EXP(—3. *CSMS))
      IF (J.GT.14)   GO TO 602
      CC=.05+.002 *(J)
      GO TO 603
 602  CC=—.20869+.019995 *(J)   +.0000404 *(J) * *2   —.000Z64 *(J)..3
      1+.0000000048.(J) * *4
 603  AET=PE *CC *RR
      J=N—LJ
      ITEST+N+LL+7 *MM
      IF(ITEST) 1111, 1110, 1111
1110  SMSB=(A(K)+B(K) *(J)—C(K) *(J) * *2) *(RSMS(K))
```

```
1111 J1=J-1
     RD(K)=A(K)+B(K) *(J)-C(K) *(J) * *2
     CSMS=(RD(K)) *(RSMS(K))
     RDBEF(K)=A(K)+B(K) *(J1)-C(K) *(J1) * *2
     INCSMS=(RD(K)-RDBEF(K)) *(RSMS(K))
     IF (INCSMS.GT.0.0)   GO TO 1241
     INCSMS=0.0
1241 SMSF=SMSB-AET+RF(I,N)+INCSMS
     IF(SMSF.LE.CSMS)   GO TO 1200
     SMSF=CSMS
1200 IF(SMSF.GT 0.0)   GO TO 128
     SMSF=0.0
 128 SMSF=SMSF
     PERCENT=100. *(SMSF)/(CSMS)
     WATER=(CSMS-SMSF)/(.5)
9999 CONTINUE
     WRITE (3, 104)   MM, PDRCNT,WATER
     FORMAT (5X, 29H WEEKS SINCE LAST IRRIGATION, I5, 5X, 28H PERCENT MOIS-
     TURE AVAILABLE, F5.1, 5X, 25H IRRIGATION WATER NEEDED, F5.1)
     PERCNT=0.0
     WATER=0.0
     IF (M.GT.0)   GO TO 888
 999 CONTINUE
     JJ=JJ-7
     IF (JJ.GT.CTC) GO TO 1002
1001 CONTINUE
     STOP
     END
```

Appendix B

LIST OF SYMBOLS

I - Integer index for meteorological stations
L - Integer index for day of the cropping season starting from October 1
K - Integer index for soil types
JJ - Integer index for crop age at a given computational date in the crop season
LL - Integer index for computational date in the crop season
M - Integer index counter
MM - Integer week index
N - Integer index in computational do loop
LJ - Integer crop planting date with respect to start of season
J - Integer index for crop age from day of planting
JI - Integer index for crop age on previous day
ITEST - Integer index used to test for the first computational day on a new moisture budget
CTC - Integer constant used to test crop age for further computation
RF - Rainfall, in inches
PAN - Pan evaporation, in inches
SS - Sunshine hours per day, in hours
WR - Total wind run per day, in miles
TEMP - Mean daily temperature, °C or °F
RH - Mean daily relative humidity, percent
RSMS - Rate of soil moisture storage, inches/foot
A,B,C - Coefficients for the equation $RD = A+B(J)+C(J)^2$
RD - Rooting depth with time relationship, in feet
CSMS - Capacity for soil moisture storage for existing root zone, in inches
SMSF - Final value for soil moisture storage for a given day, in inches
RDBEF - Rooting depth on the previous day, in feet
INCSMS - Increment in soil moisture storage since the previous day, in inches
PE - Penman potential evapotranspiration in inches/day
RR - Rate of soil moisture removal function with respect to available moisture, a dimensionless decimal value between zero and one
CC - Crop consumptive use coefficient, dimensionless ratio of actual to potential evapotranspiration for a given stage of growth
AET - Actual evapotranspiration, in inches per day, obtained as the product (PE)(RR)(CC)
DEL - Declination of the sun in radians, based on the season of the year
PHI - Latitude of the meteorological station in degrees
DD - Earth's axis inclination relationship, dimensionless value ranging from .97 to 1.03

Z - Intermediate computational value used in calculation of half day length
H - Predicted half day length in degrees
HRAD - Predicted half day length in radians
PDL - Predicted day length in hours
V - Sinusoidal function used to change cropping year days from October 1 to calendar days corresponding to declination of the sun in radians
ZEF - Intermediate computational value equal to the tangent of the half day length in radians
Y - Sinusoidal function used to change cropping year days from October 1 to calendar days for computation of earth's axis inclination, in radians
TECLS - Temperature in degrees Celsius
T - Absolute temperature in degrees Kelvin
TRANK - Absolute temperature in degrees Rankine
VAP - Conversion for latent heat of vaporization from calories to inches of water equivalent
S - Calculated value of theoretical radiation at the outer surface of the atmosphere in inches of water equivalent
P - Daily percentage sunshine as a decimal
EA - The saturation vapor pressure as a function of absolute temperature in millimeters of mercury
D - The slope of the saturation vapor pressure curve at the atmospheric temperature in millimeters of mercury per degree rankine
HE - The actual vapor pressure of the atmosphere in millimeter of mercury
U2 - The total daily wind run at 2 meters elevation, converted using a plogarithmic wind profile for elevation above the ground surface in miles per day
E1 - Total radiation input to the crop environment assuming an albedo of 0.25 for a green crop surface in inches of water equivalent
E2 - Total radiation lost from the crop environment due to long wave back radiation and sensible heat in inches of water equivalent
E3 - Aerodynamic exchange of moisture in inches of water equivalent
PERCN. - Available soil in moisture percentage
WATER - Irrigation water depth required in inches assuming an application efficiency of 50 percent.

APPENDIX C

Example: Calculate the daily potential evapotranspiration for Multan with the following data:

STA002; PHI(STA) = 30.20;

DATE 6 MAY; DAY = 218;

WR = 68 miles per day; SS = 9.5 hrs;

Mean temperature = 29.5^{o} celsius;

Mean relative humidity = 20%

Procedure: T KELVIN = 302.66 STO-0

T RANKIN = 544.79 STO-1

1) V = C1 DAY - C2 = 0.791844883 radians

2 = 45.36936981 degrees

2) DEL = C3(SIN(V)) = 0.291264141 radians

STO-0 = 16.68820 599 degrees

3) X = C4 PHI(STA) = 0.527089418 radians

STO-1 = 30.20 degrees

4) Z = -TAN(X)TAN(DEL) = 0.174481958 radians

= -9.997079787 degrees

5) HRAD = COS^{-1}(Z) = 1.395416554 radians

STO-3
6) HDEG = HRAD/C4 = 79.95148733 degrees

7) PDL = (HDEG)(G5) = 10.66 hours

STO-2
8) .P = SS/PDL = .891165413

9) Y = C6(DAY) - C7 = 3.683840083 radians

= 211.0684891 degrees

10) DD = C8 + C9 SIN(Y) = .983611912

STO-7
11) Q = W(DD)(HRAD SIN(X) SIN(DEL) + COS(X)(DEL)SIN(HRAD) = 889.2990522 langley/day

12) L = C10-C11(TCELS) = 580.66 langley/cm

STO-7
13) S = (12) Q/L = 15.31531451 mm/day

STO-6
14) SVP = C13e C14-C15/TRANKIN-C16LN(TRANKIN) =
30.87684320 mm hg

STO-5
15) D = $(\frac{1}{\text{TRANKIN}})$ $(\frac{\text{C15}}{\text{TRANKIN}})$ - C16) SVP = .986817503 mm/R

16) AVP = RH(SVP)/C25 = 6.175368640 mm hg

STO-3
17) EE = S (1-r)(A+B(P)) = 7.697564869 mm/day

18) SH = σ(TKELVIN)^4 (C17 - C18 AVP$^{1/2}$)(C19+C20 P) =
5.041607636 mm/day

STO-2
19) H = EE-SH = 2.655957233 mm/day

STO-1
20) U2 = WR(C21) = 75.07676000 miles/day

STO-7
21) E = C22 (SVP-AVP)(C23+C24(U2)) = 15.00647400

22) (D)(H) + (G)(E))/(D+G) = 5.309198071 mm/day

APPENDIX 6

TRADITIONAL AND IMPROVED IRRIGATION PRACTICES IN PAKISTAN

Wayne Clyma and Arshad Ali[1/]

Introduction

Irrigation practices describe the state-of-the-art (SOTA) of irrigation in a particular area. A SOTA study can identify the needs for improvement in irrigation practices in an area. This paper describes the concept of a state-of-the-art study and applies the concept in the qualitative and quantitative description of irrigation practices in Pakistan. Benefits and problems of three technologies, precision land leveling, improvement of delivery channels, and farmer irrigation advisory services, are evaluated and discussed.

Background

Irrigation in Pakistan began with the Mohanjadora civilization more than 5,000 years ago (22). Summer flood waters were diverted to cover lands adjacent to the river and were used subsequently to grow crops. A modern conveyance system was constructed by the British in the late 1800's. Today, it is the world's largest contiguous irrigation system serving in excess of 30 million acres.

In the early 1960's, major modifications of the irrigation system were instituted with the construction of storage reservoirs and the installation of tubewells for groundwater development. Waterlogging and salinity were major problems then and remain so today. Reviews of these developments have been presented by Khan (17), Michel (18), Corey and Clyma (8), and Clyma and Corey (6).

[1/] Associate Professor, Department of Agricultural Engineering, Colorado State University, Fort Collins, Colorado, and Assistant Professor, Department of Irrigation and Drainage, Faculty of Agricultural Engineering, University of Agriculture, Faisalabad, Pakistan, respectively.

A system of dams, barrages, major canals, minor canals, and distributaries deliver water to an outlet. The outlet is ungated and is designed to deliver a proportion of the canal flow to a command area and a community of farmers on a continuous basis. Past the outlet the channel system was built and is maintained by the community of farmers. Water is apportioned on a turn basis with the time of each turn in proportion to the land area owned and operated by the farmer. Administration of the turn system is fixed by the government or informally administered by the farmers on a rotation of from 7 to 14 days. A farmer uses all the flow from the outlet during his turn and diversion of the flow or use out of turn is prohibited by law. Further details of the distribution are described by Corey and Clyma (8) and by Hassan (13).

The topography of the Indus basin is flat with an average natural slope of 9 in. per mile. Few artificial drains have been constructed and natural drainageways are minimal. Irrigation water supplied to an area must be used within the area because there is no provision for passage to a lower elevation.

Time limitations of the turn system of water allocation and low infiltration rates require that water supplied to a field must be ponded on the surface as the opportunity time for filling the soil root zone is longer than the turn time. The ponding procedure requires a level system as neither drainage nor methods to return water to a higher elevation are provided. Level basins are used for essentially all the irrigated area.

Farmers have attempted to level their land within a basin to zero slope with traditional implements, which are bullock-drawn logs and boards. Using water for measuring levelness and his traditional tools, the farmer, of necessity, has developed a system of very small fields because he cannot maintain a small tolerance over a large land area. His basic unit is one acre in size for water control. This is subdivided into four and frequently eight parts with a system of ridges making each subdivision a separate irrigation unit. Water may be transferred from unit to unit but only after the coverage of each unit is complete.

The basis for this paper is a four year study of irrigation practices in the Punjab Province of Pakistan. Preliminary results of these studies have been presented by Clyma and Corey (6), Clyma, Ali, and Ashraf (7), Ali, Clyma and Ashraf (2), and Ali, Clyma and Early (3). This paper summarizes the results of these studies.

State-of-the-Art Concept

Art, according to the American Heritage Dictionary (10), is "A system of principles and methods employed in the performance of a set of activities: the art of building." The state of the system is known when, given the system conditions at time, t_0, and the distribution of inputs over time to t_1, the system conditions at time, t_1, can be determined (22). State has the concept that the condition of a system is known when the state variables have been defined. A state-of-the-art study of irrigation describes the state variables which define the irrigation practices of farmers in a particular area.

Plucknett et al. (21) have given a broader definition of SOTA which includes review of literature, state of present known principles and the identification of knowledge gaps. The problem is also defined within a worldwide context. The definition proposed in this paper restricts practice to a local geographic area, requires the use of presently known principles to define the state variables of the system and does not include a major literature review which, within the present context, might be called a state-of-the-science (SOTS). Application of the SOTA concept presumes the researcher is current and capable in the SOTS.

In this application of the SOTA concept, the system is water application during surface irrigation. The state variables will be defined and their values established during farmer practice. As an extension of the SOTA study, three technologies--precision land leveling, improvement of farm delivery channels, and irrigation advisory service--will be discussed with their impact on the future state of the water application system inferred from an evaluation of their benefits.

The Water Application System

Application of water to a field can be described by the primary variables of water supply rate, slope, infiltration rate, field geometry (length and width), and surface roughness. Another variable, channel shape, is constant under basin irrigation as practiced in Pakistan. Specifying the boundary and initial conditions are necessary also to completely define the state of the system.

Water application is accomplished through the management objectives of the farmer, who operates the system. A farmer answers the basic questions of: (1) When do I irrigate? (2) How much? and (3) How? in the management of his water application system. Qualitative and quantitative descriptions of the variables which define the water application process and of how a farmer arrives at answers to the above questions will be used to describe the state-of-the-art of water application.

Some authors (13) have suggested that additional variables in water application are depth of flow, rate of advance, rate of recession and depth of water applied.

These are, in reality, responses or outputs of the water application system and are completely specified when the state variables have been defined.

In this section the state variables, water supply rate, slope, infiltration rate, field geometry, roughness, and management will be sequentially discussed to describe the state of irrigation practices. First, the data collection procedure is described.

Procedure - Data from previous reports (7), (2), (3) on irrigation practices in Pakistan will be summarized and interpreted to define the SOTA for the Punjab province. Data were collected from field observations of farmer practices which include two different approaches.

In the first approach irrigation practices were evaluated from the following data which were collected before and during the time water was applied to a farmer's field.

1. The volume of water applied.
2. Soil moisture deficiency or date of last irrigation.
3. Two or more elevation profiles of the basin (field).
4. Advance and recession times of water at marked stations in the basin.
5. Infiltration from ring infiltrometers during the time of irrigation.
6. Length and width of basin.

The procedures followed were generally those proposed by Criddle et al. (9) for evaluation of border irrigation systems. Soil moisture deficiency was estimated using the "feel" method described by Halderman (12) or by using the Jensen-Haise (16) method for estimating evapotranspiration and the resulting soil moisture deficiency.

In the second approach during some irrigations, measurements of only items (1) and (2) were obtained. This reduced the number of measurements and time required per field permitting measurements of additional fields.

Water Supply Rate - Quantitative approaches to water application require that the application rate and time are known. Most farmers and researchers in Pakistan apply water to a field until any high areas in the field are covered. They assume this results in a 3 in. (7.5 cm) irrigation or at most 4 in. (10 cm). The rate at which water is applied is not explicitly considered and the time of application is the time required to cover the field.

The amount of time required to apply a given amount of water to a given area depends only upon the rate at which it is applied. The amount applied to cover a given area depends upon the application rate, surface topography (levelness and slope), infiltration rate, field geometry (size and shape) and surface roughness. Since these factors vary widely from field to field and area to area in Pakistan, the length of time to cover a given area with water and the resulting amount of water applied will also vary widely. In some 700 measurements in widely spaced geographic locations the measured application amount ranged from 1 to 13 in. (2.5 to 33 cm). Most researchers and farmers assume that the amount of water applied to cover a given area is constant. This results in excess applications of irrigation water.

Canal level and water supply rate was well regulated for several experimental outlets observed over intervals of from several months to several years. During water short years, variations are greater including complete closures due to rationing. Some outlets do have major variations, particularly at the lower end of a canal.

From the canal outlet to a field, flow rates vary widely. Under supplemented water supply conditions, government or privately owned tubewells may add water to the supply frequently doubling the flow rate. Official canal water supply at each outlet varies with the area served. Flow rates at the outlet range from less than 0.5 cubic feet per second (cfs) to more than 3 cfs (0.013 to 0.084 m^3/sec).

At a given field in a particular area, flow rates vary widely over time. Losses from the channel cause a variable flow rate at the field. Loss rate varies with the rate of flow in a predictable fashion. Spills, breakage of earthen banks, and erosion of diversion dams impose sudden changes in flow rates. During periods of peak water needs, flow rates are usually the highest and losses are usually the highest also. The result is a farmer must manage a flow rate that may vary in order of magnitude with knowledge that does not consider flow rate as an explicit variable.

Slope - The surface topography of a field affects the amount of water applied in covering the field. Extra water is required to fill the low areas of the field and additional time is required to cover high areas. In a number of instances, the measured time required to cover a high spot doubled the irrigation time and consequently the amount of water. Basins are not level in Pakistan. They may have differences in elevation from 0.1 to 0.5 ft (3 to 15 cm). In addition to not being level because of high and low areas, the fields frequently have slopes. When the slope is away from the field outlet, the farmer applies water until the field is covered with much of the water being ponded on the lower end. Several times fields were measured with the slope towards the field outlet. Excess water is required in this case to cover the field and the high portion remains underirrigated. Unleveled fields are responsible for substantial overirrigation in Pakistan.

A measure of field levelness is the range of elevations within an irrigation unit. In 30 profiles of individual areas surrounded by a ridge, 30 percent of the fields differed by at least 0.2 ft (6 cm), 33 percent ranged from 0.2 to 0.4 ft (6 to 12 cm) and 37 percent differed by 0.4 ft (12 cm) or more.

Infiltration Rate - Basic intake rates (the infiltration rate after several hours of ponding) on many soils are low, approaching 0.1 in./hr (.25 cm/hr) or less. This is probably related to the high silt content of the soil, but may also be related to soil structure, lack of organic matter and alkalinity. Some soils in Pakistan have sufficient sand content and a much higher infiltration rate. Traditional irrigation methods on such soils almost always results in overirrigation.

Two additional factors influence infiltration rates and the amount of water applied to a field. High infiltration rates frequently exist at the beginning of a cropping season. Most farmers irrigate their fields in preparation for plowing and this irrigation will frequently fill the expected root zone with water. After plowing a number of times, the field is frequently irrigated again in preparation for planting. This preirrigation is necessary primarily to insure adequate soil water for germination and emergence. When the preirrigation is applied, the soil moisture deficiency in the top 4 ft (1.2m) is frequently no more than 1 to 1.5 in. (2.5 to 3.8 cm).

The loose surface soil condition may result in 1.5 to 2 in. (3.8 to 5 cm) of infiltration during the first few seconds that water is applied to a field. It is not surprising that an additional 4 in. (10 cm) or more is generally required to cover all of the field. This results in much overirrigation.

The second factor influencing the amount of water applied is the seasonal changes in infiltration rate. Data collected in Pakistan and in the United States have shown that the infiltration rates of soils often decrease as the cropping season progresses. The amount by which infiltration decreases depends both on the initial rate and management factors. Whether farmers continue to overirrigate their fields depends on how the infiltration rate changes with time. The reduction in infiltration rates appears to at least reduce the amount of overirrigation.

On many soils where the infiltration rate substantially decreases during the season, the farmer underirrigates. From the preirrigation to the fifth irrigation the amount of water which infiltrates during the application time can vary from 5 in. (12.7 cm) to 1 in. (2.5 cm), thus varying the amount of water required to cover a field from 8 in. (20.3 cm) to 4 in. (10 cm). The combination of reduced amounts of water applied caused by a reduction in infiltration rates, and larger and larger amount of soil water extracted by the plant due to increased evapotranspiration can result in the development of severe moisture stress. One of the primary factors causing low yields of most crops in Pakistan is the severe soil moisture stress allowed to develop during periods of peak water use. The circumstance results largely from assuming that (1) a certain amount of water is applied to a field when the field is covered with water, and (2) infiltration rate changes during the season can change the amount applied to the same field by a factor of four.

Field Geometry - The size of the fields in relation to the discharge available for irrigation also affects the amount of water applied to a field. Design criteria for basin irrigation systems suggest that when irrigating a one-half acre (0.2 ha) field with 4 or 5 cfs (0.1 to .15 m^3/sec), a flow rate of from 2 to 30 times the recommended flow rate is being used (24). Use of excessive flow rates to irrigate small fields results in additional water being applied when the time of irrigation is the time to cover the field. Farmers do commonly divide the flow when tubewell plus canal water is available and they irrigate more than one field at the same time, sometimes on more than one branch of the watercourse. The flow rate may still be excessive for the size of field because field sizes frequently range from 0.25 to 0.5 acre (0.1 to 0.2 ha).

While size of field affects the amount of water applied, arrangement of the field also affects the effectiveness of water use. Preliminary experiences suggest that properly designed borders reduce the length of watercourse required to serve the fields by 60 percent. Also, a properly leveled border can be irrigated in one-half to one-third the time for unleveled fields.

In areas with only canal water, farmers reduce the size of the field because of the reduced flow rate and also to improve their ability to level precisely. In one such area, more than one-half of 200 fields (a field in this definition is an irrigation unit or a bunded area) measured were less than 0.3 acres (0.12 ha) and one-third were less than 0.2 acres (0.08 ha). Proper leveling would reduce the amount of overirrigation.

Surface Roughness - Surface roughness is variable throughout the season. In some areas, surface clods, formed during normal tillage operations, complicate water application. Vegetation density increases as the season progresses. The result is to increase the amount of water required to cover a field. The quantitative effects of vegetation on amount of water applied was not measured.

Management - The farmer operates the water application system based on his objectives. His management of the system results from how he answers the questions of: When do I irrigate? How much do I apply? and How?

A farmer irrigates using the basin system of surface irrigation. How much he applies is usually determined, as indicated previously, by the criteria of when the surface of the field is covered. The decision of when to irrigate is his primary management variable and is based on several considerations. A farmer's objectives are to manage his available water to supply his crops, maintain proper soil salinity conditions, and facilitate tillage operations.

Management of the water supply is affected by its dependability. A review of flow rate at the field outlet suggests that the flow may vary from zero to the maximum available in an unpredictable manner. The result is that a farmer will use water whenever it is available to maintain a high soil water level as insurance against the time when water is not available or is available at a reduced rate. Further, he may not have an alternative method of disposal of his canal water supply since drainage facilities are not generally available.

As others have discovered, a strict rotation system does not actually operate in Pakistan. Farmers trade and make unauthorized diversions of water under a system that greatly modifies the official turn rotation. Since many factors affect water needs other than simply the passing of time, water is used simultaneously by two farmers and out of turn sometimes as often as on a fixed schedule.

Despite these unofficial adjustments of the turn schedule, water is still frequently applied when it is not needed by the crop. A number of irrigations were observed to sugarcane, for example, when the soil water deficiency was zero. In attempting to schedule observations of the irrigation of particular fields, frequently farmers would insist that a given field would be irrigated next. At the last moment another farmer would request the turn and the water would go to a different field. These adjustments of the official turn tends to maximize the benefits derived from any surplus water.

As the crop grows, the rate at which water is extracted from the soil increases. Typically this may increase from 0.05 in./day (13 to 64 mm) early in the season to over 0.25 in./day during periods of peak water use. Thus, a farmer, who maintains the same interval between irrigations or slowly reduces the interval, will have larger and larger soil water deficits at the time of each succeeding irrigation. This increased soil water deficit will tend to decrease the overirrigation as the season progresses.

A complicating factor that affects overirrigation is rainfall. During the winter season, rainfall usually occurs when plant water requirements are low. Since water is available from the canal, irrigation continues. This contributes to overirrigation. During part of the summer, rainfall occurs when water use rates are high and the frequency and amount of rainfall sometimes exceeds crop requirements. Irrigation during this period results in overirrigation.

Waterlogging is a serious problem in Pakistan and the water table is within ten feet of the surface for 17.4 million acres (4). Waterlogging may also contribute to inefficient use of water. As the water table rises, crops draw increasing amounts of water from the water table. This use from groundwater reduces the amount of water needed from irrigation. Ahmad (1) has shown that as the water table varies from ten to three feet (3 to 0.9 m) from the surface, from 0 to 80 percent, respectively, of the evapotranspiration can be met from groundwater.

The primary point is that a high water table reduces the irrigation water needed to supply the consumptive use of crops. This reduced requirement for water should result in reduced amounts and decreased frequency of irrigations. When the farmer continues to apply large amounts of water at the prevailing frequency, a high water table results in overirrigation.

The rate of evaporation at the soil surface increases with a high water table especially in fallow fields, and consequently the rate of salt accumulation at the soil surface also increases. Leaching of salts down from the soil surface is inhibited and essentially stops at the water table. The salts thus leached are easily carried back to the soil surface by continued evaporation.

Underirrigation is practiced in Pakistan at least seasonally on many fields. This occurs during the period of peak consumptive use in March for winter crops and in July and September, before and after the monsoon, during the summer. Some fields are underirrigated consistently and these fields have developed salinity problems.

The time interval between irrigations appears to be a combination of how many turns are required to cover the area being cropped and how much rainfall and borrowed or unauthorized water is available. When a turn occurs and the water is not needed because rainfall has filled the soil moisture reservoir, the field is not ready for the preirrigation, or because of other factors, it may be used to repay borrowed water or to irrigate the field that "most needs" irrigation. During the summer season, sugarcane and rice usually are irrigated with surplus water. During the early winter, the most common use of this "extra water" is on fodder crops. In every outlet area, surplus water does occur and it is used on fields which do not need irrigating. The water requirement varies widely during the season while the supply is available at a constant rate in much of the area.[2] Then during the early stages of growth and after substantial rainfall, water applied results in overirrigation.

A review of the status of water demand on a watercourse during several years of observations suggests four periods when water is in short supply. The most obvious and traditional periods are those of peak consumptive demand during the winter and summer seasons. Farmers appear to meet the demands of these periods by adjusting the frequency of their irrigations, from two weeks to four weeks, for example. Where water is short and many watercourses are short at these times, severe moisture stress frequently develops. The other short supply periods are the time of planting for the winter and summer crops.

Summer crop plantings for sugarcane, cotton, fodders, rice and vegetables are spread over longer intervals of time and the shortage is not as great as for winter crops. Other factors such as harvesting of wheat and tillage do contribute, but a major factor affecting the acreage planted is the amount of water available for the preirrigation. For wheat, the major factor limiting the acreage sown is probably the amount of water available for preirrigation. Once sown, the frequency of irrigations is adjusted to use the available supply. Water use for preirrigation frequently results in a great wastage of water when the water supply is probably the shortest.

Water is short in Pakistan and the shortage has been documented in many ways by many people. The documentation procedures used most generally are to cite acreages, water supply and annual potential evapotranspiration or evaporation. As discussed by Clyma (5), this does not adequately describe water needs for several reasons. Water is short primarily in the sense that the total area cannot be used for maximum production with the available water supply. As presently managed, the available water supply is used excessively on many cropped fields. Farmers adjust water demand to water supply by the acres they plant and the frequency between irrigations.

Even in areas where canal water only is available and the water supply is inadequate, water is being wasted due to improperly leveled fields and poor management practices.

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[2] Where water from wells is available, this rate can be adjusted.

Some individual applications of water to a field are excessive even in water short areas. There is no practical way a farmer can irrigate an improperly leveled field without overirrigating at least some part of the area. This is the reason precision land leveling is valuable and explains why farmers invest time and effort in attempting to level fields.

Evaluation of Water Application

Quantitative evaluations of water application have usually been defined in terms of application efficiency and a distribution coefficient (17). A major disadvantage of both of the above parameters is they do not provide adequate data on the spatial and time distribution of water. Application efficiency also does not adequately describe the soil-water status when the soil moisture deficiency is not filled during an irrigation. One or two parameters can not adequately describe a multiparameter system such as water application, but may be adequate for particular management conditions.

Distribution coefficients for water application were not computed. Numerous measurements of advance, recession, replicated measurements of infiltration and surface elevation profile were obtained. The general conclusion was that because of low terminal intake rates and long inundation times the distribution of water in a field was closely associated with elevation. Because the opportunity time for high areas is a function of location within a field, the amount of infiltration is not directly related to the elevation above the average surface elevation of the field. For those portions of the field with long inundation times, the actual differences in amount of infiltration are small because of the low terminal intake rate.

Application efficiencies[3] should be discussed for areas with canal water only and areas supplemented with water from wells. The supplemented areas should probably be divided further into areas with privately operated and publicly operated wells.

A further comment should be that because of geographic and time variations in rainfall and depth to groundwater, individual variations in farmer practices, and other factors, an average application efficiency for Pakistan is not now known. The results of time and space distributed measurements of application efficiency can provide tentative estimates of application efficiency.

Results of measurements of application efficiency in supplemented water supply areas suggest that a seasonal

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3/Defined a ratio of the water stored in the root zone to the water applied to a field.

average is estimated to range between 25 and 40 percent in areas with publicly operated wells with an average near 30 percent. In areas of privately operated wells, the range is expected to be greater and the average is estimated to be 40 percent. Individual irrigations range between 0 and 100 percent with the low efficiencies occurring early and late in the season and the high efficiencies (100 percent representing underirrigation) during the periods of peak consumptive use.

Application efficiencies in areas with canal water only are estimated to range from 40 to 100 percent with an average near 60 percent. Results were even more variable than supplemented water supply areas. There is much opportunity for improvement of application efficiencies in Pakistan as suggested by Clyma and Corey (6). Improvements in the effectiveness of water use would reduce waterlogging problems, provide increased yields and permit increasing the irrigated area. Present practices result in an average of approximately half the area in crops during a season because of a shortage of water.

New Technologies

The state-of-the-art of water application defines current practices. New technology such as equipment, knowledge, or procedures can change current practices. Equipment is available in Pakistan to accomplish land leveling and the procedures have been established (10). New knowledge and procedures are available to improve irrigation delivery channels to increase the quantity of water at the field and improve the dependability. Irrigation advisory services are under development to assist in using more effectively the water presently available as well as the increased supplies resulting from precision land leveling and watercourse improvement. The implications and effects of the three technologies, precision land leveling, improved watercourses, and irrigation advisory services, will now be discussed. Their effect on the current state-of-the-art will also be described.

Land Leveling - Precision land leveling using engineering skills and a tractor drawn scraper and planer are available for use in Pakistan. A number of studies (21), (3), (9), (23) have attempted to document some of the costs and benefits as well as the needs for land leveling in Pakistan.

A number of demonstration programs have been operated by various agencies of the Government of Pakistan in cooperation with Colorado State University. Farmers are initially hesitant to try precision land leveling. Small and fragmented holdings, lack of adequate resources and lack of credit restrict the use of land leveling. The major benefit farmers perceive in precision land leveling is the reduction in time required for the preirrigation. The time for a preirrigation after leveling ranges from one-half to one-fifth of the time required before leveling.

In a survey of land leveling services supplied over several years, farmers perceived the major advantages of leveling to be:

1. Reduction in time of irrigation
2. Increased yields
3. Reduced salinity

Eckert, Dimick and Clyma (11) detailed other advantages and make a preliminary economic analysis of the benefits of leveling. The rate of return was very advantageous as a technology for farmers to adopt even when some of the advantages are not considered.

Dependable Supply - A major factor in water application is the rate at which water is applied. Another significant aspect is the dependability of the flow rate and knowledge of how the flow rate affects the amount of water applied. Variability of flow rate and lack of knowledge of how long to irrigate were previously identified as major factors in poor management of the water application system.

Several studies (6), (8) have described the problem of loss in on-farm irrigation delivery channels in Pakistan. Methods for the reduction of loss have been devised and farmers have been able to increase the quantity and dependability of their water supply (11). The dependability and flow rate information are used on improved watercourses to develop a program of assistance to farmers to improve management of the water. On an improved watercourse, an irrigation advisory service has been provided.

Irrigation Advisory Service - Effective use of water presently available as well as additional water made available through improved management is important to farmers. The farmer may also be made aware of the amount of water required to irrigate a field by supplying a constant flow rate and having him evaluate the time required to irrigate a given field. By providing at least one precision leveled field, a relative need for leveling can be illustrated by comparing the required times of irrigation. His improved management can be used to increase both the area irrigated and the level of production.

Irrigation scheduling as practiced in the U.S. involves designating a date of irrigation and an amount of application when considering a particular field and climate. Crop, soil and known irrigation practices are also considered. In Pakistan, the diversity of fields (2 to 10 per acre) the mixed cropping practices (many different crops and different crops in a field), unknown irrigation practices and communication difficulties make the concept of irrigation scheduling difficult to apply. Instead, an irrigation advisory service is being developed.

In an area where delivery channels have been improved, knowledge of existing flow rates, irrigation frequencies and climatic conditions are used to review present cropping patterns and water requirements to develop improved practices. The excessive number of units precludes scheduling each field. But irrigation amounts can be adjusted by using a more optimum irrigation time. One farmer was found to be applying more than 4 in. (10 cm) of water on a weekly basis. While the frequency may have been acceptable for vegetables, by adjusting the time, the amount applied could be reduced.

In another instance on a larger farm, more than 80 irrigation units resulted in haphazard irrigation frequencies. Wheat in one field received ten times the amount of water as another field. This farm started a system of recording irrigation times in order to better manage the allocation of water between fields and crops.

With the improved delivery system, time for a given application to a given area could be used as a basis to help farmers manage the amount applied. Recommended frequencies for given crops and soils are used to help farmers improve their ability to make decisions concerning frequency of irrigation. The result is an irrigation advisory service which improves water management but does not schedule particular fields.

Impact on Pakistan

A water management program consisting of improvement of delivery channels, precision land leveling and improved extension services is being implemented as a pilot project in Pakistan. Totaling 40 million dollars, the program is jointly financed by the Government of Pakistan and the U.S. Agency for International Development. The World Bank is planning a program to extend the improved water management practices to the rest of Pakistan.

Summary

Irrigation practices of farmers in Pakistan have been studied over a four-year period. Overirrigation is a frequent occurrence caused by farmer lack of knowledge, inadequately leveled and improperly designed fields. Results of measurements of application efficiency suggest that a seasonal average is estimated to range between 25 and 40 percent in areas with publicly operated wells with an average near 30 percent. In areas of privately operated wells, the range is expected to be greater and the average is estimated to be 40 percent. Canal water only areas are estimated to range between 40 and 100 percent with an average near 60 percent.

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APPENDIX 7

POTENTIALS FOR INCREASING CROP YIELDS THROUGH IMPROVED WATER MANAGEMENT IN THE BARANI LANDS OF PAKISTAN

FOREWORD

Recent studies have shown that improved water management can achieve significant increases in crop production in the irrigated areas of Pakistan. In the barani areas, water is a more limiting constraint on crop yields. The farmers in these areas are more completely at the mercy of our climate and deserve and need the help of our scientists and engineers to make the best use of their available water.

As a first step toward developing the basis for a sound research and development program in barani water management, I have asked the Colorado State University Water Management Team Party Chief and the Agricultural Research Council, Soil and Irrigation Directorate to prepare the following discussion paper.

The purpose of this discussion paper is to define the opportunities which scientists and engineers can use to help the barani farmer improve his water management and crop production.

Dr. Heshamul Haque
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Agricultural Research Council
Government of Pakistan

POTENTIALS FOR INCREASING CROP YIELDS THROUGH IMPROVED WATER MANAGEMENT IN THE BARANI LANDS OF PAKISTAN[1]

by
W. D. Kemper, Shahid Ahmad and Baz Mohammad Khan[2]

INTRODUCTION

The accumulating fund of basic information concerning crop production vs. available water, and estimates of precipitation and runoff indicates a substantial potential for improving water management and crop yields in the barani areas of Pakistan. This paper outlines this potential including the apparent physical and economic feasibilities in terms of the costs of labor, power and other resources available in the barani area, and current crop values. Your consideration and discussion are invited.

A. Description of Land and Water Resources of Barani Area

The barani lands can be discussed in three broad zones.

1. Areas where average annual rainfall is sufficient (38 cm and above) to grow winter wheat regularly with water management and conservation techniques. These areas are primarily in the Punjab and NWFP although some wheat can be grown in Baluchistan because of the altitude and subsequent cooler temperature and reduced water requirements.

2. Areas where average annual rainfall ranges from 20 to 38 cm. Crops that can be grown during the brief monsoon period constitute the main agriculture; parts of the Punjab and NWFP fall in this category.

3. Areas where the average rainfall is less than 20 cm where crop production is negligible and the agricultural use of the land is generally limited to grazing the small amount of forage produced.

The total cultivated area in the barani is about 17 million acres. Wheat is usually produced on 4.0 to 4.7 million

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[1] A discussion paper prepared under the auspices of the Agricultural Research Council, Government of Pakistan.

[2] Chief of Party, Colorado State University Water Management Research Project; Assistant Coordinator of the Consumptive Use Project, and Director of the Soil and Irrigation Section, Agricultural Research Council, Government of Pakistan.

acres and grain and coarse grains (maize, sorghum and millets) on about 1.5 million acres. Other crops grown are pulses, ground nuts and oil seeds. About ten million people live in this area of Pakistan.

In the barani tract the average annual rainfall varies from 10 to over 100 cms. If the average rainfall in the cultivated area is 40 cm, then roughly 23 million acre feet of precipitation is received over an average year on this cultivated area. If the runoff varies from 10 to 50 percent with an average of about 25%, the runoff loss from the cultivated portion of the barani areas is nearly six million acre feet of water per year. If the water lost by runoff from the larger acreages of range land and forest areas is added, the total loss is probably of the order of 15 million acre feet. This runoff is frequently destructive and presently provides little, if any, benefit to agriculture because it occurs largely during monsoon months when the lower portions of the river already have more than adequate supply.

This runoff is the potential water supply for supplementing water presently used in crop production. The following discussion describes how this supplemental water might be used to increase crop production.

Normal precipitation in some parts of the barani area is adequate for crop production. Here the seasonal rainfall pattern often coincides with crop water requirement. However, considerable hazards still arise from the variability and irregularity of the rainy season causing uncertain water supplies to crops. Conservation of rain water in the soil profile, reservoirs, ponds, etc., and supplemental irrigation at drought stages can reduce the hazard of crop failure.

The average barani crop yields are indicated in the following table. The existing yields are extremely low compared to the potential yields (e.g. wheat at Lyallpur 1975-76 and maize 1976 at Tando Jam) as indicated in Figures 1 and 2.

Crops	Average crop yield in maunds per acre
Wheat	6
Maize	8

B. Crop Response to Water in Pakistan

The yield of grain is highly dependent on the amount of water available during the growing season as indicated in Figure 1 which gives yield of wheat from three studies conducted in Pakistan. Note the large increases in yield which can be obtained from increases in available water in the range from 20 to 35 cm of water. The average barani wheat yield of

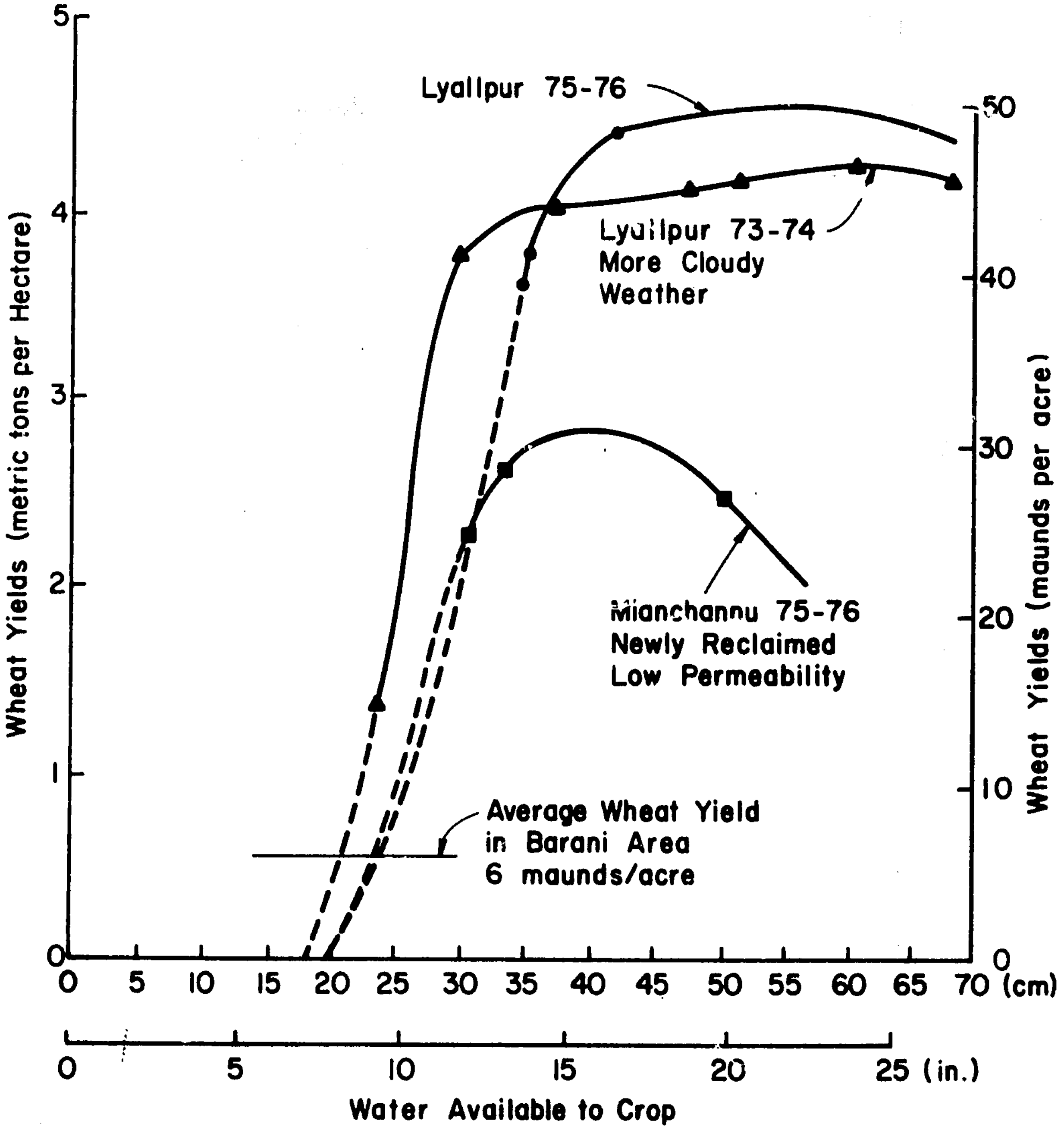

Figure 1. Wheat yields obtained with different amounts of water available during crop growth period.

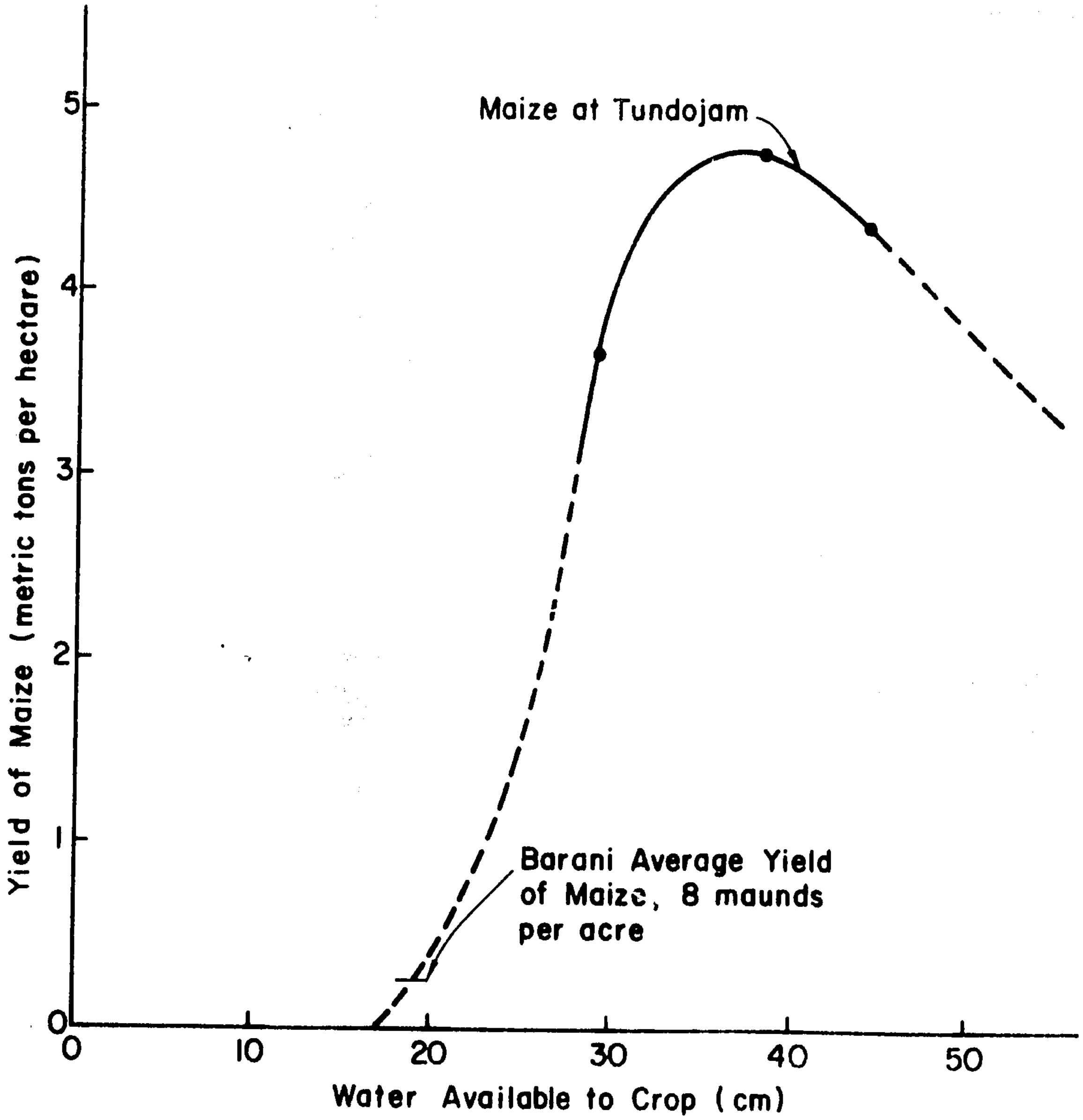

Figure 2. Maize yield, Tons per Hectare obtained with different amounts of water (cm) applied during crop growth period at Tandojam, 1976.

only 6 maunds/acre indicates that either the farmers are operating at the lower end of water availability, or that they have not applied sufficient fertilizer to achieve the potential yields indicated. A recent study (Alverson et al. 1977) indicates that farmers do not apply fertilizer when their water supply is low or uncertain. Consequently, available water supply is a primary factor regulating barani yields.

Note that the curves in Figure 1 are not all identical, even in the same location. For instance, in Lyallpur in 1973-74 (USAID 1975) the weather was cloudy and cooler than in 1975-76 (Bhatti 1976). The result was that less water was required to grow the crop in 73-74, but the maximum yields were higher in 75-76. The data at Mian Channu (ARC-1976) were taken from wheat grown on newly reclaimed lands, which have poor structure and are slowly permeable. The effect of this poor structure was considerable reduction in yield, particularly at higher levels of available water.

Figure 2 shows the yield of maize (at Tando Jam, ARC, 1976) as a function of available water. The shape of the curve is generally similar to that for wheat.

These curves relating yields to available water were obtained primarily from consumptive use studies which have been located in irrigated areas. Depending on the aridity of surrounding lands and the resulting convention of energy to the crop canopy, the water use in barani areas can exceed that shown in these figures by several centimeters per growing season. However, the elevation of barani areas in Pakistan is generally higher than the elevations in the irrigated areas, which results in lower average temperatures in the barani. Consequently, these water use estimates from the irrigated areas are reasonable estimates of the use in the barani lands.

Comparing yields from these curves to the average yields for wheat and maize in the barani shows the potential for increasing wheat and maize yields by 500% if adequate water can be made available, and soil fertility is brought up to reasonable levels (i.e. 90 and 60 lbs. of N and P_2O_5 respectively).

Water management improvement in the barani areas should involve bringing the amount of water to the crop which will bring yields up onto the "shoulders" of curves of the type shown in Figures 1 and 2. In irrigated areas, the correct amount of water can be applied by knowing the amount needed, knowing the flow in the watercourse and opening the nakka (field outlet) for the correct amount of time. In barani areas, there is generally no canal or tubewell supply, and management of water to achieve optimum levels for crop production must be based on other principles and knowledge.

C. Benefits to be Gained from Managing Precipitation

1. Retaining Incident Precipitation (In areas with from 24 to 40 cm of precipitation available during the crop season[3])

Assume existing runoff condition as in Figure 3 and wheat yield response to water as at Lyallpur as in 1975-76. In areas where the rainfall that can be made available to the crops is 32 cm, but there is 25% runoff, only 24 cm is available to the crops. The yield would be near the barani average, or about 8 maunds per acre. Retaining all the incident precipitation as indicated in Figure 3B and making it available to the plants has a potential, according to Figure 1, of increasing the yield to 37 maunds per acre, if the land is properly managed and fertilized.

Assuming the precipitation available to the crop is 40 cm and runoff as indicated in Figure 3A, if there is 25% runoff, only 30 cm of water is available to the crops. If the yield response is similar to that at Lyallpur in 1975-76 (Fig. 1), the wheat will yield near 24 maunds per acre. Retaining all the incident precipitation as indicated in Figure 3B and making it available to the plants has a potential of increasing yield from 24 maunds to 48 maunds per acre. Apparently the crop yield may be doubled by retaining only 10 cm of additional water.

In areas where the precipitation available during the cropping season is low, sandy areas may absorb more water than clay lands and in some areas (i.e. in D. I. Khan) farmers grow wheat on primarily sandy lands because the amount of water retained by the soil is higher as compared to clay lands. For instance, if the precipitation available during the cropping season is 24 cm and the runoff conditions are as in Figure 3A, then only 18 cm of water is available and the crop yield would be negligible. Retaining all the available water, the yield will be about 9 maunds per acre.

Retention of all the incident precipitation may be achieved by holding the water on the surface until it is absorbed by the soil. This may be done with contoured furrows or with contoured terraces as are drawn in cross section in Figure 4.

3/The "precipitation available during the crop season" includes that which falls during the growing season, plus the portion of the precipitation which falls prior to the crop season that is stored in the root zone and is therefore available to the crop.

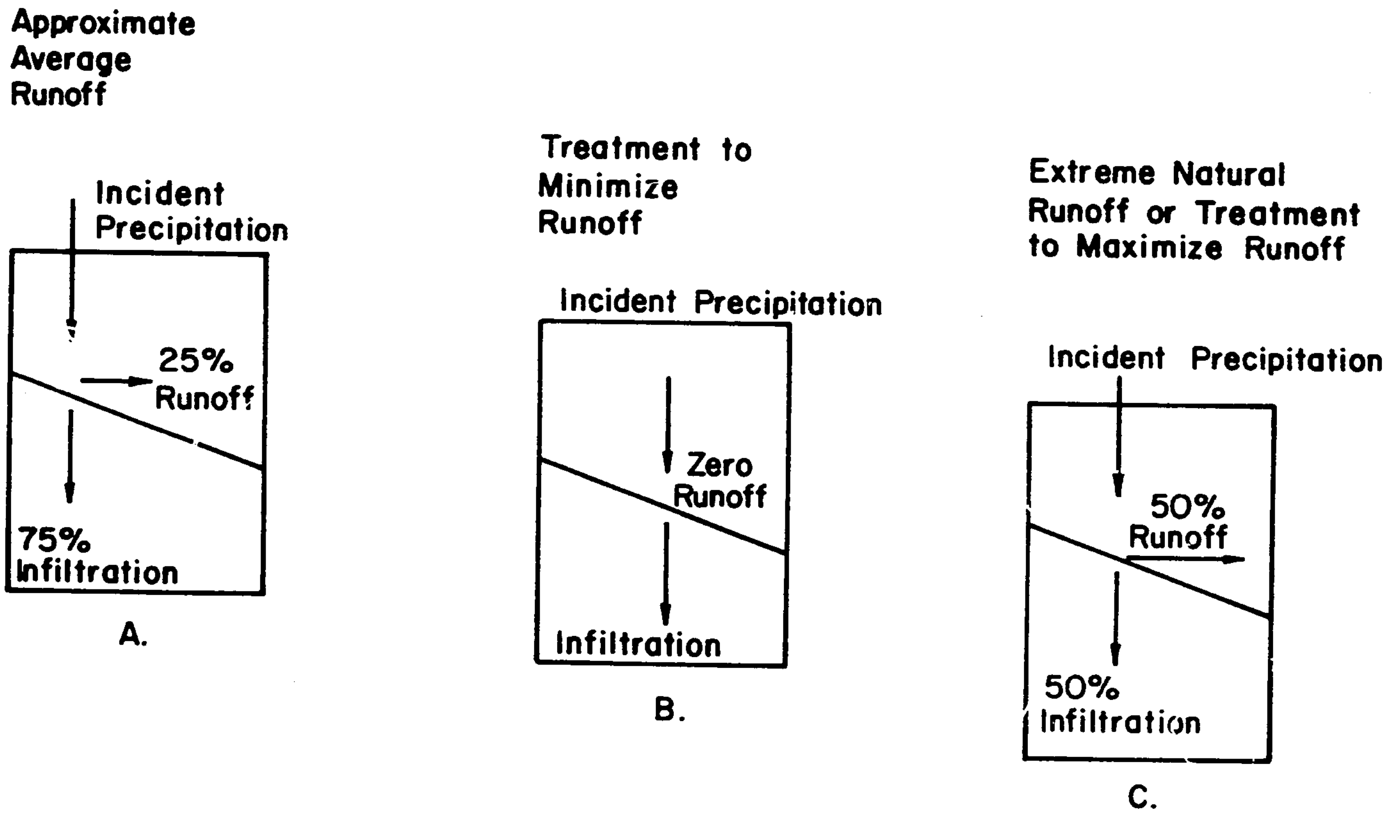

Figure 3. Distribution of Incident Precipitation Into Runoff and Infiltration.

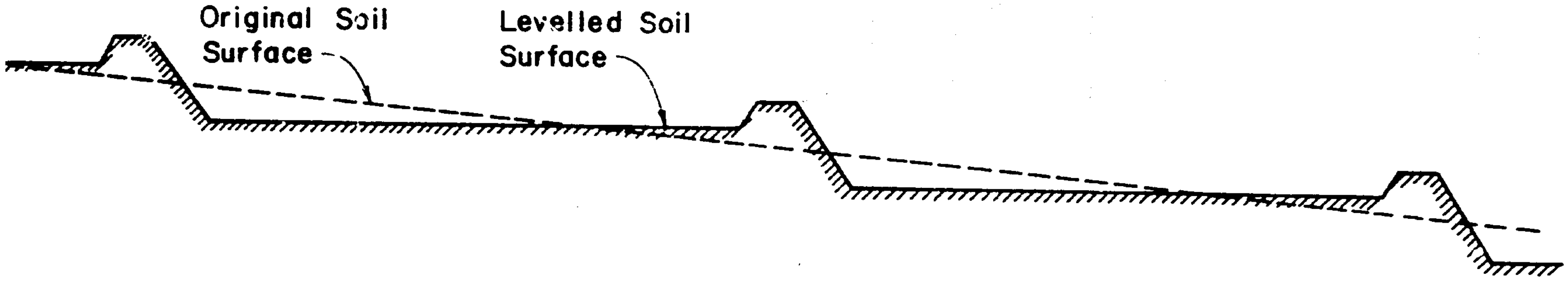

Figure 4. Benches for holding all incident precipitation and distributing it evenly over the surface to increase crop yields. (Available rainfall in 30 to 40 cm range.)

2. Runoff - Runon Possibilities (Precipitation 10 to 30 cm)

If runoff is as high as 50% as indicated in Figure 3C, or if it can be made so by vegetation removal, compaction, or chemical treatment and if the rainfall available for the season is 20 cm and the land surface can be shaped as indicated in Figure 5A so that the runoff water from the sloped "watershed" area flows into the flat cultivated area, the water available to the crop will be 20 cm (incident) plus 10 cm(runon) = 30 cm. If the yield vs watercurve is as shown for Lyallpur 1975-76 (Figure 1), the yield on the flat area would be 32 maunds per acre whereas it would be practically negligible if we do not "concentrate" this water in a limited area.

In much of the high country of Baluchistan the precipitation is only about 14 cm. Under these conditions it may be necessary to increase the watershed/cultivated area ratio to obtain adequate water for good yields. For instance, if 50% runoff can be achieved and the ratio of watershed to cultivated areas is 3/1, as indicated in Figure 5B, the water available to the crop will be 14 cm (incident) + 3 x 14/2 (runon) = 14 + 21 = 35 cm. If the same yield vs water curve is assumed (Lyallpur 75-76, Figure 1) the wheat yield should be about 44 maunds/acre on the cultivated area or 11 maunds/acre if calculated on the basis of the total watershed and cultivated area.

Farmers in low rainfall areas may have crops of different values and consequently may wish to place priorities on which crop receives the water when supply is limited. This may be done in a runoff-runon system of the type indicated in Figure 5C. In this case the high value crop might be apples, with maize as an intermediate value crop and fodder as a low value crop. If the runoff area indicated is six times the area of the high value crop, average seasonal rainfall is 20 cm and one half of this can be induced to runoff, the amount of water received by the high value plot will be 6 x 20/2 (runon) + 20 (incident) = 80 cm. In the high areas of Baluchistan and NWFP about 70 cm of water is sufficient to grow a good crop of apples. Consequently, in the average year, the farmer should allow 10 cm of additional water to go to the maize plot, giving the maize an average water supply of 10 + 20 = 30 cm, which according to Figure 2 will yield about 35 or 40 maunds of maize if properly fertilized.

In some areas it may be impossible to raise the runoff percentage to 50% because of low intensity rainfall and light textured soils. In these areas farmers may still be able to concentrate sufficient water for vegetable gardens and fruit orchards by increasing the ratio of watershed/cultivated area as indicated in Figure 6. In the Avdat area

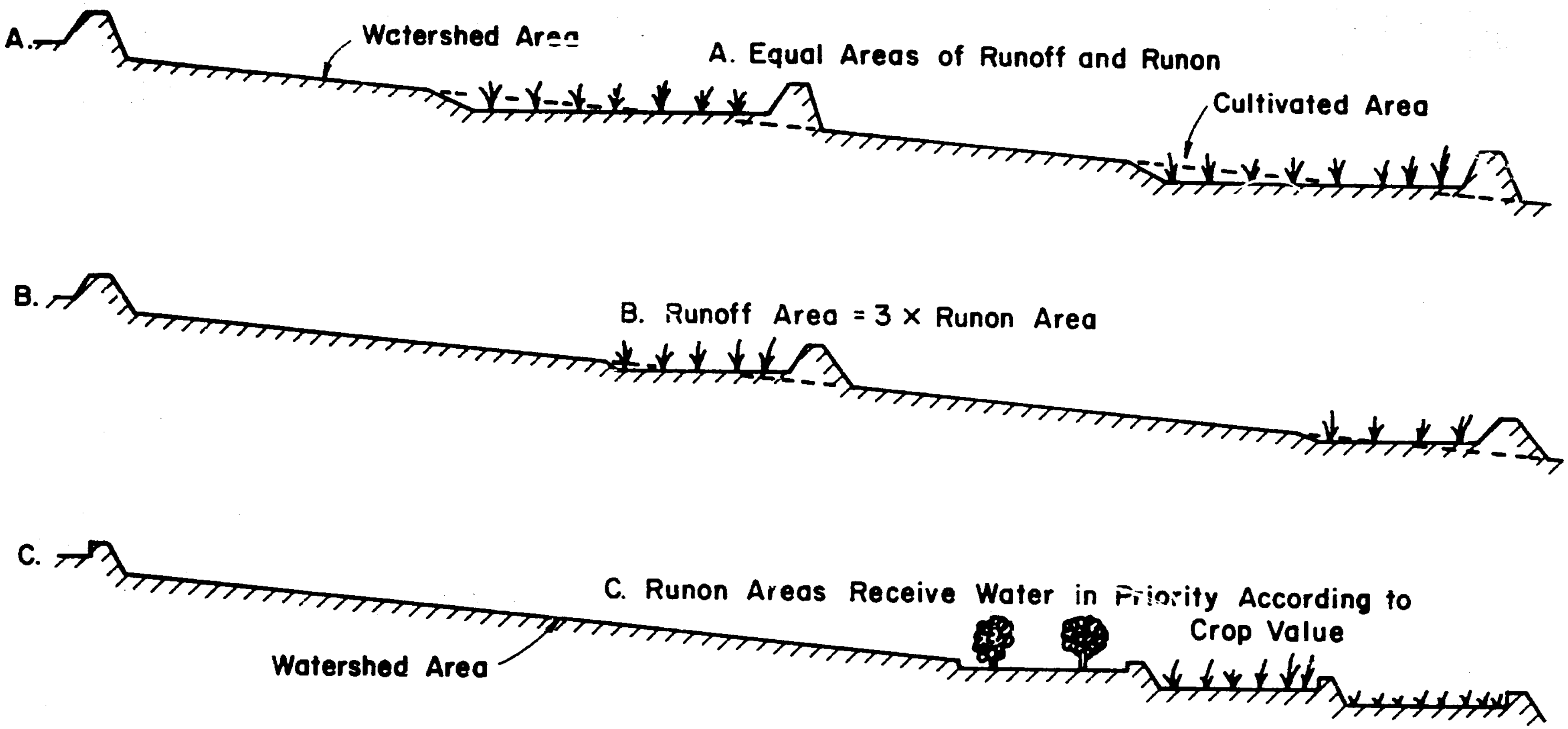

Figure 5. Runoff-Runon Systems

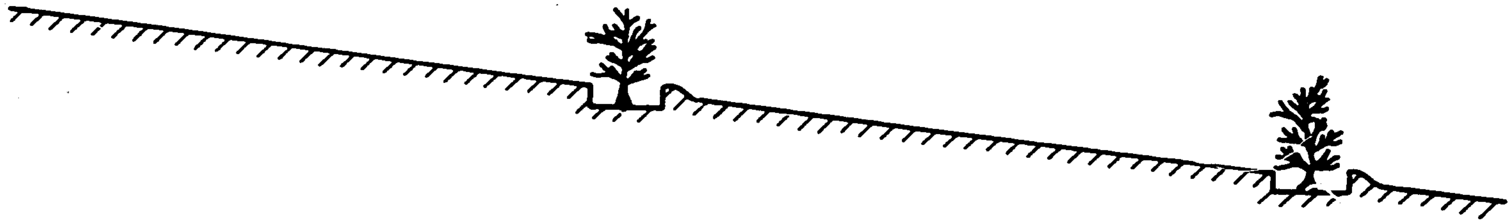

Figure 6. Using runoff to grow orchards in the desert.

(Evanari et al. 1968) apricots, grapes, and pomegranates were grown with annual rainfall of 10 cm by having runoff to runon ratios of 20 to 1. In areas where the amount of water harvestable from the watershed is 5 to 10 cm per growing season, runoff to runon ratios in the range of 6 to 2 should provide adequate water for growth of most crops. If the average seasonal rainfall is 18 cm, 30% of this can be induced to runoff, and the watershed/cultivated area is 10/1, the amount of water received by the cultivated plot will be 18 x 0.3 x 10 (runon) + 18 (incident) = 72 cms. Generally this water is sufficient to grow a good vegetable or deciduous fruit garden.

In some of the high plains of the Potowar Plateau and NWFP the average kharif season rainfall varies from 50 to 70 cm. Studies at Quaid-I-Azam University (Khalil ur Rehman 1976) indicate that the corn plots in kharif season benefit from drainage of excess rain water. The maximum yield of 53 maunds per acre of maize grain was obtained under the treatment where the soil surface was shaped to allow the drainage of excess water. In treatments where all of the rain water was retained, the maize yield was 45 maunds per acre.

Farmers can utilize this excess water by collecting it in reservoirs as indicated in Figure 7. In this case the flat benches are designed with brick or rock weirs at one end which allow overflow of water into grassed waterways when more than 10 cm of rainfall is present on the bench. These weirs may be by-passed by opening water gates or bunds to allow surface drainage in high rainfall areas when excess water becomes a problem. In summary, the benches and reservoir system can retain the desired amount of water and allow removal of excess water, distribute water evenly on the flat benches, and retain excess water which can be used for supplemental irrigation, animal watering, domestic use and/or fish production.

D. Methods, Costs and Benefits of Managing Precipitation

1. Methods

a. Increasing Infiltration Rates to Retain More Precipitation

The rainfall intensities and the infiltration rates of the soils determine the portion of the water that runs off most of the gently sloping barani lands. Little can be done to change the rainfall intensity, but the infiltration rate can be changed by using cultivation which leaves the surface with more clods and aggregates (Moldenhauer and Kemper, 1969). To maintain high infiltration rates through cultivation it must be repeated whenever the large pores at the surface which allow rapid penetration of the water have been filled by disintegration of the clods.

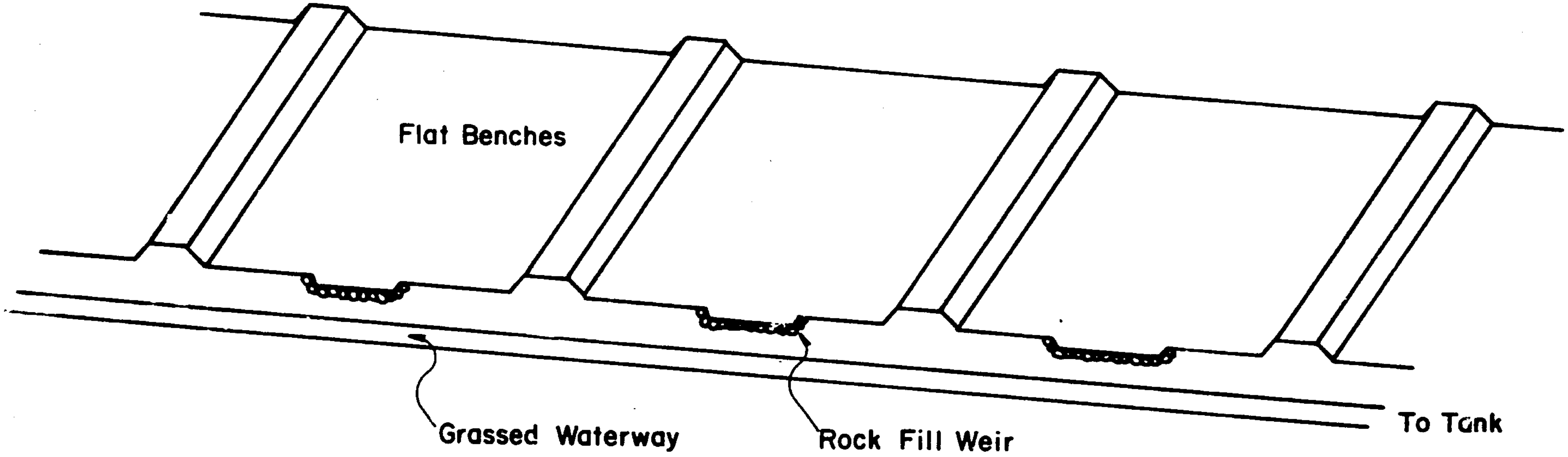

Figure 7. Flat Benches with Rock fill weirs, which allow overflow of water into grassed waterways. (Weirs may be supplemented with water gates.)

The other major means of increasing infiltration rates is to increase the wet stability of the soil clods and aggregates. The primary reason for the high runoff rates in Pakistan is the poor wet stability of the soil aggregates which is a result of the high proportions of illitic silt in the soil and the low organic matter content (Kemper and Koch, 1966). It is possible to increase the organic matter content of cultivated soils. However, the value of organic matter for animal feed and fuel is so high in Pakistan that increasing the organic matter content of the soil is not generally considered an economically feasible means of increasing infiltration rates.

Chemical treatment of the soil, such as application of gypsum, can help increase infiltration rates of soil when it has appreciable sodium ions.

b. Decreasing Infiltration Rates to Increase the Water Harvestable from a Watershed and Available for Concentration on Adjacent Areas

The generally poor wet stability of Pakistan's soils allows clods and aggregates to disintegrate quickly under its high energy rain storms and fill the large pores which conduct water into the soil. The result is high rates of runoff and accompanying soil erosion. Areas which are kept free of vegetation and are not cultivated have obviously high rates of runoff in Pakistan. Moreover, if most of the precipitation runs off in areas with annual rainfall in the range from 20 to 30 cm, little vegetation will grow. The vegetation that does start to grow can commonly be controlled by harvesting the young weeds for animal fodder.

In Botswana, vegetable gardens were grown with runoff water from school playgrounds, where traffic of children had compacted the soil, removed the vegetation, and increased the runoff (Advisory Committee on Technology and Innovation, 1974).

Compression (i.e. by running a loaded truck over a field when the surface is near field capacity or wattar condition) has been shown to decrease infiltration rates from 12.5 cm per hour to 0.25 cm per hour[4] on a loamy sand soil in Maryland, USA. The reduction of infiltration rate by compaction to 2% of its former value may be an extreme case, but it is not unreasonable to assume that the infiltration rates of many soils can be reduced to 10 to 20% of

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[4] 4/Data collected (unpublished) by W. D. Kemper (1972).

their current values by compaction. Pertinent economic questions are--how long will these effects last, what will they cost, and what is their value?

Given the potential for achieving high rates of runoff, the major concern is to "harvest" the water without causing considerable soil erosion. To achieve this, the lengths of bare surface over which water is allowed to accumulate and run off must be carefully designed and major water carrying channels must be grassed or lined with stones or other material to prevent scouring.

c. Holding the Water Where it is Needed by Crops Until it is Absorbed by the Soil

1) Contour Furrowing

Up to 5 or 6 cm of water can be held on the surface of a soil if ridge and furrow cultivation is practiced with the ridges being 15 to 20 cm higher than the bottom of the furrow, and the furrows are on equal elevation contours. Coupled with reasonable infiltration rates, this surface configuration will contain rains of up to 7 or 8 cm which occur in periods of 2 or 3 hours. Outlets should be provided at the ends of such furrows into grassed waterways, so that after the furrow is reasonably filled, additional water will flow into the grassed waterway rather than overtopping the ridges, and causing serious erosion.

2) Contour Benches

When more than about 8 cm of rain occurs in single, high intensity storms and all of the water is needed, or when there is no accessible waterway to carry away the excess water, ridges and furrows adapted to regular crop production are not able to hold the water. Contour benches, as shown in cross section in Figures 4 and 5, with bunds about 8 cm higher than the maximum level of water expected on the bench, can hold more water. The top width of these bunds should be about double their height and side slopes should be no steeper than a 45° angle. For instance, if the maximum amount of water expected in the bund was 12 cm, the bunds should be about 20 cm high, about 40 cm wide at the top and about 100 cm wide at the base.

Such bunds should be accompanied by leveling of the bench to achieve uniform distribution of the water on the bench.

These bunds and contoured benches should also be provided with overflow spillways at one end so that when the maximum amount of water which can be safely stored is reached, additional water will run out into a vegetated waterway.

The contoured benches can be used to hold all the incident rainfall as indicated in Figure 4, to receive additional water from adjacent runoff areas as indicated in Figure 5, or to receive water from grassed waterways fed from more distant watershed areas. They may also be arranged in series as indicated in Figure 5C, with high value crops having first call on available water and successively lower value crops obtaining water if water in addition to the needs of the higher value crops is availale. This type of system allows considerable management flexibility, particularly when gates are installed (or bunds breached) which allow drainage of surface water from watered fields when sufficient water has been absorbed by the soil.

2. Costs

a. Costs of Forming Contour Benches

Assuming that the bunds should be 20 cm higher than the bed of the bench and that it should be 40 cm wide at the top and 100 cm wide at the bed level, assuming an earth moving cost of Rs. 3 per cubic meter of soil and a cut to fill ratio of 1:3, assuming a cost for dressing of the bunds of Rs. 1.0 per fifty linear feet of bund, the cost of forming the bunds and leveling the benches was calculated as a function of the bench width when the average slope of the land is 1%, 2% and 4%, and these costs are shown as the curves in Figure 8. Note that there is a bench width at which cost is minimum at each slope.

These minimum costs are indicated in Figure 9 for comparison with the benefits that could be gained from such contour benches in one wheat cropping season, assuming average runoff rates before benching of 15%, 25% and 35% respectively. The benefits were calculated from the wheat yield vs water curve obtained at Lyallpur in 1975-76, assuming that all the previous runoff was kept on the land as a result of the bench terracing and brought the available water supply up to the incident rainfall. The "calculated benefit" was the yield (maunds/acre) with the indicated rainfall, minus the yield that would have been obtained if there had been runoff, all multiplied by 37 (the current value of the wheat in Rs/maund).

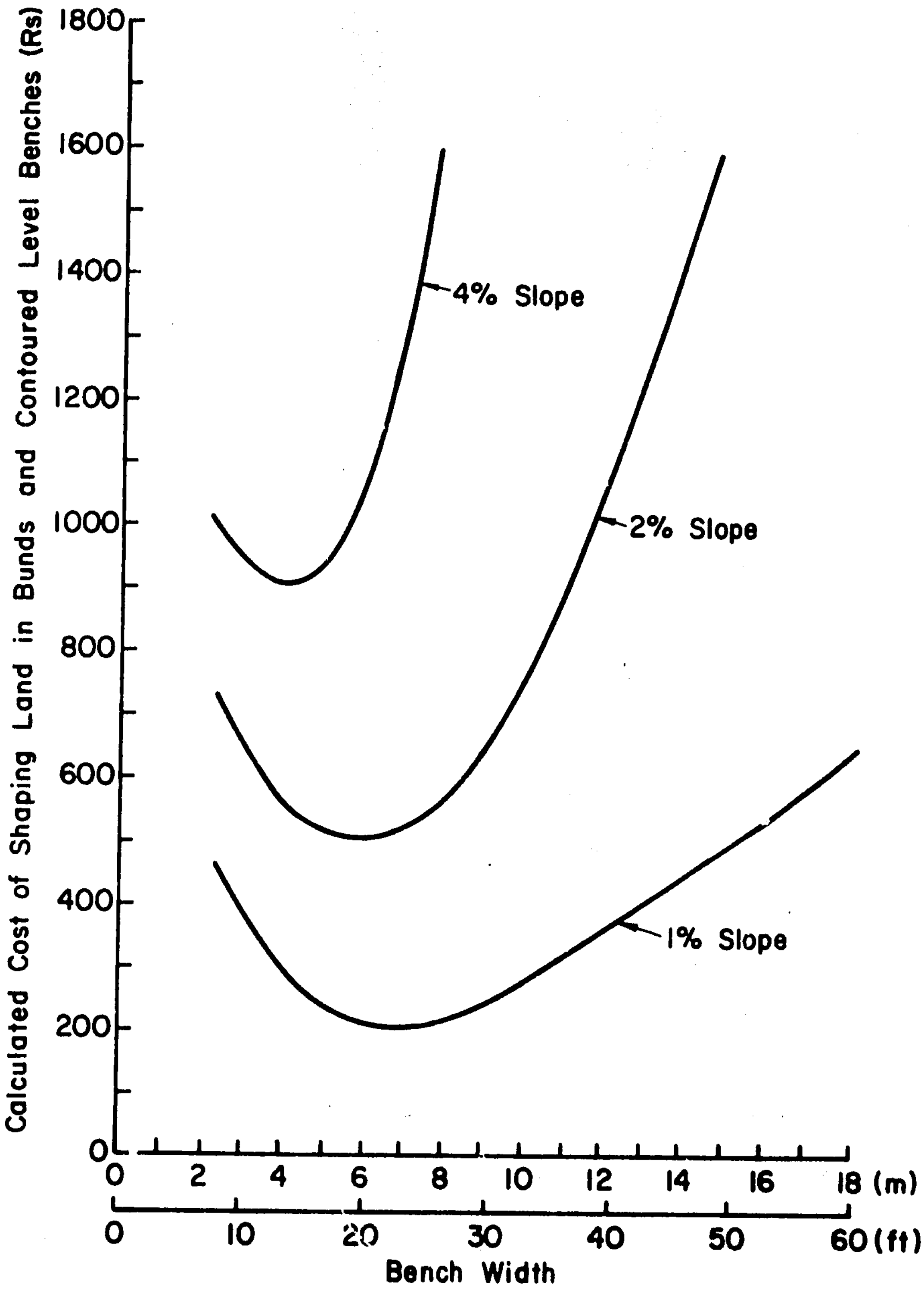

Figure 8. Cost of Shaping Land in Bunds and Contoured Level Benches* as Affected by Width of Benches and original slope.

*Assuming engineering provided by Government free of cost.

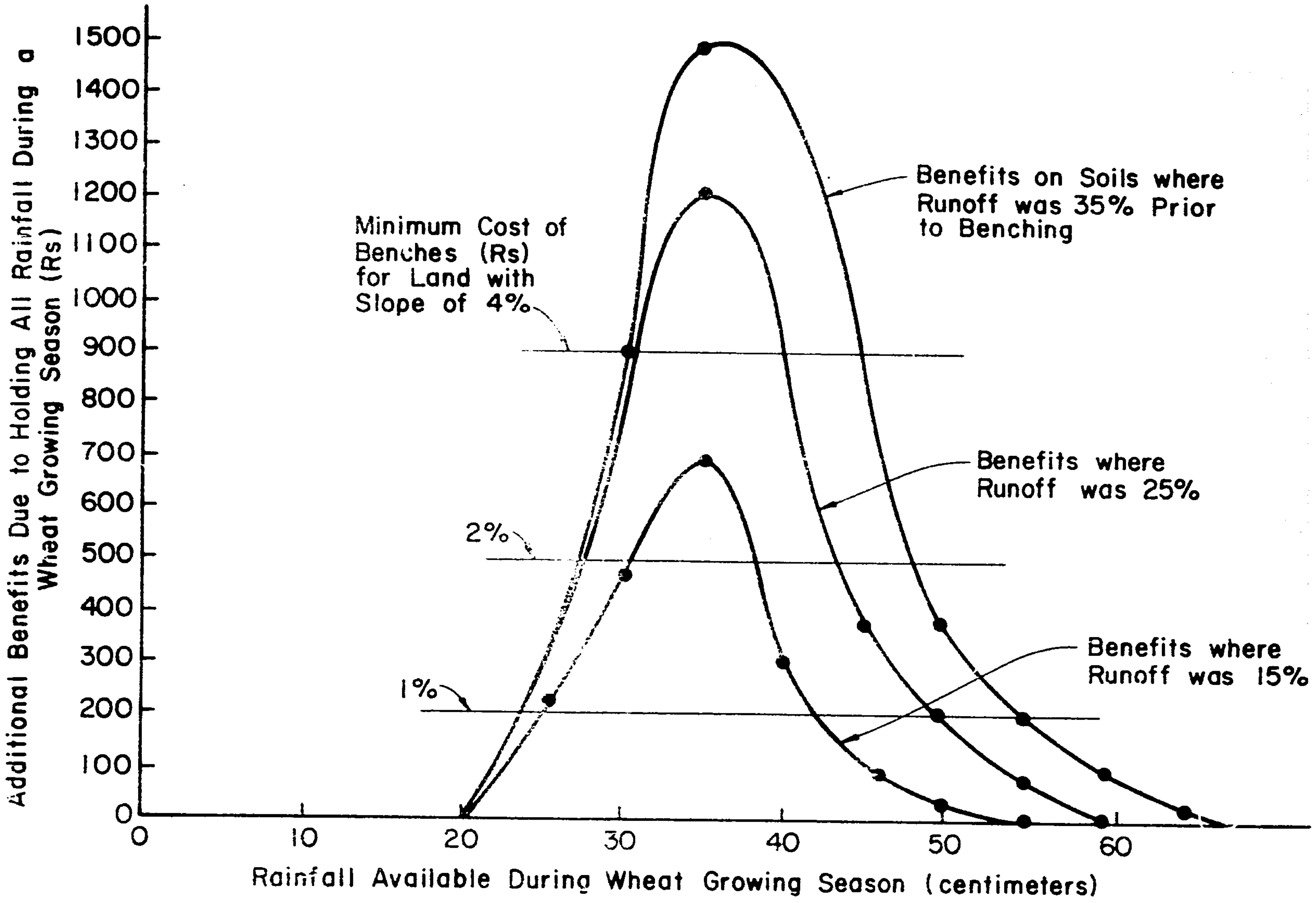

Figure 9. Calculated Benefits and Costs of Contour Benches to Retain all Incident Rainfall Assuming Original Runoff Rates of 15, 25 and 35%.

In the rainfall range of 30 to 40 cm per season, the calculated benefits from a single wheat season exceed the calculated costs of constructing the benches on land with 1% slope, even when the runoff averages only 15% before benching. When the rainfall available for the season is from 31 to 38 cm, the average benefits from a wheat season will also exceed the costs if the average slope is 2%. The reader is left to make such other comparisons as he desires. The principle fact that emerges is that farmers who have lands where the water available to crops for the wheat growing season is in the range from 30 to 40 cm with more than 10% runoff can profitably invest their labor or capital in benching their land to hold runoff water and increase crop production. Since the benches should last indefinitely with reasonable maintenance, the benefit/cost ratios for these rainfall and runoff conditions appear to exceed 10 when the average field slope is 1%, exceed 5 when the average slope is 2% and exceed 2 when the average slope is 4%. However, it should be remembered that these high yields also require adequate fertilization, extra harvesting costs, etc., that have not been included in the costs shown in Figure 9. Assuming that additional fertilizer and harvesting costs consume 30% of the additional benefits shown in Figure 9, benefit/cost ratios of 7, 3.5 and 1.4 for fields with 1, 2 and 4% slopes respectively are apparently possible.

b. Costs of Building Runoff-Runon Systems

The basic elements of the runoff-runon system are: 1) an area treated to maximize runoff, 2) a leveled and bunded cropped area where the water can run on and be held until it is absorbed by the soil.

Bunds or waterways to direct water from the runoff to the runon area may also be needed if the natural slope of the land does not provide this connection. However, these components are specific to special situations and not amendable to general treatment. Since in a large portion of the anticipated systems the design can allow direct runoff-runon, as indicated in Figure 5, only the costs of items 1 and 2 will be treated herein. Since the runon areas will generally be contoured benches of the type shown in Figures 4 and 5, their costs are indicated in Figure 8.

Costs of treating the runoff area will vary according to the treatment. Assuming a treatment involving compaction by a loaded truck when the soil water is at field capacity (as was observed to reduce infiltration rates from 12.5 cm/hour to 0.25 cm/hour on a loamy sand in Maryland), double dual wheels on the back of a truck compact an area almost 120 cm wide, but planning for 2.5 times coverage, a single pass can be considered to compact a strip 120/2.5 = 48 cm or 1.6 feet wide on each pass.

A truck traveling one mile will thus compact 5280 x 1.6 square feet, or about 0.2 acres. Then if a driver with a loaded truck is paid Rs. 10/mile for this field travel, the compaction of the watershed will cost Rs. 50/acre. The bench construction cost was Rs. 210/acre. Thus the total cost for compacting one acre of watershed and constructing one acre of bunded level bench to hold the water would be Rs. 260. This type of calculation was made for systems where, prior to benching, the benched runon areas had slopes of 1%, 2%, and 4% and the ratios of the runoff to runon areas were from 0.2 to 10. The costs of compacting the watersheds and constructing the bunded benches are also indicated for these slopes and this range of runoff/runon ratios in Figure 10.

The curves in Figure 10 represent the calculated benefits for one wheat crop that can result from installation of the runoff-runon system, assuming 50% runoff from the watershed area, yield response to water as at Lyallpur in 75-76 (Figure 1) and rainfall available during the crop season of 10, 15, 20 and 25 cm for the respective curves.

Under 50% runoff, growing wheat, with 25 cm of rainfall available to the crop,[5] it appears that near maximum benefits are reached when the runoff to runon ratio is about one. When the average rainfall available to the crop is 20 cm, the maximum benefits are approached at runoff/runon ratios of about 2. At 15 cm of rain the maximum benefit appears to be approached at ratios of about 3 and at 10 cm of rain the maximum benefit appears to be approached at about 6.

With original soil surface slopes less than 4% and it is assumed that 30% of the benefits indicated in Figure 10 are consumed by additional fertilizer and harvesting costs, there appears to be a high probability of recovering the cost of constructing the runoff-runon system within the first wheat crop season, if 50% of the "rainfall available to the crop" can be induced to run off the watershed area. When the slopes of the cultivated runon areas are down

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5/The rainfall available to the crop includes rainfall received prior to seeding which is stored in the root zone plus rain received during the growing period.

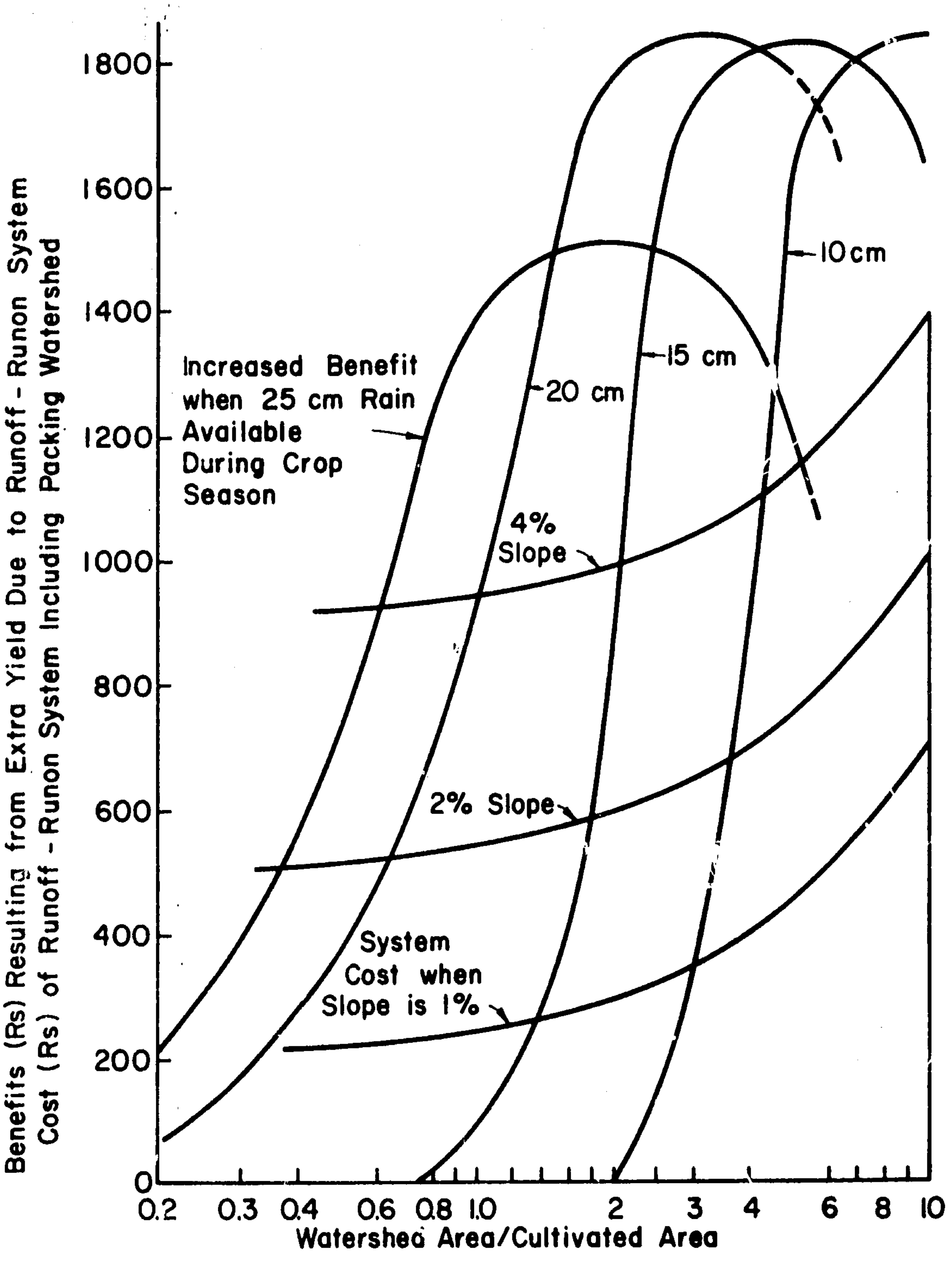

Figure 10. Benefits Resulting From Installation of the Runoff-Runon System for One Wheat Crop*, and Cost of the Systems.

*Assuming 50% runoff from the compacted watershed areas.

around 1% before leveling, it appears that the returns in a single season exceed the costs by a factor of 2 to 4.

An estimate of benefits derivable from treatments to increase runoff may be calculated as follows: Assume that the runoff from an untreated watershed area is 15% of the rainfall, but that with treatment such as the compaction at proper water content the runoff can be increased to 50%. Then assuming the wheat response to water curves at Lyallpur in 75-76 and a value of Rs. 37/maund for wheat, the values of the additional wheat that could be grown when the watersheds were providing 50% of their water instead of 15% are shown in Figure 11. The costs of compaction with a loaded truck as discussed previously is indicated by the curve near the bottom of the Figure.

This Figure (11) indicates the tremendous benefits that can accrue to this runoff-runon type of system if packing or other treatments can increase the average runoff from 15% before treatment to 50% after treatment.

E. Information Needed as a Basis for Implementing an Effective Water Management Improvement Program

Many costs involved in creating the higher yields were ignored or roughly approximated to keep this treatment reasonably brief. These include additional fertilizer costs, costs of harvesting the larger yields, costs of compaction to increase runoff, etc. A complete economic analysis of the system is needed--and this cannot be done accurately until this type of system is implemented.

The primary assumptions made in this study were the runoff rates. These may not be as large as were assumed. Runoff rates should be determined in the relevant areas of Pakistan to determine the present losses, which are the potential increased water supply in these areas.

Other important questions regarding runoff are whether and how much it can be increased by treatments such as packing, Na salts, etc., and whether the low infiltration rates resulting from packing soils will be increased rapidly by factors such as freezing and thawing and wetting and drying of the soil, and therefore require frequent recompaction to keep the infiltration rate low.

One other assumption that needs to be checked is whether the consumptive use in barani lands is comparable to that in our irrigated lands and whether the yield vs water curves are approximately the same under the irrigated and barani conditions.

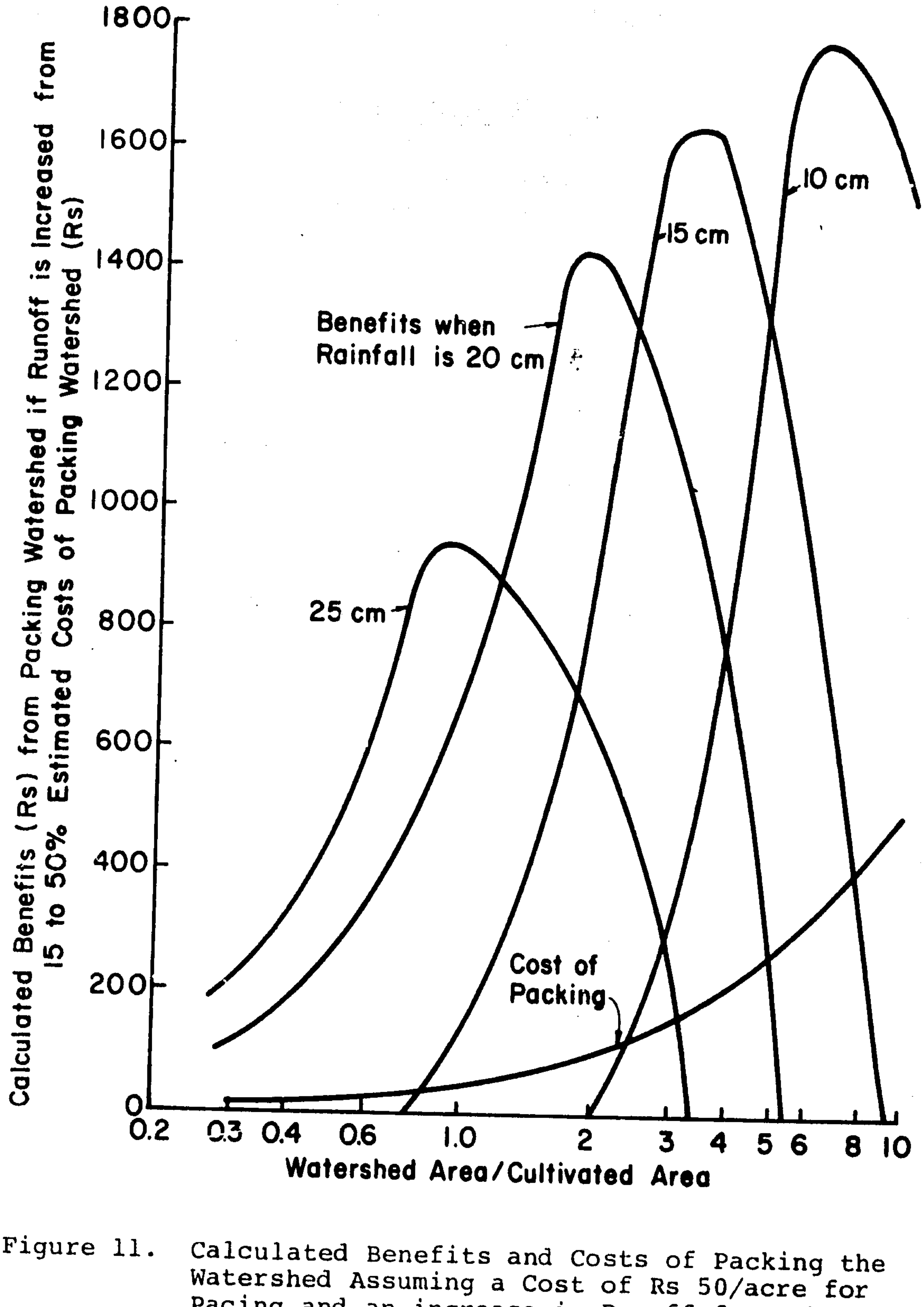

Figure 11. Calculated Benefits and Costs of Packing the Watershed Assuming a Cost of Rs 50/acre for Pacing and an increase in Runoff from the Watershed Area from 15% to 50%.

If the assumptions made in this paper are even reasonably correct, there is a good investment opportunity available to the farmers of the barani lands--in water management. The engineers and scientists can help the farmers optimize that investment.

SUMMARY AND RECOMMENDATIONS

Crop responses to water, obtained in the irrigated areas of Pakistan, indicate potentials for increasing the barani yields of wheat and maize from their present average yields of 6 and 8 maunds per acre up to 40 and 50 maunds per acre respectively by increasing the amount of water available during the growing season up to 35 cm under adequate fertilization.

In areas where groundwater and canal supplies are not available, the only source of additional water is retaining water which presently runs off, or utilizing runoff from some areas to supplement incident rainfall on others.

In areas where runoff exceeds 15%, the benefits derivable from benching the land to retain all the incident rainfall exceed the cost of construction where the slope of the soil ranges from less than 1% to 4% and when rainfall available during the growing season is in the range from 30 to 40 cm. When the rainfall and runoff are in this range and the original slope of the land is less than 2%, it appears that the returns during the first cropping season can exceed, the total investment.

When rainfall available during the crop season is less than 25 cm, satisfactory yields are not attainable for maize and wheat, even when all the incident rainfall is made available for crop use. If a substantial percentage of the rainfall on these areas can be induced to runoff from "watershed areas" supplementing incident rainfall on cropped areas, substantial crop yields on the cultivated area appear to be possible in much of the barani tract which is presently considered to have no significant productive potential. Whether these runoff-runon systems are feasible depends on the percentage of the rainfall that can be induced, by reasonably priced treatments, to runoff from the watershed areas. If as much as 25% can be induced to runoff, many areas can productively use this type of water management system. If runoff can be increased to 50%, this type of farming holds the potential of bringing most of Pakistan's dry barani lands into production.

The calculations involved in drawing these conclusions assume that:

1. Runoff exceeds 15% of incident rainfall on substantial portions of Pakistan's barani lands.

2. The yield vs water use function for crops in barani areas is reasonably close to that obtained for the same crops in the irrigated areas.

3. The available water from precipitation and runoff from watershed areas is all absorbed by soil in the plant root zones.

The apparent potential benefits justify checking these assumptions and evaluating pilot installations.

This will require:

1. A survey to obtain estimates of the percentage runoff from barani lands.

2. Development and testing of methods designed to increase runoff from watershed areas.

3. Evaluation of the crop yield vs available water curve in barani areas where considerable amounts of convected energy are introduced into the crop canopy from surrounding barren areas by air currents.

4. Evaluation of the rainfall amounts, intensity, runoff and the portions of the water which infiltrate the cultivated area and are retained in and pass through the root zone.

5. Installation of bunded benches for holding all incident precipitation on the soil in areas where rainfall available during the cropping season is in the 30 to 40 cm range.

6. Installation of runoff-runon type systems for supplementing incident rainfall where the rainfall available during the growing season is in the 15 to 25 cm range.

7. Monitoring yields and costs of construction, maintenance and crop production on the systems installed in 5 and 6.

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APPENDIX 8

WATERCOURSE CONVEYANCE LOSSES IN THE MONA RECLAMATION EXPERIMENTAL PROJECT AREA[1]

by
Tom Trout and Muhammad Munir[2]

INTRODUCTION

Any hydrologic system naturally seeks a steady state condition where inflow to the system is equal to outflow. The equilibrium of the Indus Basin system was perturbed with the advent of major irrigation works in the late 19th and the 20th centuries. Water which previously flowed directly to the sea through river channels was being spread across the plain with the intent of serving the evapotranspiration needs of the newly planted crops. But, as with all irrigation systems, only a portion of the diverted water is actually used by the plants. A large proportion of the remainder eventually seeps downward from canals, watercourses and fields, until it reaches the groundwater.

Thus, irrigation in the Indus Basin increased the inflow to the groundwater. According to Lieftnick, et al. (1968), 57% of the projected 49 million acre feet of inflow to the groundwater in 1975 was a result of irrigation. In response to this added inflow, the groundwater table began to rise as the system began to seek a new equilibrium. Because the slope of the basin and its underlying groundwater table is so small compared to its areal extent, the increasing groundwater depth increased water tables slopes and consequently increased subsurface outflow very little. The only other natural outlet for the growing volume of water stored beneath the soil surface was direct evaporation or transpiration from the groundwater. So the water table continued to rise until it came near enough to the surface, that the water being infiltrated to it from the new irrigation systems could eventually be released into the atmosphere.

Such a hydrologic equilibrium was developing in the Basin when the effects of the rising water table began to be felt about the middle of the 20th century. Not only was the high water table damaging crop growth, but the salts present in

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[1] Joint contribution of the Mona Reclamation Experimental Project and CSU Water Management Research Project.

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the groundwater were moving with the water to the soil surface and accumulating there as the evaporation continued.

Recognizing the dangers of a high water table, Pakistan began a program, which is still being expanded, of installing tubewells to pump water directly from the groundwater for application on crops in hopes of creating a new hydrologic equilibrium with the water table at a lower level. The system is presently seeking a new equilibrium in response to this pumping program, but it is becoming evident that the results are not going to be as great as was initially hoped. Such pumping programs, although having inherent potential advantages, are quite costly. Consequently, additional solutions to the problem are being sought.

One obvious method of reducing the water table height is to reduce the seepage inflow to the groundwater. Although this factor has always been recognized, a lack of data has lead to an improper value being placed on it. Most studies which have considered the problem have accepted that seepage from canals is too expensive to reduce in such a large system, and that seepage from watercourses and deep percolation from fields was a relatively small percentage of the diverted volume. The Lieftnick (1968) report assumed only 10% of the inflow to the watercourse system is lost, and that half of that amount is evaporated to the atmosphere.

In 1973, Colorado State University and Mona Reclamation Experimental Project began to make the measurements necessary to determine the magnitude of watercourse losses. Their measurements indicated that the watercourse losses under operational conditions were significantly higher than the 10 percent which was previously reported.

This paper is a summary of the loss measurements made on the Mona Project area. All of the data is available in more detailed form in the publications referenced at the end of this report. The other portion of the losses from the farm level irrigation system which eventually end up in the groundwater, deep percolation from the fields, is presently being studied, and is being reported as data is collected.

CONVEYANCE LOSS DATA

Conveyance losses in over 250 sections of watercourses have been measured in the Mona area. These measurements have been concentrated primarily on 9 watercourse systems. A summary of the collected data is presented in Table 1. Much of the present data collection is in connection with watercourse renovation programs designed to determine the costs, methods, and benefits of reducing conveyance losses.

The first comprehensive set of conveyance losses was made by Clyma, Arshad and Ashraf (1975), in 1973 on the

Table 1. Conveyance loss data summary from Mona Reclamation Experimental Project Area.

Watercourse	Experimenter	Watercourse condition	No. of meas.	Type of measurement	Loss rate						Total loss
					Cusecs/1000 ft			%/1000 ft			%
					Ave.	Max.	Min.	Ave.	Max.	Min.	
TW 122	Clyma, Arshad, Ashraf, 1975	unimproved	6	inflow-outflow	.47	1.00	.20	13.8	20.4	6.2	34
TW 78			20	"	.22	.44	.02	10.0	20.0	1.0	36
TW 137			30	"	.28	.50	.13	11.0	22.0	5.2	21
TW 130	Early & Lowdermilk, 1975	unimproved	4	inflow-outflow				5.9			33
TW 81		unimproved	7	"				12.8			53
TW 78		After pucca improvement of sarkari khal	5	"				17.5			51
TW 91	Akram, Kemper Dobbs, 1975	unimproved	1	inflow-outflow	.15			8.0			
TW 78	Akram, Kemper 1976	2 years after pucca improv.	17	ponding	.31	.96	.01	6.6			
		After patching pucca improv.	10	"	.02	.04	.01	0.4			
TW 78	Akram & Kemper, 1976	After earthen improvement	7	ponding	.10	.23	.06	2.0	5.0	1.3	
		18 months after improvement	2	"	.13			3.0			
TW 78	Akram & Kemper, 1976	unimproved	21	operational study							
		unimproved	8	ponding	.51	.75	.06	11.0	16.0	1.0	
		After earthen improvement	2	"	.41	.44	.38	9.0	10.0	8.0	
		After compacted earth improvement	3	"	.12	.16	.10	3.0	3.0	2.0	

Table 1. Conveyance loss data summary from Mona Reclamation Experimental Project Area. Cont'd.

					Loss rate						
		Watercourse	No. of	Type of	Cusecs/1000 ft			%/1000 ft			Total loss
Watercourse	Experimenter	condition	meas.	measurement	Ave.	Max.	Min.	Ave.	Max.	Min.	%
TW 56L	Bowers, et al. 1976	unimproved	18	inflow-outflow	.29	.88	.11	6.6			57
		earthen improved	36	"	.21	.48	.01	4.0			33
TW 51	Azeem, et al. 1976	unimproved	18	inflow-outflow	.16	.42	.03	3.8	10.6	0.9	45
		earthen improved	12	"	.13	.99	.02	2.5	17.3	0.9	31
TW 56R	MREP & CSU Staff, 1976	unimproved	13	interview				4.7			
		earthen improved	13	"				1.3			
		earthen improved		inflow-outflow	.16			4.8			
TW 81R	Trout, et al. 1977	unimproved	57	operational study	.26	.90	.16	13.0			56
		unimproved	4	ponding	.17	.46	.04				

watercourses of Tubewells 122, 137 and 78. The measurements were made by the inflow-outflow method with cutthroat flumes. They found that watercourse losses were variable, generally increased with initial flow rate and length of channels, and were higher in tubewell supplemented watercourses. The data was the first that indicated that a high proportion of the public tubewell water added to watercourse systems never reached the intended field. The overall average conveyance loss rate found was 11.6 percent per 1000 feet (11.6%/1000 ft).

In 1975, as part of a Watercourse Survey in the Punjab, Early and Lowdermilk (1976) measured conveyance losses on watercourses serving Tubewells 78, 81, and 130. They found average loss rates of 12%/1000 ft and average total conveyance losses from the mogha to the farmers' fields of 46 percent. They found that total losses in these SCARP supplemented watercourses were about 20 percent higher than in the average of 15 watercourses surveyed in the Punjab.

Realizing the magnitude of conveyance losses, CSU and MREP began a program of watercourse renovation in 1973. The first phase of this program involved brick masonry and concrete (pucca) channel linings. Most of the government authorized sections of Tubewell 78 and Tubewell 122 watercourses were lined with various pucca linings in 1973-1974. In 1976, Akram and Kemper (1976) measured losses by the ponding method in lined sections and found that leakage in some of the lined sections was reduced practically to zero, but in others was comparable to unlined sections. It was determined that the leakage was primarily through mortar joints in the masonry and voids in the concrete, both caused generally by using mixes that are dry, poorly mixed, and contain inadequate cement. Filling of holes and/or replastering of the lining reduced the loss rate from the initial average value of 6.6%/1000 ft to 0.4%/1000 ft. Although conveyance losses can be reduced and nearly eliminated with pucca lining, the improvement can be minimal if the quality of construction is not high. Also, the previously mentioned Early measurements on Tubewell 78 watercourse, which were made after the lining program, indicate that lining the government authorized sections (sarkari khal) of a watercourse system will not automatically reduce losses. The high total loss value of 51 percent was believed to be largely caused by greatly increased losses in the farmer's branches which had not been enlarged to handle the increased flow entering them from the lined channels. This is similar to the problem pointed out by Clyma and noted previously of increasing the inflow to a section without increasing its capacity. It also became evident that pucca lining is a very expensive procedure (Rs. 27,000 to Rs. 56,000 per 1000 ft.) so less costly alternatives were tried.

On one long branch of tubewell 78 watercourse, branch D, contractors were hired to completely rebuild the channel up to design specifications design specifications, with clean earth, Concrete outlet and check structures were also installed during the earthen improvement process. The measured loss rate after completion of 2%/1000 ft. shows that losses can be greatly reduced by such means.

The next phase of the CSU-MKEP program was to determine whether farmers would provide the labor for the earthen improvement process. This would allow a great reduction in government investment in the project, utilize available farm labor during seasons when normal labor requirements in the rural sector are low, and give the farmers a pride in their watercourse which perhaps would motivate them to do the required periodic maintenance and cleaning of their conveyance system.

Branch I of Tubewell 78 watercourse was chosen as a test section. Eight ponding measurements were first made to determine loss rate. The average loss rate was found to be 11%/1000 ft. Then an operational loss measurement was made to determine total conveyance losses. This study, which involved setting flumes at the head and at all flowing nakkas (outlets) while water was flowing in the section indicated that only 43 percent of the inflow was reaching the fields. Fifteen percent of these losses were attributed to transient conditions in the channel such as wetting up of dry banks, the infiltration during the movement of water from one nakka to the next, dead storage, bund ruptures, etc. These operational losses are not accounted for in steady state loss measurements, whether by ponding or by inflow-outflow method.

Studies were also conducted on Branch I to better determine the cause of the high loss rates. These studies (Akram and Kemper, 1976) indicated that:

1. Loss is much higher through the upper portion of the banks. This postion is normally very porous with much organic matter and rodent and insect activity. The banks are often nearly vertical and sediment does not deposit on the upper portions to seal the holes and pores.

2. Forty-five percent of the total loss in Branch I was from the junction and nakkas where banks are thin and cross sections large.

3. Bank compaction and bank core compaction can reduce losses to 25 percent of the previous losses in a section.

The farmers of Branch I did rebuild their watercourse, but not up to the desired specifications. Loss rate was reduced by about 50 percent (Akram and Kemper, 1976). Tests in short sections of the branch indicated that, with proper compaction, the loss rate could be reduced to 3 percent per 1000 ft in rebuilt earthen watercourses.

As a result of the low cost (about Rs 2 per foot including concrete structures) and the potential loss reduction with earthen improvements, a major program of farmer improved earthen watercourses was begun in December, 1975. At the date of this report, 4 watercourses have been improved serving Tubewells 56L, 51, 56R, and 81R. Extensive before improvement loss measurements were taken on 56L, 51 and 81R indicating average loss rates of 6.6 percent, 3.8 percent and 13%/1000 ft respectively, and total losses of 50 percent, 45 percent and 56 percent respectively. On Tubewell 56R watercourse farmer inquiries indicated about a 4.7%/1000 ft loss rate.

All of the farmers on Tubewell 56L watercourse were interviewed to try to determine the relationship between their water supply, cultural practices, and crop output. The collected data (Hussain et al., 1976) on cropping intensity, yields, acres irrigated per turn, and number of irrigations given per crop, when related with the distance of the fields from the mogha, allowed another measure of conveyance losses to be made. Figure 1 depicts these relationships and compares them to the physical conveyance loss measurements.

To develop the graph, first the farmers were divided into those who farmed land on the head, middle, and tail section of the watercourse. The average watercourse distance to each section was 2,750, 7,175 and 10,150 feet respectively.

Then each set of data was averaged for the various sections, and yield and number of irrigations data for the several crops for each section was averaged. Graphs were then made of this averaged data versus distance from the mogha, and best fit lines were extrapolated back to 0 feet distance. This intercept value was then used as a normalization factor so that all other values were represented as a percentage of the value at the mogha. Two assumptions were made which resulted in the given relationships. First, it was assumed that the farmers in the various portions of the watercourse produce the same total crop output per unit of water available. This assumes, among other things, that irrigation application efficiency is uniform across all farms. This assumption is probably overly conservative, as farmers at the tail who are given less water would possibly learn to apply it more efficiently. This assumption leads to the product of cropping intensity and average crop yields per acre being a value of conveyance efficiency. As can be seen from Figure 1, this assumption with the collected data leads to a loss rate of about 5.5%/1000 ft. The second assumption made was that on the average all farmers apply equal depths of water during a single irrigation. This assumption leads to the product of cropping intensity and number of irrigations per crop; and of acres irrigated per hour both being evaluations of water availability to the farmer, or, as presented, of conveyance efficiency. The second evaluation leads to a 4.5%/1000 ft loss rate value. The first, because of a high value in the

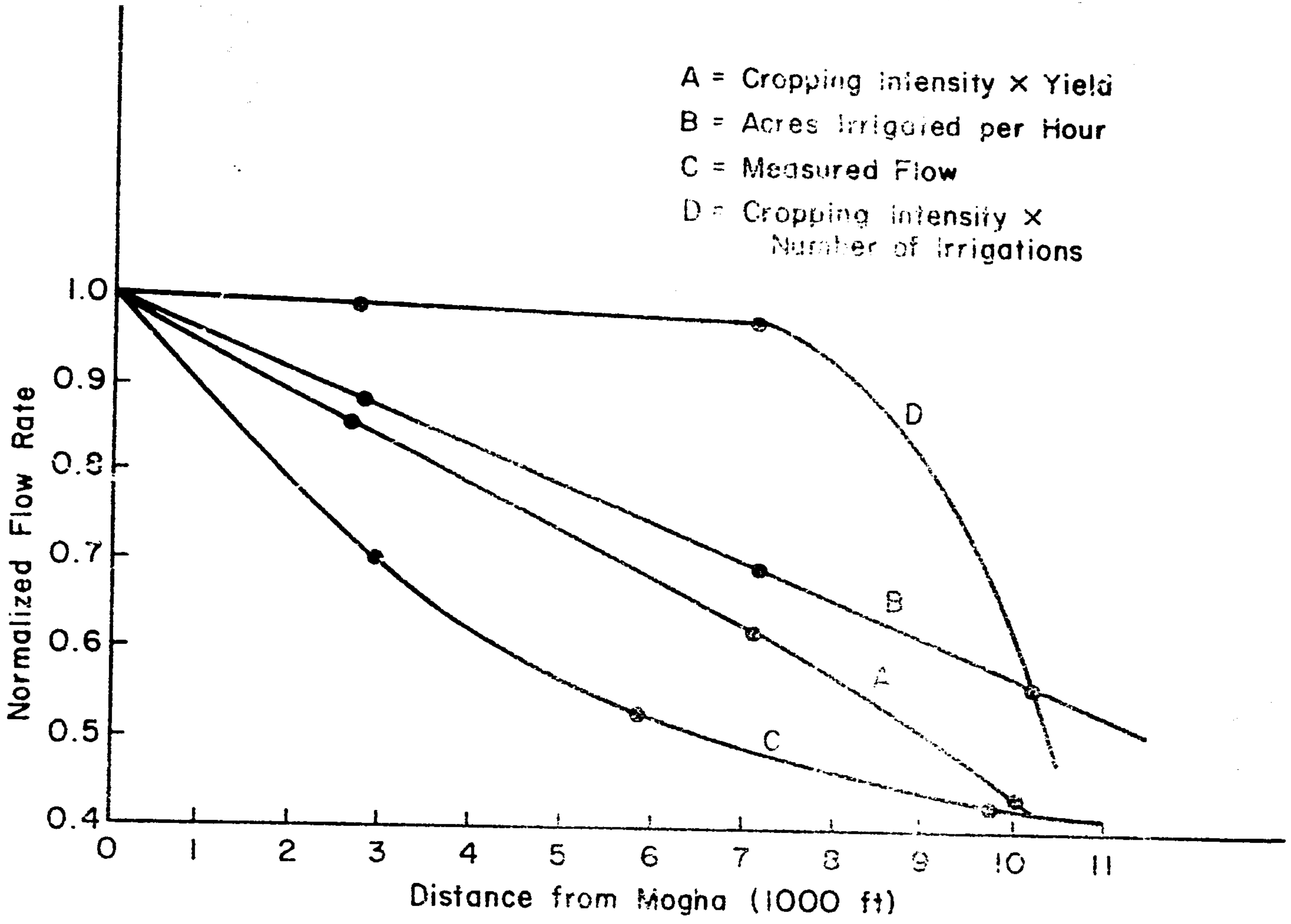
A = Cropping intensity × Yield
B = Acres Irrigated per Hour
C = Measured Flow
D = Cropping intensity × Number of Irrigations
Normalized Flow Rate
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0
1
2
3
4
5
6
7
8
9
10
11
Distance from Mogha (1000 ft)
A
B
C
D

Figure 1.

middle section, does not agree well with the other curves, although it indicates comparable losses at the tail. The measured flow plotted in Figure 1 is the average values for the head, middle and tail sections.

Although these relationships do not coincide, as could be expected from the small sample size and general assumptions made, they do support the physical measurements and point out that the farmers at the tail of a watercourse are only getting 40 to 60 percent of the water which is available at the head of their watercourse. Similar types of analysis will be done in the future on additional watercourses.

A "warabundi" operational conveyance loss study was conducted on Tubewell 81R watercourse before improvement. In this study all of the water entering and leaving the watercourse conveyance system was measured during a one week turn (warabundi). In this way total volumes of water entering and leaving the system, rather than just steady state flow rates were calculated, and the resulting losses were total operational losses, as in the Branch I of Tubewell 78 study previously mentioned. The study found an overall loss of 56 percent for the system on the 350 acre watercourse.

Such a complete study allows further determinations of the causes of conveyance losses. Preliminary findings indicate:

1. Losses are higher as higher elevation fields are being irrigated, indicating the dependence of loss rate on water surface level in the channel.

2. Conveyance losses increase by about 5 percent at night probably because farmers are less willing or able to stop visible leakage at night.

3. Dead storage is a small percentage of total losses.

4. Overtopping and visible leakage is a small percentage of total losses.

5. Seven percent of the total operational losses are transient and are not measured under steady state conditions.

These findings, of course, apply to the particular watercourse studied, but future warabundi studies will indicate whether they can be generalized.

Conveyance loss measurements were also made after improvement on Tubewells 56L and 51 watercourses. A summary of the before and after improvement measurements is given in Tables 2 and 3.

Table 2. Losses on Tubewell 56L Watercourse.

Condition	Ave. inflow (CSC)	Loss rate CSC/1000'[1]	Loss rate %/1000'[1]	Loss %[2]	Volume Inflow ac-ft/wk	Volume Loss ac-ft/wk	Field delivery (ac-ft/wk)
Before improvement	4.0	.29	6.56	50.5	55.3	27.9	27.4
After improvement	5.4	.21	4.03	33.0	75.0	24.8	50.2
Percent change	+36.0%	-28.0%	-39.0%	-35.0%	+36.0%	-11.0%	-83.0%
"Adjusted" after improvement[3]	4.0	-	1.76	17.4	55.3	9.6	45.7
Percent change	0.0%	-	-73.0%	-66.0%	0.0%	-66.0%	+67.0%

[1] Weighted averages of average measured loss rates on each branch considering the percentage of total irrigated land on the watercourse irrigated from each branch.

[2] 7,700 feet is the average length of watercourse utilized in reaching the fields. Of that length, about 800 feet is farmer's branch and was not improved. This section is consequently calculated in after improvement values at before improvement loss rates.

[3] Bowers, et al. (1976) found the relationships: Loss rate (%/1000 ft) = $.182_e{}^{.39Q}$, applied to one section after improvement. The after improvement loss rate has been adjusted downward by the percentage indicated by this equation for the indicated reduction in inflow.

Table 3. Losses on Tubewell 51 Watercourse.

Condition	Ave. inflow (CSC)	Loss rate		Loss %[2]	Volume		Field delivery (ac-ft/wk)
		CSC/1000'[1]	%/1000'[1]		Inflow ac-ft/wk	Loss ac-ft/wk	
Before improvement	4.7	.16	3.76	45.0	64.2	28.9	35.3
After improvement	5.0	.13	2.53	31.0	69.4	21.5	47.9
Percent change	-6.0%	-19.0%	-33.0%	-31.0%	+6.0%	-26.0%	+36.0%
"Adjusted" after improvement[3]	4.7	-	2.17	27.0	64.2	17.3	46.9
Percent change	0.0%	-	-42.0%	-40.0%	0.0%	-40.0%	+33.0%

[1] Weighted averages of average measured loss rates on each branch considering the percentage of total irrigated land on the watercourse irrigated from each branch.

[2] 12,000 feet is the average length of watercourse utilized in reaching the fields. Of that length, about 700 ft is farmer's branch and was not improved. This section is consequently calculated in after improvement values at before improvement loss rates.

[3] Wala, et al. (1977) found that the relationship: Loss (CSC) = $.0497e^{0.511Q}$, applied to one section after improvement. The after improvement loss rate has been adjusted downward by the percentage indicated by this equation for the indicated reduction in inflow.

Because measurement locations and flow rates often differed between the before and after data, an attempt was made to adjust the measured data to make comparisons possible. The percent increase in field deliveries for the watercourses serving Tubewells 56L and 51 was 83% and 36% respectively. A portion of this increase is the result of increased inflows to the system through the mogha which was, before improvement, submerged and not receiving its full allotment. When the loss rates after improvement are adjusted for the lower inflow rates available before improvement, to make them more comparable, the total losses (measured under steady state conditions) were reduced by 66% and 40% respectively. This adjusted increased water availability to the farmers of 800 acre feet per year on Tubewell 56L watercourse could be utilized to crop over 250 acres of additional land at a water allotment of 3 acre feet per acre. The cost of the improvement was about Rs 2 per foot of watercourse, or Rs 59,400. On Tubewell 51 watercourse where 500 acre feet per year of additional water is available, the total improvement cost was Rs 33,186. If the life of such improvements is only five years, 20% of initial cost is reinvested each year in maintenance and repair, and the costs are discounted at 15% and calculated on an annual basis, the cost of the additional water is Rs 37 and Rs 33 per acre foot on the two watercourses.

On this basis, further studies are being conducted at Mona with the assistance of CSU personnel to better understand the Pakistan watercourse conveyance system and why it loses so much of its precious water. Functional relationships are being derived between channel design parameters and loss rates, core materials are being developed to make the banks less permeable, low cost lining materials are being tried, and the effect of compaction on loss and rodent and insect activity are being assessed.

Implications of the Findings

In the Lieftnick Report, where watercourse conveyance losses were assumed to be 10%, only 4.5 million acre feet (MAF) of water was projected to be entering the groundwater from this source in 1975. The CSU-MREP data on watercourse losses indicate that 40 to 50% of the watercourse inflow is lost in SCARP areas. If we assume the same watercourse inflow and evaporation losses as stated in the Lieftnick Report, that losses from SCARP watercourses are 45% and from non-SCARP watercourses 35%, and that 25% of the diverted water flows in SCARP watercourses, the total inflow to the groundwater from the conveyance system is 30 MAF, an increase of 25.5 MAF over the projected value. This implies that the net inflow to the groundwater is much greater than previously assumed, and either groundwater storage is continuing to increase, or other factors in the water balance are incorrect. Twenty-five million acre feet of water could raise the water table about 3 feet under irrigated areas if there is no additional outflow.

If the types of watercourse improvements mentioned above are carried on throughout the Indus Basin, this inflow could be reduced by 50%, or about 15 MAF per year, reducing the pumping requirement and the amount of water completely lost to use to saline groundwater areas.

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APPENDIX 9

REVIEW OF WATERCOURSE LOSS MEASUREMENT IN PAKISTAN[1]

Mohammad Ashraf, W. D. Kemper, Mohammad
Munir Chowdhry, Bashir Ahmad and Thomas Trout[2]

Introduction

There is often a significant difference between our objectives and our achievements. This is a phenomenon common to most human endeavor. However, if we delude ourselves into believing that our objectives have been achieved, when they have not, we halt our progress because we believe that further improvement is not possible. Rediscovery of this potential for improvement, like repentence in our personal lives, opens the way to progress.

The farmers of Pakistan generally need more water, and a walk along their watercourses reveals losses by overtopping, seepage, leakage through rat holes and extensive leakage through the bunds near junctions. Difficulties in organizing all the individuals concerned for the cooperative efforts necessary for good watercourse clearance, maintenance and improvement programs play a major role in maintaining the present average delivery efficiencies at a low 53%. However, another major factor which has lulled us into complacency was a misinterpretation of earlier watercourse loss data which led to the conclusion that our delivery efficiencies were 90%. The procedure used was designed to determine the unavoidable losses, or the losses that were going directly down to feed the groundwater. These losses were found to be only about 10% and a delivery efficiency of about 90% represents what farmers can do with an excellent earthen watercourse. Unfortunately, the achievements of our farmers are falling short of this objective, and the difference between 53 and 90% delivery efficiency represents their potential for improvement.

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[1] Jointly prepared by Colorado State University and the Water and Power Development Authority. WAPDA Publication No. 71.

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Previous controversies over the apparently divergent loss data prompted an inquiry into the manner in which the various sets of data were taken. The following paper describes the manner in which the various sets of data were taken, rationalizes the differences and concludes that the average Pakistani farmer can increase the amount of water delivered to his fields to 90/53=170% of the amount presently delivered. The reality of this potential for improvement has been demonstrated by over 200 farmers on 6 watercourses in the Punjab, who have cooperated to improve their watercourses and have increased the supply of water delivered to their fields so they are now receiving from 110 to over 300% of the water they received before improvement.

Historical Resume of Measurements

Kennedy, Benton and Blench

Kennedy in 1881 estimated the total losses in watercourses (from mogha to fields) to be 28%. Average losses of 28 and 29% were estimated by Benton and Blench respectively. These estimates were considered to be representative of the losses until 1965.

Lower Indus Project Report (Hunting Technical Services 1965)

Water loss measurements were conducted on 11 watercourses during 1963-64. Straight sections 500 feet long with almost uniform cross section were bunded at each end, filled with water and its rate of recession was measured. Nakkas were avoided in the measurement sections as far as possible and those which could not be avoided were "properly sealed." The ponded stretch was filled a few inches above the normal full supply level which was ascertained from the local cultivators or irrigation department staff. Initial readings of the water level gauges were taken about one hour after filling, or whenever "the surface had settled". Subsequent readings were taken at intervals of an hour or less until the water level had receded by about 6 inches. Three tests were performed on each watercourse.

The loss rates varied from 2.3 to 8.3 with average of 4.9 cusecs/msf (per million square feet) of wetted perimeter. Assuming a wetted perimeter of 5 feet the loss rates work out to .011 to .041 with average of .025 cusecs/1000 feet watercourse. A summary of the result is given in Table 1. The supply rate of water to these watercourses was not reported, but a sampling of other watercourses measured in this area had flow rates of 1.4 cusecs, so an average supply of 1.4 cusecs was assumed in estimating 1.8% loss per 1000 feet shown in Table 1. The average distance from mogha to fields in Pakistan's watercourses is about 5000 feet. Consequently,

TABLE 1

WATER LOSS DATA SUMMARY

DATA COLLECTION AGENCY	SITE	Number of		WC Section		Loss Rate (QSEC/1000')				Total Loss %+	Remarks
		Water-courses	Sections	Inflow (Cusecs)	Length (Ft.)	AV	MIN	MAX	%/1000'		
1	2	3	4	5	6	7	8	9	10	11	12
Kennedy from (7)	Punjab									28	*
Benton from (7)	Punjab									28	*
Blench from (7)	Punjab									29	*
Hunting Technical Service (6)	Sind Gudu Left Bank Sukkur Left Bank Sukkur Rt. Bank Ghulam Mohd Rt. Bank Ghulam Mohd Left Bank	11	11			.025	.011	.041	1.8		Ponding Method** used on straight sections 500' long***
Punjab Irrigation Research Institute (7)	Punjab Niazbeg, Kasur, Khangah Dogran, Shorkat	11	11	0.6-3.3	10,000 to 23,000	.040	.006	.067	1.5	15	Ponding Method as above.
Boom and Gerhards (1)	Mian Channu	6	6	1.0-2.75	1,600 to 10,800	.069	.019	.150	4.1	22	Inflow-Outflow Method.
WAPDA/ CSU (1)	Multan	1	18	0.9-2.1	500 to 9,170	.079	.034	.190	6.2	22	Inflow-Outflow Method.

TABLE 1- Continued WATER LOSS DATA SUMMARY

DATA COLLECTION AGENCY	SITE	Number of		WC Section		Loss Rate (QSEC/1000')				Total Loss	Remarks
		Water-courses	Sec-tions	Inflow (Cusecs)	Length (Ft.)	AV	MIN	MAX	%/1000'	%+	
1	2	3	4	5	6	7	8	9	10	11	12
WAPDA/CSU and AGR. DEPT. (1)	Shadab	1	10	0.6-2.2	400 to 3,680	.146	.000	.318	21.4	43	Inflow-Outflow Method
WAPDA/CSU (1)	Lyallpur		44	0.6-3.0	600-8,250	.137	.000	.476	9.0	25	"
WAPDA/CSU (1)	Mona	3	28	1.2-4.9	1,300-8,800	.286	.02	.500	11.0	32	"
WAPDA/CSU (1)	Sargodha	6	6	.24-2.4	600-1.980	.426	.167	.742	40.0	40	"
WAPDA/CSU (4)	Lyallpur	2	57		1,700-8,720				12.2	32	"
	Multan	4	76		700-13,300				17.7	42	"
	Lahore	4	10		400-3,200				30.9	38	"
	Sargodha	4	16		1,560-6,140				13.0	47	"
	Gujranwala	2	19		650-6,550				11.1	42	"
WAPDA/CSU (5)	Muzaffargarh	2	35		800-4,500				27	47	"
	Bahalwalpur	4	54		150-3,250				45	66	"
	Sukkur				120-2,180				72	67	"

TABLE 1- Continued

WATER LOSS DATA SUMMARY

DATA COLLECTION AGENCY	SITE	Number of		WC Section		Loss Rate (QSEC/1000')				Total Loss %+	Remarks
		Water-courses	Sections	Inflow (Cusecs)	Length (Ft.)	AV	MIN	MAX	%/1000'		
1	2	3	4	5	6	7	8	9	10	11	12
WAPDA/CSU (5) cont.	Dadu	3	44		950-4,981				14	60	Inflow-Outflow Method
	Thar Parker	3	47		550-9,240				20	54	"
	Thatta	4	25		20-5,900				48	30	"
CSU/WAPDA (11)	Mona TW 81	1	57		600-8,000	.26	.16	.90	13	56	" ++
WAPDA/CSU (2)	Mona TW 56	1	18	1.83-4.8	1,340-11,300	.366	.11	.88	8.52	44	Measured before improvement
	Mona TW 56	1	36	2.0-6.65	1,100-9,800	.22	.01	.48	4.45	25	Measured after improvement

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*These data could be found only in secondary sources which did not indicate the method by which the measurements or estimates were obtained.

**The loss rates in cusecs/1000 ft are calculated from their data on loss rate per million square feet of wetted perimeter, assuming a wetted perimeter of 5'.

***Supply rate of water to these watercourses was not reported, so an average supply rate of 1.4 cusces (representative of watercourses in those areas) was assumed to calculate the % loss/1000 ft. The supplement to Vol. 17 of the Hunting LIP report could not be located in the time frame allowed.

+All % loss figures are given as percent of inflow to the watercourse.

++These measurements involved complete monitoring of all water that entered and left this watercourse during a complete warabundi rotation (one week).

(Bracketed numbers below agency refer to reference numbers in the References.)

the L.I.P. report data has been construed to mean that only about 10% of the water supplied to the watercourse is lost before it reached the fields.

Irrigation Research Institute (1972)

Loss measurements by ponding method were made on 12 watercourses in Punjab by the Punjab Irrigation Research Insitute in 1972. They selected straight sections 500 feet long with no weeds or nakkas. The surface recession was recorded over large time intervals in which surface level dropped from 0.5 to 1.0 feet. The recession rates used to calculate the loss rates were the average rates observed while the water level receded at least 0.5 feet. They measured the rate of flow in these watercourses, but apparently the full supply level was not measured or estimated under operational conditions. Loss rates between 0.067 to 0.006 cusecs/1000 feet were measured. The average % loss per 1000 feet was 1.5, which is close to the L.I.P. figure and firmly established the "fact" in the minds of many hydrologists in Pakistan that the loss from watercourses was no more than 10%. A summary of the I.R.I. results is given in Table 1.

Boom and Gerhards (as reported by Clyma, Ali and Ashraf, 1975)

Watercourse loss rates were measured with Cutthroat flumes on six watercourse sections near Mian Channu during Rabi 1973-74. A summary of their data is given in Table 1.

Clyma, Arshad and Ashraf

Clyma, Arshad and Ashraf (1975) measured watercourse losses on several watercourses in the Punjab between 1973 and 1975. All measurements were made with Cutthroat flumes. At Mohlenwal Khurd in the Shadab project area, near Lahore, ten measurements were taken in cooperation with the Agriculture Department on one watercourse which was supplied by the canal, jalars, and private tubewells during Rabi 1974-75. In Multan district, losses were measured on one watercourse in conjunction with the Agriculture Department's Integrated Rural Development Program project during Kharif 1974. In Lyallpur district, 44 measurements were made during Kharif 1974 on several non-SCARP watercourses supplied with a large range of inflows. Six watercourses in a SCARP area near Sargodha were studied in connection with a farm water management inquiry.

In the Mona Reclamation Experimental Project area, three large SCARP watercourses were measured to determine losses. The measurements were taken under widely varying inflow rates, between January 1973 and November 1974, as preliminary data for a watercourse improvement program. Data for the three Mona tubewell watercourses, as well as the previously mentioned data are summarized in Table 1. Table 2 below summarizes the Clyma et al. findings for total losses as related to inflow and type of watercourse.

TABLE 2. Total Conveyance Losses in Percent, for Three Types of Canals for Varying Inflow Rates

Water Supply Inflow Rate (cusecs)	Small Watercourses			Larger Watercourses		
	Well Maintained	Canal Supply Only	Canal Plus Tubewell	Well Maint.	Canal Supply Only	Canal Plus Tubewell
		(%)			(%)	
1.0	8	30	64	-	-	-
1.3	8	29	-	-	-	-
2.0	7	26	50	11	39	-
3.0	-	-	43	9	-	64
4.0	-	-	40	-	-	60
5.0	-	-	41	-	-	61

Early, Ali and Lowdermilk (1976-77)

One objective of this study was to gain a reliable estimate of the watercourse losses in the Punjab and the Sind. Three criteria were used in the selection of the sample villages and watercourse sites.

First, villages with pakka improved watercourses were studied to determine causative factors in farmer acceptance or non-acceptance of the improvements and the amount of loss improvement attributable to the pakka sections. Four watercourses of the total forty studied were of this type.

Secondly, villages were chosen with watercourses which were studied in the mid-1960's by Sir Alexander Gibb, Hunting and IACA in the Upper Indus and Sir Murdock MacDonald and Hunting in the Lower Indus Basin. Since villages were the target units of the survey, the remainder of the watercourses in those villages comprised the additional watercourses for that district. This led to the selection of 22 watercourses in the sample of forty.

The third criteria was the geographical coverage of districts and canal commands which were representative of the country's agro-climatic zones. These agro-climatic zones were comprised of areas with a dominant cropping pattern, and with rainfall deficits within certain ranges. The cropping combinations included the following Rabi-Kharif combinations: wheat/cotton, wheat/rice, fodder/rice, mixed and orchard, wheat/sugarcane/fodder, wheat/fodder, wheat/sugarcane/rice.

The four climatic combinations delineated were as follows: annual rainfall deficit less than 45 inches, between 45 and 55 inches, between 55 and 65 inches, and greater than 65 inches were the ranges selected.

These agro-climatic, district and canal command considerations led to the choice of areas in which six villages with a total of fourteen watercourses were selected at randon.

The measurements in the selected watercourses were made by the inflow-outflow method using Cutthroat flumes. A summary of results on water losses is given in Table 1.

Trout, Bowers, Wahla, Yasin, Iqbal and H. U. Khan (1977)

During the week of December 6, 1976, a complete operational loss study was made of T.W. 81-R watercourse of the Mona Reclamation Experimental Project area. The study involved measuring all of the water flowing into the head of the watercourse (2.6 cusecs when the tubewell was operating) and all of the water entering the fields being irrigated, during a one-week warabundi (turn rotation). The commanded acreage of the watercourse was 330 acres. The maximum and average length of utilized watercourse was 8000 and 5000 feet respectively. Conveyance efficiencies were measured by computing total volumes of water entering and leaving the watercourse system. The overall operational losses on the system were 56% of the inflow. The loss rates in the individual sections varied between 0.90 and 0.16 cusecs/1000 feet (35% and 6% loss of total inflow per 1000 feet). Average loss rate in one of the two major branches was about 65% while on the other it was less than 45%. This difference was probably caused by the level of the water in the first branch being much higher with respect to the field than in the second branch. Operational loss studies are planned for additional watercourse systems in the future.

A similar study was conducted by Kemper et al. (1975) during Rabi 1975, on Branch I of the watercourse which serves T.W. 78. The total loss in the branch was 59% of the inflow. The combined mogha and tubewell inflow into Branch I was 4.7 cusecs.

These two studies were both on watercourses which were in poor condition and have subsequently been improved by the farmers.

WAPDA and CSU Staff (Tubewell 56L Watercourse)

During October and November of 1975, loss measurements using the inflow-outflow method were taken on the watercourse serving T.W. 56L in the Mona Project area. The farmers were then convinced to destroy the old earth banks of their sarkari khal and rebuild the channel to the proper cross section, elevation and alignment. The USAID sponsored Water Management Project of MREP designed and installed pakka control structures at the major junctions on the sarkari khal. This work was completed in two months and the water losses were measured again in the main channel and branches of the sarkari khal. The data are reported by CSU-WAPDA staff (1977) and summarized in Table 1.

Measurement Methods - Their Relevance and Their Accuracy

Ponding Method

a. Procedure

A watercourse section of arbitrary length is selected and a bund is built at the lower end. The section is then filled with water, a bund is built at the top end and the rate at which the water level recedes is recorded as a function of time. This rate of fall (in ft/sec.) when multiplied by the length of the watercourse (ft) and the average width of the water surface (ft) during this time interval, yields the rate of water loss in cubic feet per sec. If the measured loss rate is to be a good estimate of the loss during operation, the elevation of the operational water surface must be determined precisely and the rate of recession must be determined when the water surface is at the operational level.

The equipment needed for the ponding method includes a measuring tape to measure the length and width of the watercourse, a measuring stick to determine its depth and other measuring sticks to be firmly fixed at the midpoint of each watercourse section to mark the operating level of the water and to monitor the recession of the water surface in that section. A watch to measure the elapsed time and a shovel or kassi to build the bunds at the ends of the section complete the needed equipment.

The rate of loss is commonly expressed in terms of cusecs of water loss per 1000 ft, though the test sections are generally less than 1000 ft long. In order to make comparisons between watercourses of different size, it is often desirable to express the water loss in terms of cusecs of loss per million square ft of wetted surface. Expression of the loss rates in this form requires measurement of the wetted perimeter of the watercourse. This can generally be estimated within 5% by taking 10 profiles of the depth of water across the watercourse and can generally be estimated within 10% by knowing the width and depth of the watercourse at 6 or more representative locations along the watercourse.

The rate of water loss (cusecs per thousand feet) for a watercourse section with the surface at any specific level can be determined by multiplying the water surface recession rate (feet/sec) at that level by the average surface width at that level (in feet) times 1000 ft. The recession rate is determined by measuring the slope of a line relating the water surface level to time, as shown in Figure 1. The loss rates shown in Figure 2 were determined by this procedure. In this figure, the loss rates for the four sections are plotted with respect to varying water surface levels at the midpoints of the sections. The loss rate at the predetermined full supply level is the relevant value under operating conditions, and the value which should be comparable to flume loss measurements.

b. Type of Results Obtained and Their Accuracy

The recession of the water surfaces of four sections of a watercourse with time are shown in Figure 1. This data was taken on a watercourse serving fields near the Mohlenwal-Khurd Village near Lahore, by WAPDA, Harza, Irrigation Department, Agriculture Department and Colorado State University personnel during an irrigation field day December 7, 1975. Prior to taking these measurements the water had been running in this watercourse for over two hours which should have brought the water content of the banks and bed to near their steady state value. The operational level of the water at the midpoint of each section to be bunded had been identified by forcing measuring sticks down through the water and through the bottom sediments until they were fixed solidly and exactly 1 inch of the measuring stick was left above the water surface. The bunds were closed successively with the one at the bottom end of the fourth section being closed first. After the bunds are closed, water in the upper end of the section continues to flow toward the lower end until the water level at the lower end is equal to that at the upper end. These fluctuations at the upper and lower end, which continue for some time, are at a minimum in the middle of the section. Each of these sections was filled to slightly higher than the operating level so that the slope of the line at the operating level could be established. Due to minimal "freeboard" there was some overtopping at the bottom ends of two of these sections during the first ten minutes following bund closure. This overtopping had generally stopped by the time the water surface levels at the midpoints of the sections receded to the operational level. The water level at the lower end of the sections at that time were generally an inch or so higher than the normal operating level at the lower ends.

Inflow-Outflow Methods

a. Equipment, Procedures and Accuracy

In these methods the rate of inflow and the rate of outflow from a particular watercourse are measured. When elevation of the water in the watercourse is contant with time, the rate of inflow minus the rate of outflow is assumed

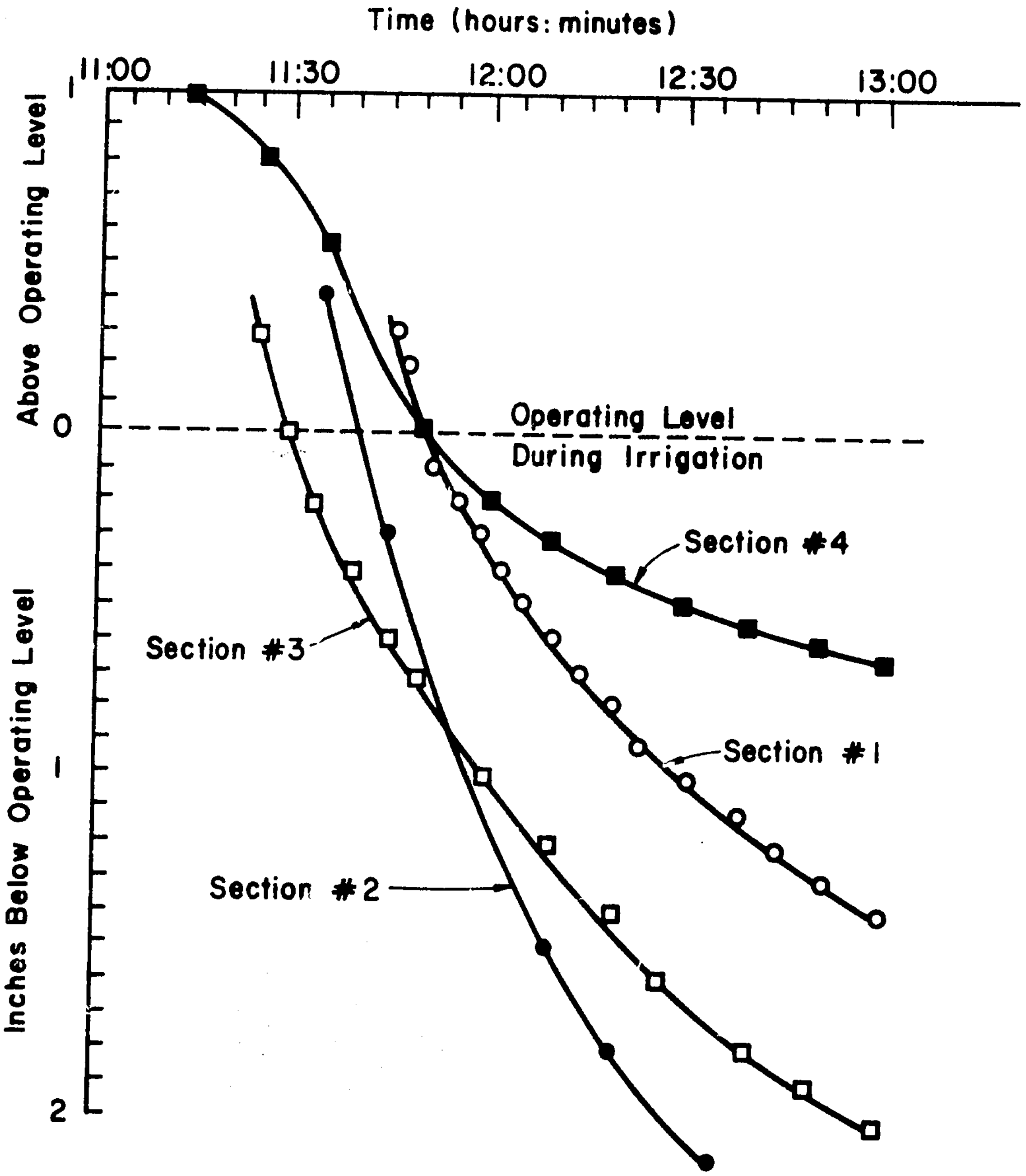

Figure 1. Recession rate of water surface in the four test sections of the Mohlenwal Khurd Watercourse.

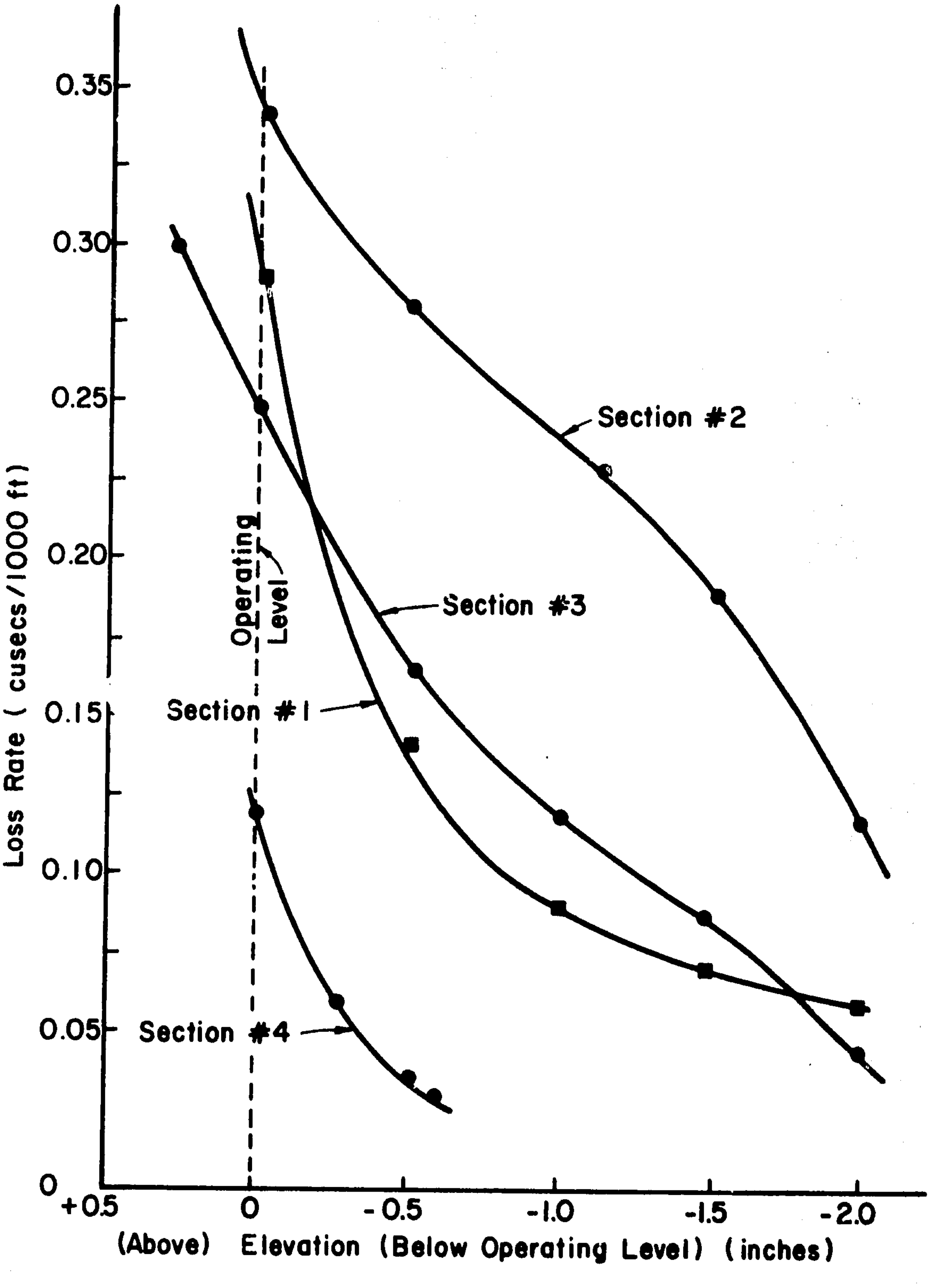

Figure 2. Effect of water surface height in watercourse on rate of water loss in sections shown in Figure 1.

to be the rate of loss from the watercourse. The most effective equipment manufactured in Pakistan for this type of measurement is a flume of the Cutthroat type. They are available with throat widths of 4", 8" and 12", and the flumes with three foot length are recommended for watercourse loss measurement. Flumes with these exact dimensions have been calibrated in hydraulics laboratories, where precise independent measures of the flow of water could be obtained and the elevation of water in the stilling wells or on the staff gauges mounted on the side of the flume could be measured at the same time. Tables of these calibrations are available which allow reasonably accurate estimates of the flow rate from readings of the water height on the gauges of the flumes. They require a headloss of at least .06 ft if reasonably accurate measurements are to be obtained. The amount of headloss can be adjusted to about 0.1 ft by placing the flume with a proper throat width at the proper elevation. These flumes have been calibrated with their base in a horizontal position and with the water flowing directly to the flume. Consequently, they must be installed with the flume completely horizontal in both the direction of flow and at right angles to the flow. A small carpenter's level is generally used to assure that these conditions are met. If the difference in flow between two flumes is to provide an accurate estimate of the loss rate, the amount of water in that watercourse section must not change appreciably in the time that these measurements are taken. If the flow coming into the watercourse is relatively constant, this steady state condition is generally met after a period of time dependent on the rate of flow and the width, depth and slope of the watercourse. Generally a volume of water equalled to about twice the volume required to fill the watercourse section at operational level must be passed by the first flume before steady condition at the lower flume is obtained. In some cases infiltration into the banks is relatively rapid and a longer period of time must be allowed before steady state loss measurements can be obtained.

Generally the rate of water flow through these flumes can be measured to plus or minus about 5% if the indicated precautions are taken. This means that the difference in flows between flumes can be measured to ±7%. The accuracy with which the flow measurement can be taken and the rate at which water is leaking out of the watercourse per unit length of watercourse determine the length of watercourse which must be included in order to estimate losses with reasonable accuracy. For instance, if the difference in flow rates between two consecutive flumes can be measured with ±7% accuracy, rate of water loss from the watercourse is about 10% per 1000 ft, the loss in 5000 feet of watercourse will be about 50% and the measurement obtained will be in the range from 43 to 57%. If the length of section (at this loss rate) is only 2000 feet, the actual loss of 20% may be estimated by readings from 13 to 27%, which would not be sufficiently accurate for many purposes.

However, this random measurement error is generally normally distributed and consequently the mean of several measurements taken on a watercourse will have measurement component of its error which will be $7\%/\sqrt{n}$ where n is the number of independent observations included in the mean.

b. Example of Measurement

The flow rates measured at three flumes on a watercourse are shown in Figure 3. One flume was near a low capacity tubewell. The flume #1 was about 250 feet below the tubewell and flume #2 was 1245 feet below #1, near where water was entering a farmer's field. The full flow of the tubewell reached the flume #1 at 8:45 and the water began to flow through the second flume at 9:12. This early arrival at the second flume was partially due to some water standing in sections of this watercourse before the tubewell started pumping. The flow at the second flume had reached steady state by 10:25 and at this steady state rate, 0.13 cusecs, approximately 36% of the water was reaching the field. When it was apparent that this steady state had been obtained, the test section was bunded in the four sections discussed earlier under Ponding Methods.

Comparison of Results by Ponding and Inflow-Outflow Methods

The rate of loss measured by the flume under steady state conditions was 0.36 - 0.13 = 0.23 cusecs and our confidence limits would be ±0.03, or from 0.21 to 0.26.

The loss estimates by the ponding method in sections 1, 2, 3 and 4 were 0.065, 0.148, 0.084 and 0.030 cusecs respectively for a total loss of about 0.33 cusecs. It is probable that this higher rate of loss estimated from the ponding measurements (as compared to the inflow-outflow measurements) was a result of slight amounts of overtopping and greater permeability of the upper portions of the banks in the tail portion of these sections where the water level had risen as much as 0.1 foot above the observed operational levels. Close agreement between the two methods of loss measurement is obtained if the evaluation of loss rate is made when the water surface elevations at the midpoints in the sections were 0.3" below the observed levels. If the pond loss rates had been evaluated one inch or two inches below the observed operational levels at the midpoints of the sections, the ponding method loss rates would have been 70% and 32% respectively of the flume measured loss rate. This extreme dependence of loss rate on the level of the water surface requires that the operational level of the water surface be precisely defined and the recession rate be determined at precisely that level if the ponding method is to be used to estimate operational losses with a reasonable degree of accuracy.

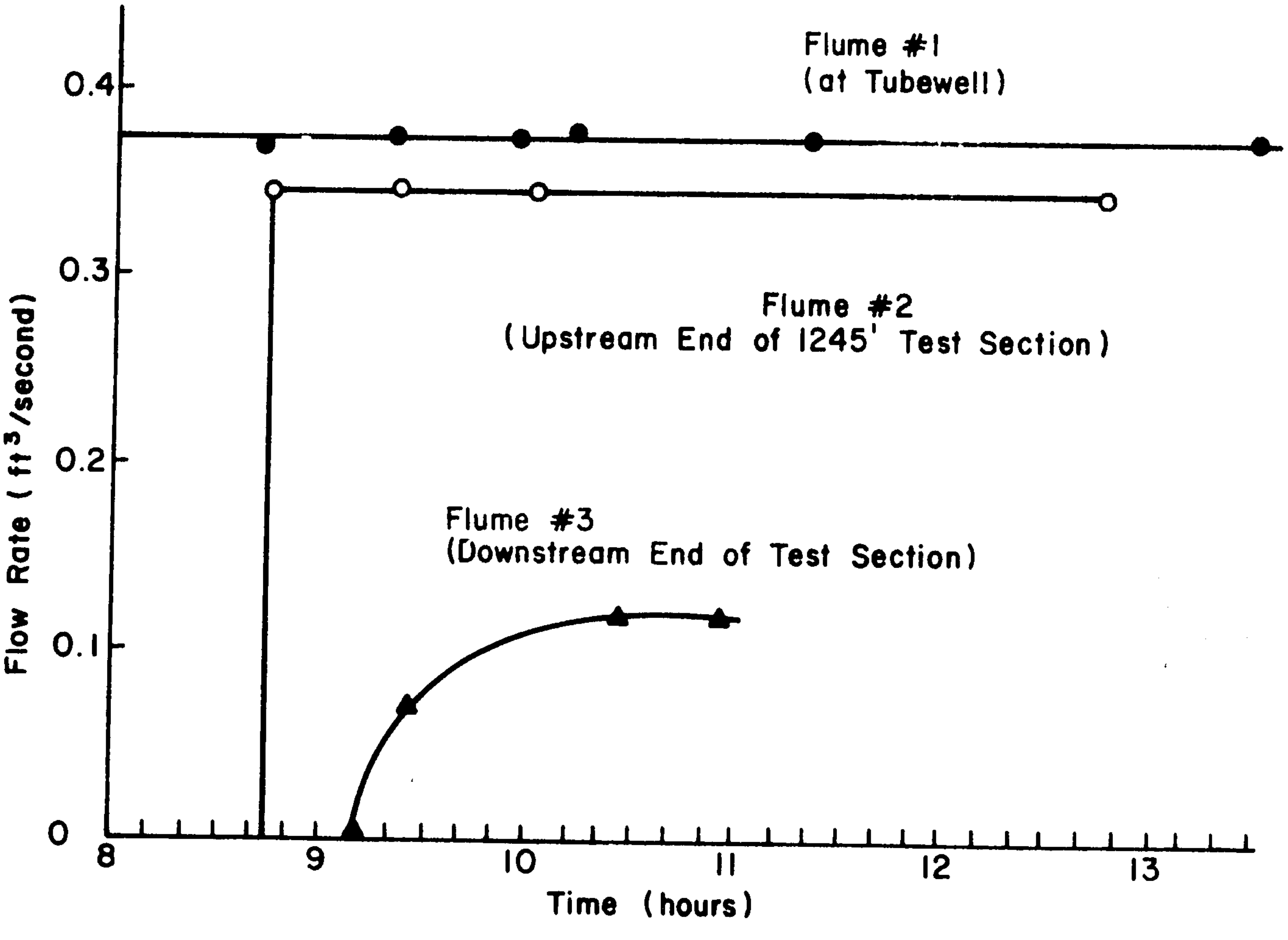

Figure 3. Flow measured at flumes on the Mohlenwal Khurd Watercourse.

This sensitivity of loss rate to water surface elevation in a watercourse is somewhat greater than normal. However, this type of sensitivity has been noted in the Lower Indus Report (e.g. Figure 2.7, Volume 17). On 34 sections of 5 watercourses, observed by Kemper et al. (e.g. 1975) using the ponding methods, the water loss decreased by an average factor of about 2 for each 0.2' decrease in water surface level in the watercourse. In this limited sample of watercourses, the majority of the loss obviously takes place through the upper portions of the banks and very little loss occurs in the bottom of the watercourse.

In summary, this comparison points out that while the ponding method is an accurate measure of the losses under the ponded condition, extreme care is necessary to estimate operational losses from ponding measurements. Underestimation of the operational level results in underestimation of the recession rate, which will result in drastic underestimations of the operational losses. However, it is also apparent that the flume measurements cannot estimate losses in short sections with a satisfactory degree of accuracy. Consequently, on short sections where different treatments or conditions are to be evaluated, the ponding method is the only feasible method, while on long sections where the operational losses are to be determined, the inflow-outflow (flume) method can provide reasonably accurate estimates of loss.

Flume measurements can also be used to determine total losses from a watercourse system under the constantly changing flow conditions encountered in changing flow from one field to another. This is possible by placing a flume at the head of the watercourse system and other flumes at each field outlet, and recording flow through each flume over time as was done in the T.W. 81R warabundi study by Trout et al. (1977). In this way, total volume of flow entering the watercourse system, and the total volume of water entering the fields being irrigated is measured, allowing a direct evaluation of conveyance efficiency under operational conditions. Additional losses not recorded in steady state measurements, such as dead storage, initial high infiltration rates in dry banks, losses during the time watercourse sections are being filled, and other operational spillage and wastage are measured. Although the additional information collected in such an operational study is valuable, the study requires a major effort in personnel time and equipment to complete successfully. A complete measure of operational losses involves collecting data during a complete warabundi turn rotation. A good estimate of total losses can be made by randomly selecting a sample of the irrigations in a warabundi, such as was done in the Early et al. (1975) and the Early et al. (1976) data.

Reasons for Differences in Reported Losses

Definitions

During the 1975 FAO sponsored conference on waterlogging and salinity, a gentleman who had helped plan some of the earlier studies raised an objection to some of the WAPDA-CSU data on water losses because "these losses included avoidable losses." By this objection he clearly defined a difference in definition of the word "losses" as used in the different studies. The methods used in the Lower Indus Project study and in the Irrigation Research Institute study were designed to measure "unavoidable losses" or "seepage and evaporation losses." The manner in which the L.I.P. methods were designed to measure the "seepage loss" is indicated by the following quotation from Volume 17 of the L.I.P. report:

> 1. Ponding Method
>
> This method was used to measure the seepage losses. For this purpose, 500 feet of watercourse length was taken along a straight section of the channel. The number of farm outlets from the watercourse within the ponded stretch was kept at a minimum in the selection process. The outlets which had to be included were carefully sealed before the pond was filled to avoid abnormal leakage.
>
> The ponded stretch was filled a few inches above the normal full supply level which was ascertained from the local cultivators or irrigation department staff. Initial readings of the water level gages were taken about one hour after filling or whenever the surface had settled.

The wording and procedure used by the Irrigation Research Institute are practically identical. Both appear to be measuring the "seepage" component of losses which directly feeds the groundwater. In both the L.I.P. and I.R.I. studies, only the ponding method was used.

The methods used by WAPDA-CSU are designed to measure "total losses under operational conditions." If rat holes, insect holes, improperly closed outlets, or high water levels resulting from vegetative growth in the channel are causing water losses, the technicians taking the measurements are instructed to not tamper with the existing farmer's system, but to measure the losses as they exist.[3]

These differences in definitions of losses and consequent differences in measurement procedures probably account for a major portion of the higher losses reported in the WAPDA-CSU studies.

The utility of the L.I.P. and I.R.I. seepage loss estimates apparently lies in the degree to which they approximate unavoidable loss which cannot be stopped by the farmers, or the degree to which these losses approximate the portion of loss which goes directly to the ground. However, a major portion of the leakage or spillage from rat holes, overtopping, etc., also finds its way to the groundwater (Kemper, Clyma and Ashraf, 1975) and consequently this unavoidable loss is not an accurate measure of the recharge to groundwater from watercourses.

The "total loss under operational conditions" subtracted from the water delivered to the watercourse from the canal and the tubewell yields the amount of water delivered to the farmers fields. The total loss under operational conditions could be considered the ultimate potential for improvement of water delivery (for instance, the water that could be saved by delivering it through a pipe line with zero loss). However, an estimate of potential for improvement of water supply through earthen improvements on the watercourse is more pertinent to the present state of our economic development. The difference between the total loss existing under operational conditions and the "unavoidable seepage and evaporation loss," is a good estimate of this potential for improving water supply by earthen improvements.

Selection of Test Sections

According to the description in the L.I.P. and I.R.I. reports, a definite preference in selecting sections was given to sections which were uniform so the average width and wetted perimeter could be estimated more accurately. In other words, sections where erosion, animal activity and borrowing soil from the banks (to close nakkas) near junctions had weakened the banks and made them more leaky, were avoided. They state that they generally filled the watercourse to a level 2" higher than operating level prior to starting their measurements.

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[3] One exception to this rule is recommended to the technicians. When the increased elevation of the water surface level upstream from a flume has caused observable overtopping or flow through additional holes, the observable extra leakage due to installation of the measuring instrument is to be stopped. (Generally the technicians were instructed to install the flume at increasingly lower elevations until an upper limit of 95% flume submergence was reached to minimize this problem.)

In major portions of the watercourses in Pakistan, the operating level is within two inches of the tops of the lowest places on the banks or bunds. Consequently, the sections chosen for these ponding studies were from the better sections of the respective watercourses. The watercourses chosen for study were chosen to represent specific canal command areas.

Watercourses selected for the WAPDA-CSU studies were chosen to represent certain categories including perennial and non-perennial canal command areas, watercourses studied in the L.I.P. and I.A.C.A. studies, and to represent agro-climatic regions. Sections chosen within the watercourses consisted of the complete length from the head of the watercourse to the farmers' fields which were chosen to represent delivery to regions in the watercourse command area near the head, near the middle and near the tail of the watercourse. Since approximately equal numbers were drawn from the head, middle and tail sections of watercourses, and since watercourses commonly have one head and more than one tail, it is probable that the average length of watercourse selected in the WAPDA-CSU studies is slightly less than the actual average length of watercourses to the farmers' fields.

Elevation of Water Surface in Watercourse During Loss Measurement

As was pointed out in the measurement methods section, the loss is extremely sensitive to height of water in the watercourse.

Technicians conducting the L.I.P. studies recognized the need for knowing the operational level and "ascertained this level from local cultivators or irrigation department staff." Questioning a few cultivators on watercourses as to the elevation of the operational level of watercourses where the actual level had been measured by CSU-WAPDA staff indicates that farmers tend to underestimate the operational surface elevations by about one inch when asked when the water is no longer in the watercourse.

The loss data in the I.R.I. report are an average of the rate of loss over time periods of 8 to 23 hours during which the level in the watercourse dropped about 6". Their initial rates of loss, which were probably taken with water surface levels near the operation are not given, but the fact that the eight and ten hour time period data show loss rates that are about twice as fast as data from twenty-three hour periods indicates that their recession curves were similar in shape to those shown in Figure 1 and Figure 2.7 in Vol. 17 of the L.I.P. report. They interpreted the decreasing rate of loss with time to the soil becoming more saturated. Most of the WAPDA-CSU data on ponding losses were taken following the time when the channel had been used for periods of one to twenty-four hours. The same large decline in rate of loss was noted as the water level dropped, showing that the major part of the decline in rate of loss was due to successively lowered levels of the watercourse surface.

The I.R.I. also noted a decline of loss rate following successive fillings, which they attributed to increasing saturation of the soil under the watercourse. There is an alternative explanation. In any watercourse (or field) where standing water is maintained for more than a few days, algae begin to grow on the wet surface and tend to seal the surface. The rate of permeability is generally increased by drying the soil and the algae, or by skimming off the algae and the surface layer of the soil. Using the average loss rates rather than the loss rate at operational levels probably leads to an underestimate of the losses which occur during the operating conditions by at least 50%.

When the inflow-outflow measurements were being taken, the level of water in the watercourse was the normal operational level, except for the reach immediately in front of the lower flume where the water level is raised as a result of head loss at the flume. In most cases the flumes were set so the head losses were about 0.1 foot and, consequently, the water surface immediately above the flume was elevated by 0.1 foot. Slopes of the water surface in operating watercourses in the Punjab measured to date average about 0.6 feet per 1000 feet. In a watercourse with a slope of 0.6 ft/1000 ft., the effect of raising the water level by 0.1 foot at a flume raises the water surface level by about 0.05 feet at a location about 170 feet upstream from the flumes and the rise in water level generally becomes insignificant at locations more than 340 feet above the flume.

Under these conditions, the average water level rise in the 340 foot section immediately in front of the flume is about 0.05', and according to the observed average effect of elevation on loss, this would cause the loss during measurement in this 340 foot section to be about 1.2 times the loss in the watercourse under normal operating conditions. If loss in a section 5000 feet long is being measured, the section with raised water level is about 7% of the total length and the loss during measurement would be about 1.015 times the loss during normal operational conditions. However, in test sections 1000 feet long the measured loss would be about 1.07 times the loss during normal operational doncitions.

In a few cases in the WAPDA-CSU studies, flumes were installed in a manner such that the head loss was as much as 0.3 feet. If the average slope of the watercourse was 0.6 feet/ 1000 feet, the water surface elevation 500 feet above the flume would be raised about 0.15 feet and this would approximate the average increase in water surface elevation in the 1000 foot section of the watercourse immediately upstream from the flume. In this section the measured loss would average about twice the loss under normal operational conditions. Under these high head loss conditions, and if the technician did not reduce the effect of raised water surface elevation by stopping flow through additional holes or overtopping, if a 5000 foot section was measured the loss would average about 1.2 times the loss under normal conditions. If the loss was measured in a section 2000 feet long, the measured loss rate would be about 1.5 times the loss rate which would occur under normal operating conditions.

Watercourse operational levels have less slope in the Sind than in the Punjab and consequently the effect of a head loss in raising the water surface level extends further upstream. The limited data available indicates slopes of the water surface during operation of about 0.4 feet per 1000 feet. Under these slopes, the effect of a flume in raising the water level would extend about 1.5 times as far upstream, and its effect on loss measurement would be 1.5 times as great. Fortunately, by the time the WAPDA-CSU loss measurements were being taken in the Sind watercourses, technicians had been trained to set their flumes with about 0.1 ft of head loss. This would cause measured water losses on sections 5000 feet long to be about 1.02 times the loss during normal operating conditions and the measured water losses on sections 1000 feet long to be about 1.1 times the loss during normal operating conditions.

Effect of Avoiding Nakkas and Degraded Sections of the Watercourses

As discussed earlier, the L.I.P. and I.R.I. studies deliberately chose to avoid, or seal nakka and junction sections where leaks could occur, and preferentially selected watercourse sections for study where there was no degradation of the watercourse. The overall effect of avoiding junctions and nakkas on the loss rates may be roughly estimated from a limited study conducted by Kemper and Akram (1975) on one branch of a watercourse. They found that 45% of the water loss occurred in the degraded sections within 30 feet of junctions, despite the fact that these junction areas included only 19% of the length of the branch. Taking the losses on the straight sections of this branch (avoiding the junctions and degraded sections) and assuming that these straight sections were representative would have resulted in an estimate of operational loss that was 64% of the actual losses.

The inflow-outflow method measures the total leakage from all sections.

Age of the Watercourses

There is data on the age of only a small percentage of the watercourses. Studies by Kemper et al. (1975) showed that the loss rates on newly constructed watercourses, where the soil in the banks had been reasonably compacted, were commonly less than 0.1 cusecs/1000 feet, while the losses from "mature watercourses" in the same areas averaged about 0.4 cusecs per 1000 feet. This high loss from old watercourses was attributed largely to the multitude of insect, worm, and rodent holes in and through the banks which raise the infiltration rate of the upper portions (often vertical faces) of the old banks to 5 to 10 times that of soil in adjacent fields.

Differences Between Day and Night losses

The primary factor causing difference between day and night losses using the ponding method is evaporation which is usually only a few percent of the total loss. However, during operational conditions bund ruptures, flow through new rat holes, etc., are closed more frequently during the daylight hours than during the night hours. On some watercourses at some times (Clyma and Arshad, 1974) the delivery efficiency can be 10 to 20% lower at night than during the day. Averages over more time and numbers of watercourses indicate (Trout et al. (1977) and Early and Lowdermilk, in progress) delivery efficiency during the dark hours is about 5% lower than during the daylight hours.

Losses in Rabi and Kharif Seasons

There should be some tendency for farmers to take better care of their watercourses during the times of greater need for water as in October and November. A preliminary review of the data indicates little difference in the delivery efficiencies of this and other seasons. The fact this season is also a time of heavy labor demand by other farm activities may be part of the reason for lack of significant extra effort on watercourse maintenance during this season. Studies are in progress in the Mona Project to determine the seasonal delivery efficiencies with more precision and to determine the effects of existing and improved cleaning and maintenance programs.

Summary

Kennedy, Benton and Blench estimated that 28% of the water supplied to watercourses was lost before it reached the farmers' fields. The Lower Indus Project used a ponding method to measure water losses in selected straight sections of 11 watercourses in the Sind in 1963-64. The Irrigation Research Institute (Punjab) used the same criteria to select 12 uniform, straight sections 500 feet long on 12 watercourses and used the same method of measurement. The average losses reported by these two groups were 1.8 and 1.5%/1000 feet respectively. These losses have been coupled with an average length of watercourse from mogha to field of 5000 feet to conclude that watercourses lose no more than 10% of the water passing through them.

Measurements taken by WAPDA, CSU and Agr. Dept. personnel using the inflow-outflow method on 606 sections of 51 watercourses indicated loss rates varying from 4 to 72% per thousand feet of watercourse. These data, taken under operational conditions indicate that almost half of the water supplied to the watercourses was lost before it reached the farmers' fields.

The reasons for the inflow-outflow method used by WAPDA-CSU yielding higher losses than the ponding method used by the LIP and IRI are: (1) The sections chosen by LIP and IRI avoided (or sealed) the junction and nakka areas which have been found responsible for about half of the loss; (2) The water levels at which loss rates were measured in the IRI studies were lower than operational levels for most of the time over which the averages were taken, and it has been found that loss rates are reduced by about 50% when the water surface is lowered 0.2 feet in the average watercourse; (3) During the measurements taken by the WAPDA-CSU teams, losses were determined as they exist in the watercourse system. Losses through rodent holes, broken bunds, overtopping, etc., were allowed to continue unless the farmers stopped them. The LIP-IRI studies were conducted to determine seepage and evaporation losses (unavoidable losses) only, and they cannot be used as an estimate of operational losses.

The difference between the average operational losses as measured by WAPDA-CSU and the unavoidable losses as measured by LIP-IRI is about 40% of the present supply to the watercourses of Pakistan. It is a good measure of the potential improvement of water supply to farmers' fields that could be achieved by careful, well-designed earthen improvement of watercourses.

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APPENDIX 10

OPERATIONAL CONVEYANCE LOSSES ON TUBEWELL 81-R WATERCOURSE[1]

Tom Trout, S. A. Bowers, Mohsin Wahla,
Hayat Ullah Khan, Mohd. Yasin and M. Iqbal[2]

INTRODUCTION

Colorado State University Water Management Research Project and Mona Reclamation Experimental Project are working to determine means to improve on-farm water management in Pakistan's irrigated regions. An important component of this system is the network of small watercourses which convey the water from the government distributary outlet, the "mogha," to the field being irrigated. Although the primary portion of this conveyance system is authorized by the government, all practical upkeep and maintenance of the entire system is left to the farmer. Potential improvement in such a system is first assessed from a knowledge of the existing workings and inefficiencies of the system.

In the past four years, many measurements of the water losses from these village watercourses have been made by CSU engineers and their Pakistani cooperators. These measurements have indicated that from 30 to 50 percent of the water presented to the farmers at the mogha is lost from this conveyance system on most watercourses (Clyma et al., 1975; Early and Lowdermilk, 1975; Early et al., 1976). However, all of these measurements have essentially been taken while the system was in steady state, or flowing at a constant rate. This type of measurement fails to measure the additional operational losses present in the watercourse systems. Operational losses include water initially infiltrated into the dry channel banks, water losses from the watercourses during the movement of water from one field to another, dead storage water left in the bottom of channels after their use, and losses resulting from short term breaks or leaks in the watercourse, both intentional and accidental.

The authors are aware of only one previous study designed to measure operational losses in Pakistan watercourses. This

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[1] Contribution from Colorado State University and the Mona Reclamation Experimental Project, WAPDA. Portions of the work were supported by USAID/Pakistan Agreement No. 204-75 and by USAID/Washington Contract No. AID/ta-C-1411. Water Management Field Report No. 7, Colorado State University.

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study, conducted by W. D. Kemper et al. (1975) took place during the 15 hours which water was flowing in one branch of a watercourse system. The conclusion of this study was that operational losses result in an additional 15% total loss over steady state measurements.

This study was conducted to determine the total water losses, including operational losses from a village watercourse system during one complete week. This time period was chosen because in the studied watercourse, and in most watercourses in Pakistan, the water is allotted to the farmers on a turn basis ("warabundi") over a one week rotational period. In order to better understand the present system and to determine potential design improvements, an attempt was made not only to measure total losses but also to determine their causes and distribute them to the various categories.

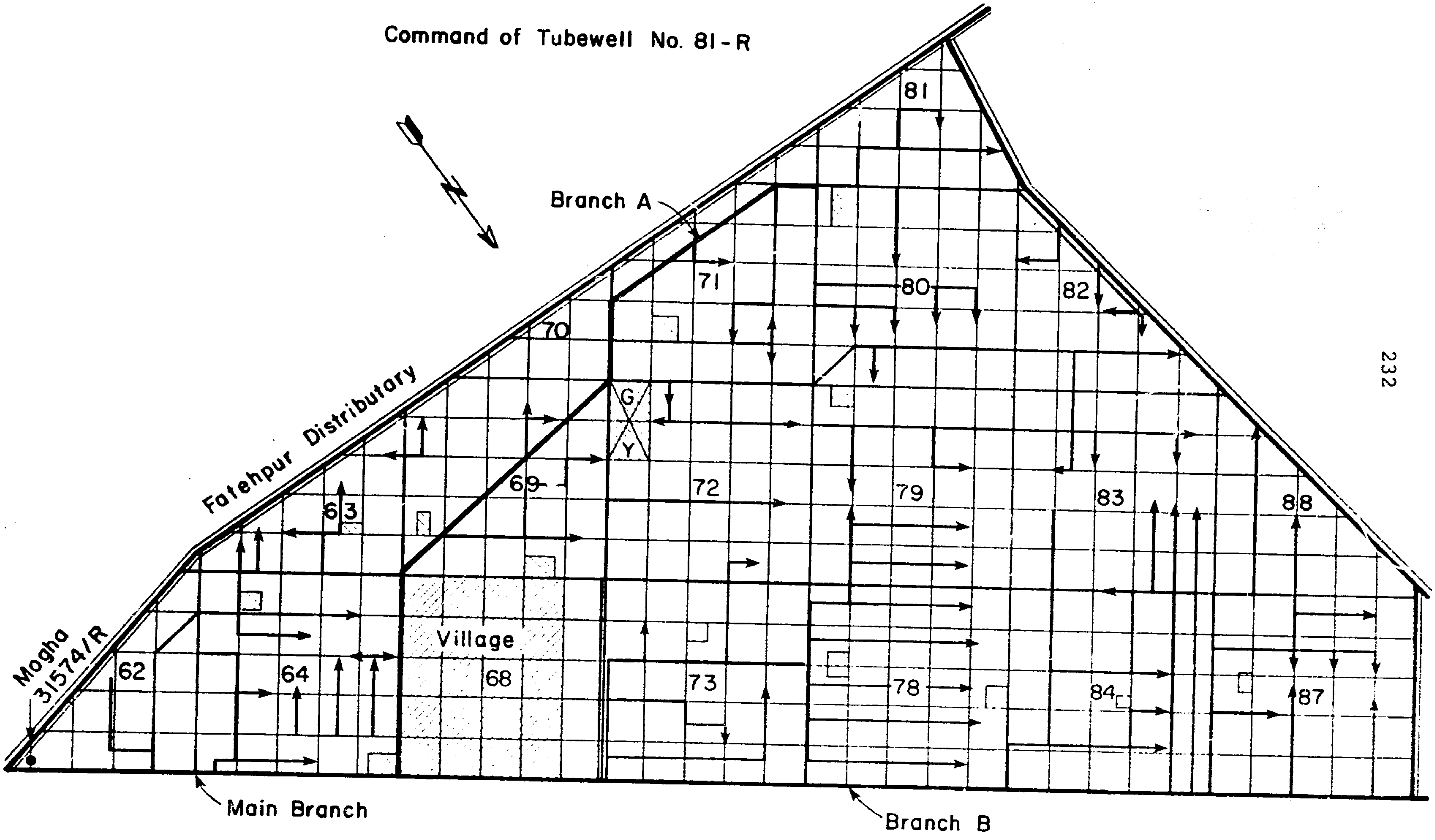
SITE AND SITUATION

The watercourse served by mogha 31574/R of the Fatehpur Distributary in the Mona Reclamation Project (MREP) area, Bhalwal, was chosen for this study. The watercourse is supplemented by part of the flow of Tubewell 81 of the SCARP-II (Salinity Control and Reclamation Project) Project, and will be referred to as TW 81-R watercourse. A watercourse in the Mona Project area was chosen because of the availability of trained extension personnel to assist in the measurement process. Tubewell 81-R was chosen because the farmers had shown interest in the watercourse improvement program developed by CSU and MREP, and the collected data could also be used as initial data for the improvement program. The cooperation of the farmers was also favorably affected by the promise of the pending improvement program.

The watercourse commands 366 culturable acres. Primary "rabi," or winter season, crops in the area are alfalfa, berseem, wheat, sugarcane and citrus. There are a total of 75,000 feet of watercourses in the area (205 ft/acre) of which 11,000 feet are government authorized "sarkari khal" which was originally laid out and constructed by the government. The watercourse includes a 2100 ft main watercourse through which water flows about 90% of the time. Water then flows about 3 1/4 days in the southern A Branch and 3 days in the B Branch. Figure 1 shows the layout of the watercourse command area.

The total inflow to the watercourse system, when the tubewell was on, was 2.6 cubic feet per second (csc). With the tubewell off, the mogha flow was 1.1 csc. These values remained quite consistent during the week. The mogha flow, and thus total flow, may have been reduced up to 0.1 csc while the tubewell was on during the week due to the presence of

Figure 1. Layout of Tubewell 81-R Watercourse.



the flume, which decreased the head drop across the mogha by 0.2 ft. The amount of flow decrease depends upon the degree of submergence of the mogha.

The tubewell was turned off 20 hours during the week at irregular intervals. This is much less than the general practice of tubewell scheduling in the SCARP II area and perhaps a result of the presence of the survey team.

There are 20 land holdings listed on the warabundi (turn rotation) list for the watercourse. Land holding sizes varied from 6.4 to 46.6 acres with a median size of 14.8 acres. The annual cropping intensity for the present "rabi" (winter season) and past "kharif" (summer season) was 174%. This is higher than the average cropping intensity in the Mona Project area of 138% (1975-76 Patwari data). There is about one cubic foot per second of inflow to the watercourse for each 140 acres. This is close to the SCARP design of 150 acres/csc, but much higher than most non-SCARP areas.

The study was conducted from the 7th to the 14th of December. All of the rabi wheat had been planted, and some was given its first irrigation during the week. Nearly half of the land irrigated during the study was planted to newly germinated wheat. Other major crops were alfalfa or berseem, citrus orchards (often interplanted with wheat, alfalfa or berseem) and sugarcane. The canal system was scheduled to be closed for about one month; one week after the study ended, for the annual maintenance work.

PROCEDURE

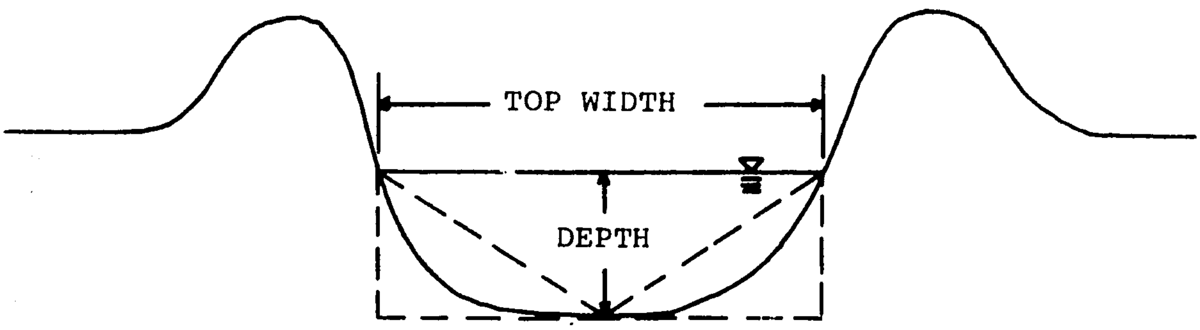
The primary objective of the study was to determine the total conveyance losses in a watercourse system. Consequently, the primary measurements made were of all the water entering the watercourse at the head and of all the water entering the fields being irrigated. Flow rates were measured with Cutthroat flumes (Skogerboe et al., 1973). A flume was set near the head of the watercourse below the entrance of the tubewell water, about 75 feet downstream from the mogha. The second set of flumes were set at the end of the sarkari khal section of the watercourse being used. A third set of flumes was used to measure the water flowing in the watercourse near the farmer's "nucca", or field outlet. Sometimes, two field flumes were being read simultaneously. An attempt was made to anticipate the farmer's activities and have field flumes set before the water arrived, although this was not always successful. Flume readings were made every 10 minutes during the entire week.

The second objective of the study was to evaluate the various types of losses. For this purpose, the additional flumes were set in the government authorized watercourses to determine how much of the losses occur in the farmers' branches, and how much in the authorized sections. Channel cross sections were measured to determine a channel's potential storage volume and to calculate losses as related to wetted area. Water surface width and five equally spaced depth measurements were used at each cross section to estimate cross sectional area by Simpson's Rule numerical integration.

The volume of water which lays in the bottom of the watercourse sections after all drainable water has entered the field is lost to the farmers' present use. This dead storage is therefore considered a loss of irrigation water in the conveyance system. This loss is caused by channel inverts being below the level of the field being irrigated, and by deep sections followed by sections with higher beds.

Dead storage losses in the TW 81-R watercourse system were measured during the study. Dead storage was determined by measuring the top width and center depth of the water lying in the bottom of channels from which the inflow had been diverted from two to twelve hours earlier. Two readings were taken per 200 ft length and the readings were averaged. The cross sectional area of the sections were estimated by multiplying the product of the two dimensions by 0.75. This simplified method which assumes the area is about half-way between the cashed line, a triangle and a rectangle indicated in Figure 2 was used as an approximation of the real, irregular cross sectional shapes, since further accuracy would have demanded much more measurement and calculation time.

Figure 2. Dead storage measurement in a typical channel cross sectional shape.



Dead storage was measured in about 80% of the total drained channels; the other 20% were estimated to contain the same volume per unit length as the average measured volume. During the elapsed time between the conclusion of a channel's draining and measurement, dead storage water will infiltrate into the channel bottom. This infiltration rate will be very low through the silt covered watercourse bottom, but will still result in an underestimation of true dead stroage. Based on findings from a few test sections, one inch was added to the depth measurements in sections where more than five hours had elapsed since drainage ceased.

All visible leakage through insect and rodent holes, poorly closed nuccas, and weak, thin banks were observed, and sometimes measured. Measurement was made by collecting a volumetric sample in a pan or by observing the increase in depth of a small known bunded area with time. The area of land adjoining the watercourse which was wetted by leakage was also approximated.

A topographic survey of the commanded fields of the watercourse area, and a water surface profile of the sarkari khal was made to help determine the effect of elevation of the surface of the conveyed water relative to the surrounding fields on loss rates.

A socio-economic survey of the farmers on the watercourse was also made to determine their cropping patterns, yields, and perceived water usage and needs. The results of the survey were then compared to the physical measurements.

Because system inflow and outflow were measured over time, the total loss values were determined on the basis of volumes of water, instead of the usual method of comparing rates of flow.

Water volume values were determined by plotting flow versus time through the various flumes and calculating the area under each curve. Figure 3 is an example of these plots. The area under each curve was determined by trapezoidal rule integration over 12 minute intervals. Twelve minute intervals were chosen because of the graphical scale utilized. Generally, very low flow measurements are difficult to make on the flumes so the flow measurement curves were interpolated to recorded beginning and ending times. The potential error caused by erroneous interpolation is small compared to the total flow.

Total efficiency was calculated by dividing the sum of the volumes of water passing through each field flume (plus an estimate of the small amount usefully used in unauthorized ways) by the total volume of water passing through the head flume.

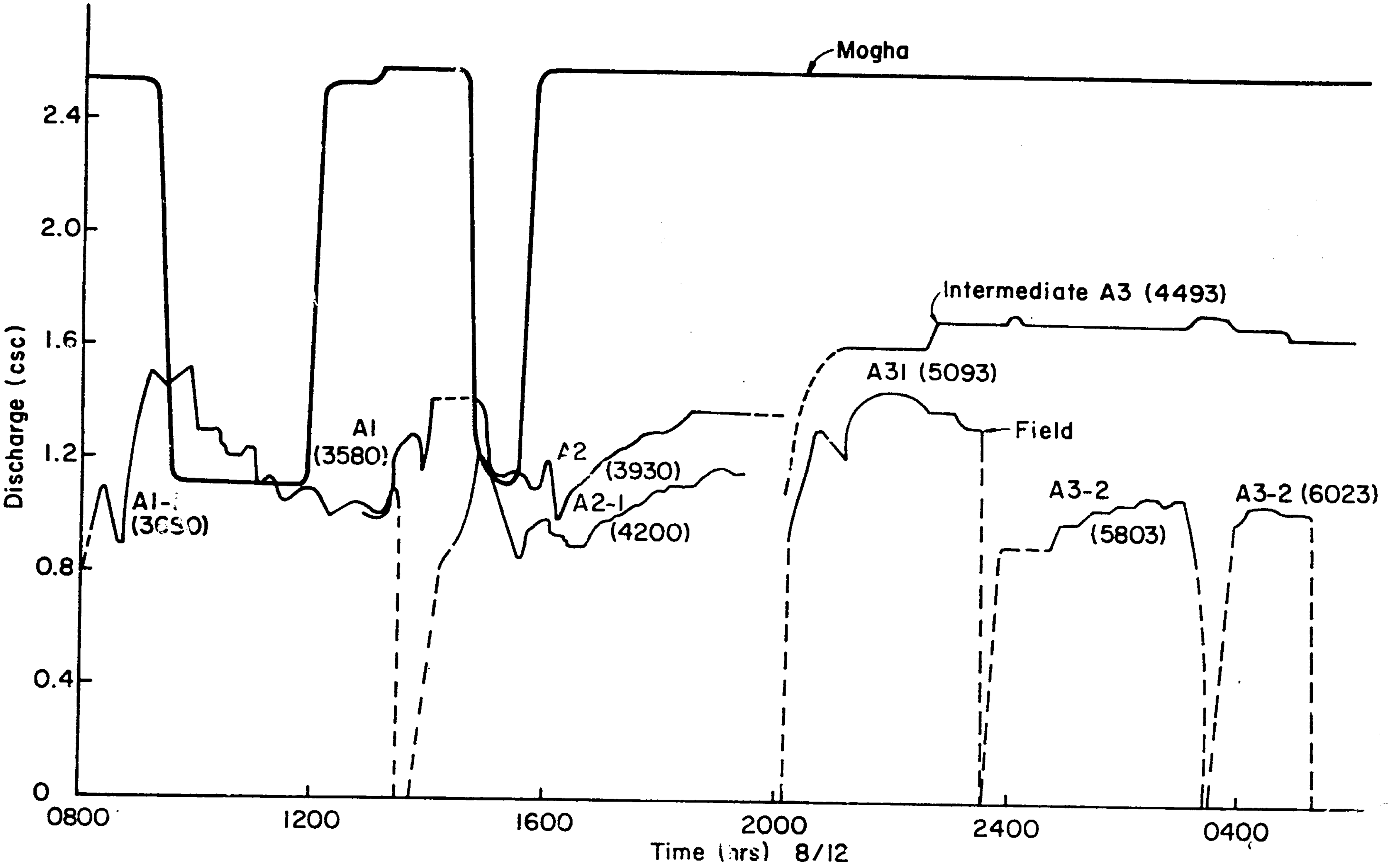


Figure 3. Discharge through the mogha, intermediate and field flumes over time.

Since one field flume was often set to measure flow into several fields, these flumes were not always located directly at the field nucca. The fields' flumes were commonly located from 0 to 4440 feet upstream from the field being irrigated. Additional losses, beyond those measured in the flumes, therefore, occurred. The conveyance loss rate in the section above the field flume was determined and when multiplied by the length of channel between the flume and the nucca produced an estimate of the additional unmeasured losses. This adjustment, which has been made in the above efficiency values, decreased total efficiency by 2 percent.

An attempt was made to determine the functional relationships between several parameters of the physical watercourse system and conveyance losses. Because the number of variables are great their effects are difficult to quantify, the sample size was small, and measurements were imprecise, simple linear regression analyses were used. From this analysis the significance, sign, and in some cases, slope of the relationship could be determined, but not the functional form. Graphical analyses were also done to determine whether non-linear relationships were indicated.

RESULTS

During the week in which the watercourse was studied, only 44% of the water entering the watercourse at the head passed through farmers' nuccas into their fields. Nearly 20 acre feet of water was lost from the conveyance system. Water which was stolen and the potential dead storage which was drained into fields was recorded as being usefully used. Table 1 summarizes the volumetric inflow and outflow. Complete flume and field data are given in graphical form in Figure A-2 in the Appendix.

Conveyance efficiency varied with branch and distance from the mogha. Average efficiency (delivered/available water) while water was flowing in the 2100 foot main branch was 68%, in Branch A was 33%, and in Branch B was 52%. Low efficiencies of 15% to 25% were measured near the tail of Branch A, 6000 to 8000 ft from the mogha, where the maximum flow to some fields was only 0.4 csc (compared to 2.6 csc at the head).

Sixty-six percent of the total losses occurred in the sarkari khal sections, or above the intermediate flumes. Eighty percent of the average channel length in use was in these sections. So the loss rates in the farmers' branches averaged nearly double those in the sarkari khal. Table 2 summarizes canal usage and weighted average loss rates.

Table 1. Conveyance efficiencies and losses on TW 81-R Watercourse during waribundi loss study.

Flowing Branch	Flume	Total Measured Flow		Total Conveyance Efficiency	Farmers Branch Eff.	Total losses		Percent Losses	Farmers Branch Losses		Distribution of losses between Sarkari Khal & Farmers Branches
		$10^3 ft^3$	Ac-Ft	%	%	$10^3 ft^3$	Ac-Ft	%	$10^3 ft^3$	Ac-Ft	
Total System	Head	1516.4	34.81								66% 34%
	Intermediate	957.6	21.98	63		556.8	12.78	37			
	Tail	692.5	15.90	46		823.9	18.91	54	265.1	6.09	
	Adjusted Tail*	672.0	15.45	44	70	843.5	19.36	56	284.7	6.53	
Main	Head	167.5	3.84								43% 57%
	Inter.	144.7	3.32	86		22.8	0.52	14			
	Tail	117.8	2.70	70		49.9	1.15	30	26.9	0.62	
	Adj. Tail*	114.3	2.62	68	81	53.2	1.22	32	30.4	0.70	
Branch A	Head	766.8	17.60								75% 25%
	Inter.	386.3	8.87	50		380.5	8.73	50			
	Tail	261.1	5.99	34		505.7	11.61	66	125.2	2.87	
	Adj. Tail*	255.1	5.86	33	66	511.7	11.74	67	131.2	3.01	
Branch B	Head	582.1	13.36								56% 44%
	Inter.	426.6	9.79	73		155.5	3.57	27			
	Tail	313.6	7.20	54		268.5	6.16	46	113.0	2.59	
	Adj. Tail*	303.5	6.97	52	73	278.6	6.40	48	123.1	2.82	

*Adjusted downward as explained in Procedure section.

Table 2. Tubewell 81-R watercourse weighted average loss rates.

	Total System	Sarkari Khal	Farmers Branches
Length Utilized (ft)	37,000	11,000	26,000
Total Usage (10^3 ft-hrs)	904.3	722.3	182.0
Loss ($10^3 ft^3$)	843.5	556.8	284.7
Ave. Loss Rate (csc/1000 ft)	0.26	0.21	0.43
Ave. Flow Rate in Section (csc)	2.0	2.1	1.45
Ave. Loss Rate (%/1000 ft)	13%	10%	30%

The average conveyance efficiency at night was less than in the daytime (6:00 - 18:00 hrs), by a total of 5% (47% and 42% respectively). This finding reflects the unwillingness and difficulty of the farmers to monitor their watercourse system and close leaks in the darkness.

Figure 4 is a graphical representation of the steady state flow through the various flumes as a function of the distance of the flume from the mogha. Flow rates were taken as the maximum steady state value measured in the flume. Flows which did not reach steady state or which occurred while the head flow was less than 2.6 csc were not plotted.

Each flume in the figure is identified. The letter represents the channel branch. Intermediate flumes are identified with one number. Field flumes are identified by adding a second number to the identifier for the intermediate flume which was being used at the same time. Loss rates in various sections of the watercourse can be found by determining the slope of a line drawn between the points representing the flumes above and below the section of interest. For example, the average loss rate in the section of Branch A from 0 to 4000 feet from the mogha can be found by connecting the origin and point A2 with a straight line and determining the slope of that line (average loss rate = 0.30 csc/1000 ft). Likewise the loss rate in the farmers' branch between Branch A and flume A2-1 can be determined by connecting points A2 and A2-1 and computing the slope. It should be noted that the number of an intermediate flume is not representative of its relative distance from the head. Progressive flumes in a branch are determined by moving to the right across the graph and noting the placement and branch of the flume.

It will be noted from the figure that negative losses are sometimes indicated between progressive intermediate flumes. This is caused by the fact that the flume is measuring the actual average loss rate to the head and that loss rate is sensitive to changing water surface levels. The water level in a channel section will often drop as lower fields are irrigated farther down the branch. Past studies have determined that loss rates in these channels decrease as the water surface level decreases thus making possible a lower average loss rate per unit of length of channel. True steady state loss rate values can be determined only between flumes being measured simultaneously, such as between the head and an intermediate flume and between an intermediate flume and the concurrent field flumes.

From Figure 4, it can be seen that steady state loss rates in the sarkari khal varied from 0.08 to 0.40 csc/1000 ft averaging about 0.3 csc/1000 ft and the loss rate in the farmers' branches varied from 0.13 to 0.50 csc/1000 ft with an average value of about 0.4 csc/1000 ft.

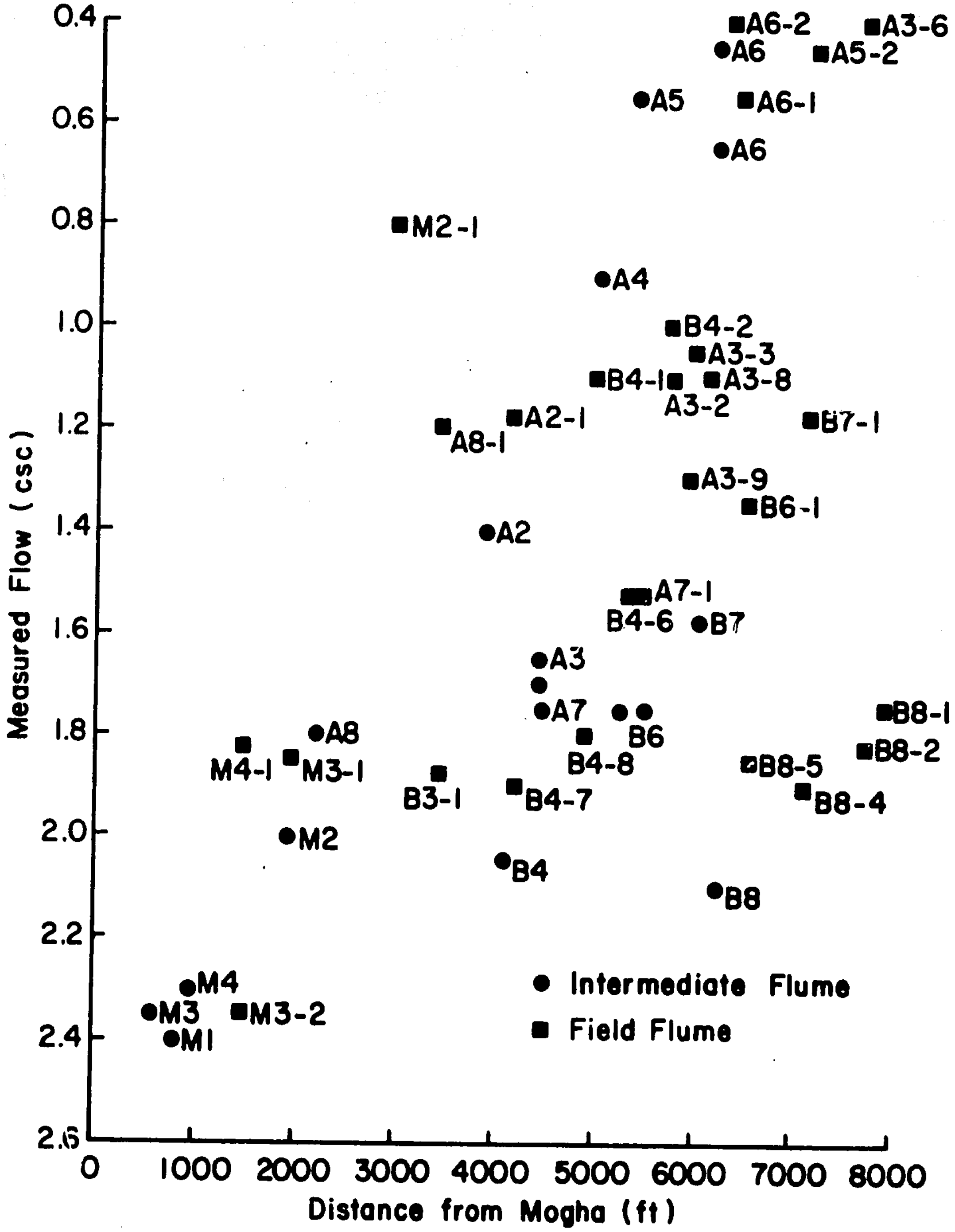


Figure 4. Measured Flow Rate in Flumes vs. Distance of the Flume from the Mogha.

One type of steady state loss which can be estimated is evaporation from the water surface. The average potential evapotranspiration in the Mona area the first week of December is 0.63 inches/week (Reuss, et al., 1976). If we assume free surface evaporation is about the same as potential evapotranspiration, and the average water surface width in the channels is 4 ft, the average evaporation rate would be 3.5×10^{-4} csc/1000 ft, which is about 0.1% of the average loss rate. Over the entire week, about 0.03 ac-ft of conveyance water was lost to water surface evaporation.

From Table 1 it can be noted that Branch B was a much more efficient conveyor of water than Branch A. During the study it was also noted that the level of water in Branch A was higher relative to the surrounding field level than in Branch B. This suggests a relationship between irrigated field elevation and conveyance loss rate. Figure 5 is a plot of the average slope of the water surface in the channel between the mogha and the field, and the steady state loss rate during the time the field was being irrigated.

Slope of the water surface was chosen as the independent variable because it is a parameter which determines the depth of water in a channel of given cross section which is flowing at normal depth. For example, in a trapezoidal channel with 1:1 side slopes flowing at 2 csc with a Manning's roughness coefficient of 0.04, if the slope is decreased from 0.0004 to 0.0003, equivalent to 0.5 ft elevation difference between fields 5000 ft from the mogha, the flow depth would increase by 0.1 ft in the channel. This average slope is determined by the elevation difference between the water surface below the mogha and the field surface, divided by the channel length to the field. Fields irrigated from the main section of the watercourse were not included in the analysis because other factors apparently increased the loss rates above the range found in the other branches. The linear regression line which best fits this data is Loss Rate (csc/1000 ft) = 0.46 - 0.31 x (Water Surface Slope (Ft/1000ft)). The coefficient of determination (r^2) for this relationship is 0.35, which is significant at the 99% level. This indicates that, for the studied watercourse, 35% of the variation of the loss rate from the mean value can be explained by the variation in water surface slope. As the average water surface slope decreased, and the depth of flow in the channel and elevation of the water surface relative to the adjoining fields increased, the loss rate also significantly increased.

The effect on loss rate of elevation difference between the field and the water surface below the mogha was also analyzed. Both the regression coefficient and the coefficient of determination were higher for this relationship than the previous one with:

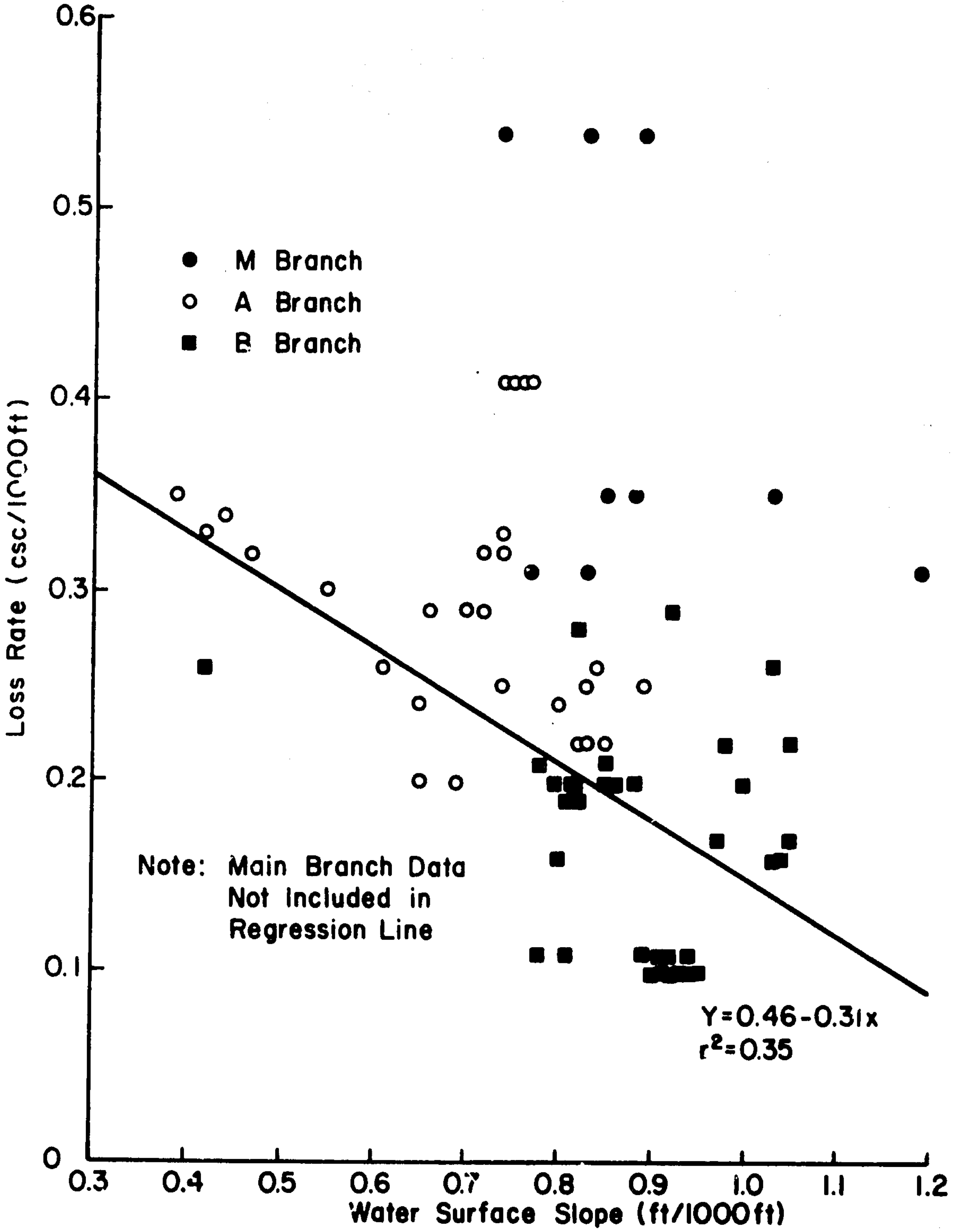


Figure 5. Loss Rate Vs. Water Surface Slope

$$\text{Loss Rate} = 0.45 - 0.04 \times (\text{Elevation Difference (ft)})$$

$$r^2 = .66$$

The r^2 value is unexpectedly higher than for the preceeding relationship. This high r^2 value is at least partially caused by the intercorrelation between distance from the mogha and loss rate ($r^2 = .49$) and distance from the mogha and elevation ($r^2 = .75$).

Although there were in some sections many observable leaks, the total volume of visible leakage was a small percentage of the total losses in any branch. The largest amount of visible leakage in any 200 ft length section was 0.1 csc. There were 20 measurable leaks in the left bank of this section, primarily through rat and ant holes. About one-third acre of the adjoining field was flooded. The largest individual leak in the section (about .015 csc) was through a piece of broken pottery reportedly purposely buried in the bank to promote leakage into the adjoining field. The loss rate of visible leakage in the section was 0.5 csc/1000 ft.

Total measured visible leakage in the main channel was between 0.01 and 0.02 csc, depending upon the time measurement was made, or about 2 to 4% of the total losses in this section. Total measured leakage in 3100 ft of Branch A was 0.21 csc or about 20% of the total losses measured with flumes in this section. In a 2000 ft section of Branch B total observable leakage was 0.01 to 0.02 csc, or about 3 to 6% of the total losses. If visible leakage losses are 3% of the total in Main and Branch B, then about 8% of the total losses in the sarkari khal, or about 3% of the total inflow is lost to visible leakage on the sarkari khal.

Although most of the observed leaks were from about one cm diameter ant holes which leak about 0.001 csc each, about half of the total volume of visible leakage was through the earthen nuccas. Because these dirt bunds or checks are made from loose soil, a small leak through them will quickly wash out a larger hole. One nucca leak of about 0.2 csc was observed. If was later closed by a farmer.

A total of about one acre of land along the main channel and Branch A was flooded with leakage. Many of the nucca leaks flow into unused channels rather than into fields.

Operational Losses

Of the total 56% conveyance losses measured during the week, 7% can be attributed to operational losses. This value was derived by determining the potential flow into the fields if all flumes had flowed at steady state during the entire turn rather than building up to, and dropping from, the maximum measurement over time. This value can also be interpreted to mean that the farmers would receive 13% more water if they could eliminate operational losses.

Table 3 summarizes transient conditions and operational losses on the watercourse for each farmer. From the table it is evident that smaller farmers lose a higher proportion of their water allotment during transient conditions, but total operational losses depend more directly upon the number of feet of channel filled to irrigate an acre of land.

Farmers who must fill lengths of the sarkari khal, are generally given an extra time allotment in their warabundi turn. On Tubewell 81-R watercourse this allotment is about 15 minutes per 1000 ft filled. Measurement indicates that water generally required 30 minutes to travel 10000 ft in a dry watercourse, and an additional 30 min/1000 ft wetted to reach steady state. (Inflow changes caused by the tubewell turning off or on also affected flow rates along the channels at the rate of about 30 min/1000 ft.) Also, those who expend time filling the sarkari khal do not drain the sections at the end of their turn, and regain part of their water. Actual cost in water loss amounted to about 45 minutes per 1000 ft of sarkari khal filled. So farmers who fill the sarkari khal are losing about 30 minutes of water for each 1000 ft they must fill.

Part of this water is later drained from the sarkari khal by the last farmer on each branch. On this watercourse, Branch A drained for 3 1/2 hours after the water had been turned into Branch B and Branch B drained about 2 1/2 hours at the end of the rotation. Both branches drained the equivalent of about 2 hours worth of steady state flow. On Branch B, 27 minutes is deducted from the last farmer's allotted time to account for drainage. No deduction is made on Branch A. The reason for the inconsistency is not known.

Of the approximately 82,000 ft^3 of canal inflow during sarkari khal filling, about 20% was drained out at the tails, 10% was drained by an intermediate farmer with a low field, 20% was left as dead storage, and 50% was lost to seepage.

One farmer, who owned land on both Branch A and B, traded water from one branch to the other during his turn. He filled 3,600 extra feet of channel in the process and lost 11,500 ft^3 (3.2 ac in) of water to operational conditions. About half of that loss was to dead storage.

The average rate of water leakage during the filling time can be determined by a mass balance analysis of the relevant sections, according to the formula:

Table 3. Farmer Operational Losses.

Farmer No.	Distance From Mogha to Fields Total (ft)	Sarkari Khal (ft)	Farmers Branch (ft)	Acres Owned (ac)	Acres Irrigated During Week (ac)	Warabundi Time Land (hrs)	Distance Adjustment (hrs)
MAIN BRANCH							
1	2185	590	1595	20.5	3	9.3	+.2
2	1700	975	725	19.3	3	8.7	0
BRANCH A							
3	3980	3453	527	14.5	3	6.5	+.5
4	3980	3600	380	13.4	1.25	6.1	0
5	4420	4000	420	13.3	1.5	6.0	0
6	6023	4500	1523	20.9	3	9.5	+.4
7	5620	4500	1120	6.6	1	3.0	0
8A	8012	4500	3512	46.1	1	21.1	0
8B	6730	4500	2230	"	4	"	"
9	5375	5370	0	18.5	1.4	8.4	+.4
10,11,12	7440	6320	1120	32.0	2.5	14.5	0
13	6120	6120	0	3.6	.75	1.6	0
BRANCH B							
14A	3770	3145	625	25.5	1	11.6	+.2
14B	5720	4500	1220	"	2.5	"	"
15	4100	3145	955	6.4	2	2.9	0
16	6130	4135	2000	42.6	7.25	19.3	0
17,18	6970	5235	1735	30.8	5	14.0	0
19	7385	6055	1330	9.9	1.5	4.5	0
20	8075	7140	935	41.4	8.5	18.7	+.25, -.5

Table 3 (continued)

Farmer No.	Distance Wetted		Distance Drained		Operational loss			St.state Flow Rate at Field (CSC)	Total Conveyance Efficiency (%)
	S.Khal (ft)	F.B. (ft)	S.Khal (ft)	F.B. (ft)	Volume ($10^3 ft^3$)	Percent of Outflow (%)	Volume per 1000ft ($10^3 ft^3$/ 1000 ft)		
MAIN BRANCH									
1	0	1600	0	1600	9.4	14%	5.9	2.0	64%
2	385	1050	0	1050	.6	1%	0.4	2.0	68%
BRANCH A									
3	2500	440	0	440	4.1	14%	1.4	1.2	35%
4	660	220	0	220	2.1	8%	2.4	1.2	51%
5	400	420	0	420	3.4	13%	4.1	1.2	30%
6	500	1980	0	1980	5.0	12%	2.0	1.2	38%
7	0	1100	0	550	2.3	28%	2.6	0.8	20%
8A	0	3200	0	2310	2.	24%	0.8	0.4	> 27%
8B	0	1320	0	2230	[illegible].9	14%	5.3	1.1	
9	900	0	0	0	1.7	7%	1.8	0.8	31%
10,11,12	1000	1650	200	1650	1.9	8%	0.7	0.45	17%
13	0	0	4000	0	(-5.1)	(-125%)	(-1.3)	0.45	35%
BRANCH B									
14A	480	625	1100	625	1.8	12%	1.7	2.0	> 51%
14B	2375	1220	2375	1220	9.7	18%	2.7	1.55	
15	1045	955	0	955	5.3	27%	2.7	1.86	49%
16	1000	5500	0	5500	20.2	20%	3.1	1.6	44%
17,18	1100	1735	0	1735	4.7	7%	1.7	1.35	45%
19	820	1330	0	1330	3.2	17%	1.5	1.15	38%
20	1100	2530	7000	2530	(-3.4)	(-103%)	(-.9)	1.8	68%

$$\int_0^T Q_{in} dt = \int_0^T Q_{out} dt - \int_0^T Q_L dt + \Delta V_{storage}$$

Cross sections (CS) of full sections were measured, and when multiplied by section lengths (L), give storage volumes ($V_{storage}$). Average inflow (Q_{in}) can be assumed equal to the previously measured flow through the upstream flume since net upstream channel storage change will be small. If time, T, is chosen as the equivalent lost time, then outflow (Q_{out}) will be zero. Now the mass balance equation reduces to:

$$\int_0^T Q_L dt = Q_{in(ave)} \times T - CS_{ave} \times L.$$

Although Q_L cannot be found directly, the average loss rate over the time, T, can be found by dividing the integral by T.

This calculation was made on six sarkari khal sections where all the relevant data was available. Although the results were quite variable, they indicated that the average loss rate during filling was about equal to the loss rate in the same section during steady state flow. Since the average wetted perimeter during this time is less than the full supply level wetted perimeter by about 50%, the actual infiltration rate into the dry banks and bed is about 50% higher than the steady state value during the filling period.

Individual farmers' operational losses depended also upon how many feet of farmer branches they filled, which depended upon how far their fields lie from the sarkari khal, and how scattered the fields they wish to irrigate are. Figure 6 depicts total operational loss as a function of feet of channel wetted during the turn. The linear regression line has a slope of 2700 ft^3 of water lost per 1000 feet of channel wetted.

A total of 46,000 ft^3 or 12.7 acre inches of dead storage water was lost to farmers on 41,000 ft of drained watercourse sections during the week, or about 1.1 ft^3 per foot drained. This is about half of the total water lost to operational conditions. Six hundred feet of the main channel was never drained and 4000 ft of channel was drained twice, during a trade of water from one branch to another. The total volume of water lost to dead storage was 3% of the total volume entering the head of the watercourse and about 5% of the total losses. Thirty-two percent of the dead storage volume occurred in the government authorized watercourses. During the time in which water was traded from one branch to another out of the warabundi turn, 3600 extra feet of watercourse were drained and 10% loss of water to dead storage resulted.

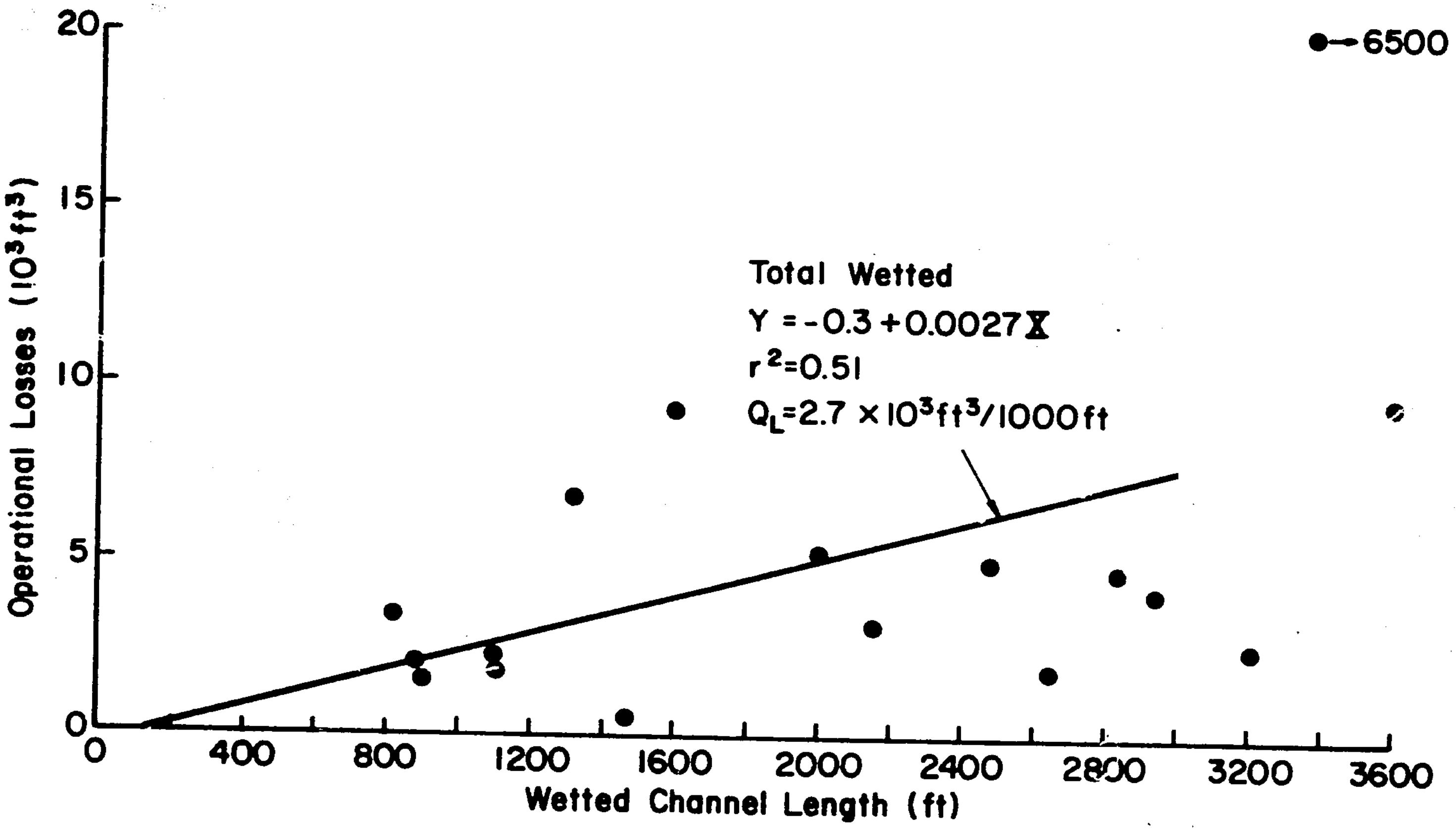


Figure 6. Operational Loss vs. Channel Wetted.

Farmer Water Use Perceptions

The Economics Section of Mona Reclamation Experimental Project conducted a socio-economic survey of the farmers of TW 81-R watercourse. Among other questions asked of the farmers were several relating to water use and management. Chaudrey M. Hussain, Mona Senior Research Officer in Economics, supplied the thus far unpublished data for this analysis.

One series of questions related to total water usage by the farmer during the past two season. From the farmer's knowledge of total acreage of each crop, his memory of the number of irrigations applied to each crop, and his estimate of depth of irrigation, total field application for each farmer and for the total watercourse was calculated. The total field application in the past year was calculated from this data as 398 acre-ft. However, actual measurements during the warabundi study indicated that irrigation depths were about 50% greater than the farmer's estimates. With this adjustment, the total field application would have been 596 ac-ft. If we accept 2.6 csc as the average combined inflow to the watercourse and 1.1 csc as the canal inflow, assume that the canals were closed a total of four weeks during monsoon and cleaning, and that the tubewell runs 60% of the time, the conveyance efficiency for the watercourse would have been 45%. Although this calculation includes several potential inaccuracies, the total efficiency value does lend credence to the 44% efficiency value measured during this study.

The farmers were also asked the number of irrigations required by each crop. Comparing these answers to the actual number of irrigations given indicates that the farmers perceive that they require 54% more water to adequately irrigate their fields.

Linear regression analyses were made between several farmer perceived activities and results and the measured factors of distance from the mogha and delivery efficiency. The regression coefficient and equation for these relationships are given in Table 4. Data from 17 farmers were used in the analyses, and only area of wheat irrigated per hour and perceived delivery efficiency versus distance from the mogha were significant at the 95% probability level. Perceived delivery efficiency was determined by asking the farmers how much of their water was lost before reaching their fields.

Farmers generally had a poor perception of relative water availabilities. Total annual application, area of wheat irrigated per hour, and perceived delivery efficiency for each individual farmer all correlated poorly with the measured efficiency to each farmer's fields.

Table 4. Relationships between farmer perceived and measured water use (based on information from 17 farmers).

Dependent Variable	Independent Variable		
	Distance from the Mogha (1000 ft)	Measured Delivery Eff. (%)	Perceived Delivery Eff. (%)
Total Annual Application (Ac-in/Ac)	Y = 27.2 - 1.04x[1] (-3.8%/1000 ft)[2] r^2 = .07[3]	Y = 16.2 + .12x r^2 = .08	
Perceived Delivery Efficiency (%)	Y = 102 - 6.3x (-6.3%/1000 ft) r^2 = .53	Y = 60.8 + .17x r^2 = .03	
Area of Wheat Irrigated per Hr (Ac)	Y = 0.5 - .03x (-5.5%/1000 ft) r^2 = .23	Y = 0.3 + .0011x r^2 = .03	
Measured Delivery Efficiency (%)	Y = 77.4 - 5.9x (-5.9%/1000 ft) r^2 = .44		
Cropping Intensity (%)	Y = 201 - 5.0x (-2.5%/1000 ft) r^2 = .09		
Normalized Yield	r^2 = .01	Y = 0.89 + .014x r^2 = .14	Y = .72 + .04 r^2 = .19

[1] Regression equation

[2] Percent change per 1000 ft

[3] Coefficient of determination

Note: r^2 = .37 represents significance at the 99% level
r^2 = .23 represents significance at the 95% level

The same three factors correlated better with the distance of the farmers' fields from the mogha. Their answers can be interpreted to indicate that they feel they are losing between 3.8% and 6.3% of their water supply per 1000 ft of channel. Measurements indicated a loss rate of 5.9% per 1000 ft with an $r^2 = .44$. Cropping intensity on the watercourse also decreased with distance from the mogha, but with a lower rate (2.5%/1000 ft) and less significance.

A value for total normalized yield per acre owned for the year across the 7 major crops in the area was derived from cropping patterns, intensities, and yields. The normalization factor for each crop was the average yield of that crop on the watercourse. If the assumption is made that yield is a function of water application, this value should be another evaluation of relative conveyance efficiency. Although the above assumed function is often non-linear, plotting did not indicate other than linear dependence, and linear analysis was made of this factor versus water use values. Total normalized yield did increase with the farmers' perceived water application ($r^2 = .19$) and with measured delivery efficiency ($r^2 = .14$), although neither relationship is significant at the 5% level. Yield did not vary significantly with distance from the mogha. Farmers at the tail seem to be getting comparable total yields from their land as those at the head on this watercourse, in spite of the decrease in water available in their channels.

Field application volumes were measured on 90 fields. Volume applied per acre (irrigation depth) decreased with distance from the mogha according to the equation:

$$\text{Irrigation Depth (in)} = 5.07 - .0002 \times \text{(feet from the mogha)}$$

$$r^2 = .05$$

The relationship is significant at the 95% level. The same relationship for only wheat gave similar results and correlation. Time required to irrigate one acre, although increasing slightly with distance from the mogha, correlated very poorly with it ($r^2 = .02$). This relationship for wheat alone was even poorer. There is very large variability between farmers on depth of irrigation applied, even to the same crop in the same growth stage.

Watercourse Parameters

During the week, 37,000 feet of watercourse was used or about 50% of the total channels in the watercourse command area. All 11,000 feet of the government appropriated watercourse were used, and 40% of the total farmer branches were used. Fifty-six acres, 15% of the commanded acreage, were irrigated in 99 bunded units. The average irrigation time per acre was three hours. Average depth applied was 3.4 inches. Although only 30% of the total footage utilized was sarkari khal, 80% of the foot-hours of canal usage was in government authorized sections.

Over 100 channel cross sections were measured in all areas of the watercourse. Cross sectional areas varied from 1.3 ft^2 to 15.6 ft^2 with an overall average of 5.2 ft^2 in the sarkari khal and 3.5 ft^2 in the farmers' branches. During the week, about 150 x 10^3 cubic feet (3.4 ac-ft) of volume of watercourse were filled. Average velocity in the watercourse was 0.35 ft/sec, and varied between 0.1 and 0.6 ft/sec.

Twenty sets of cross section data were analyzed graphically. Wetted perimeters of these sections varied from 4.1 to 7.2 feet and averaged 5.9 feet. Hydraulic radii varied from 0.40 to 1.17 with an average value of 0.82. Cross sectional shapes were approximated with circular arcs with radii between 2.3 ft and 4.0 ft (averaged 2.8 ft), and actual measured depths. Approximations of the cross sectional area by this method was always within 20% of the true value, and half of the time was within 6% of the true value.

The average infiltration rate into the watercourse wetted perimeter during the week was 1.8 inches per hour, which is about 6 times the infiltration rate into the surrounding fields.

DISCUSSION OF FINDINGS

A warabundi loss measurement study is the most thorough watercourse conveyance loss measurement method yet tried in Pakistan, and potentially the most accurate. Accuracy, of course, depends upon the measuring devices used and the personnel involved. During this study, 3000 flow readings were made on 55 different flumes settings by 14 different people including 5 engineers. The data indicated that over 50% of the water which entered Tubewell 81-R watercourse during the studied week was lost to immediate use by the farmers.

Generally Cutthroat flumes under field conditions measure correct flow to within 5% if correctly installed. This means that flow differences between flumes can be determined within ±7% (Ashraf et al., 1977). However, assuming the errors are random and normally distributed, total error in a series of measurements would be $7\%/\sqrt{n}$ where n is the number of observations. For our study, although flume error in individual measurements could be significant, overall accuracy should be within $7\%/\sqrt{55} = 1\%$.

One factor which has not yet been fully analyzed is the effect of increasing flow depth in the channels by the head loss created in flumes. As stated above it has been determined that raising the water surface level in a channel can significantly increase the loss rate from that channel. In order to accurately measure water flow in channels, a head loss must be created. Cutthroat flumes were chosen for the study because they minimize the necessary head loss. But wherever a flume is set, the water surface level upstream from the flume is increased from 0.1 to 0.3 feet, therefore, creating extra losses in the system.

The depth of flow increase will extend upstream from the flume several hundred feet, depending upon the slope and hydraulic characteristics of the channel. This upstream depth increase can be calculated from the channel's hydraulic characteristics. For example, in a channel with a slope of about .0006 ft/ft flowing at 2.5 csc with a normal depth of 1.0 ft ($A = 3.6$ ft^2, $R = 0.7$, vertical sides at full supply level, $n = 0.4$), if the water surface elevation is raised 0.2 feet with a flume, the rise in the water surface 470 ft upstream will still be 0.1 ft.

Preliminary work on 40 sections on SCARP watercourses indicate that the functional relationship between water loss rate (Q_L) at any water surface elevation relative to full supply level (d), is exponential, and of the form

$$Q_L = Q_{LO} \; e^{bd}$$

at elevations near ($\pm$0.3') full supply level. The constant Q_{LO} is the loss rate at full supply level, and b is a constant which determines, when combined with Q_{LO}, the rate at which the loss rate increases as depth is increased. The constant b is positively related to Q_{LO}. For a loss rate, Q_{LO}, of 0.20 csc/1000 ft, data indicate that b is about 4.0.

Using the backwater curve calculations and loss rate formula, it can be incrementally calculated that a flume which causes a 0.2 ft head loss in the described channel would increase losses in a 2200 ft section by 0.12 csc. This means that, in a 5000 ft section, the actual losses would be increased by 12%, in a 3000 ft section by 20%, in a 2000 ft section by 31%, and in a 1000 ft section by 54%. For the studied watercourse, the average length of channel to the field was 5300 ft. Two flumes were set in that length, making the average distance between flumes 2650 ft. The flumes, as set, created head losses between 0.1 and 0.3 ft, although generally in sections where the depth factor was most critical (i.e., little freeboard, small slope, weak banks), 0.1 ft head loss was created. If we assume an average 0.2 ft head loss and 2650 foot long sections, the average loss rate would have been increased by .05 csc/1000 ft to 0.25

csc/1000 ft, which is near the measured average loss rate. If total losses were increased by 22%, real losses should have been 46% instead of the measured 56%. It should also be noted that the flume effects will be larger in shorter sections, and thus will increase losses more in measurements nearer the mogha and in farmers' branches.

In order to get an indication of the validity of these flume effect assumptions on the data collected, a multiple linear regression analysis was made on the effect of flume head loss and section length between flumes on loss rate for all the flumes which were set during the week. The regression equation indicated that loss rates were higher in shorter sections, as predicted; but, contrary to the above result, loss rates were inversely affected by flume head loss. In sections where head loss through the flume was greatest, loss rate was least. This indicates that the engineers, before setting the flumes, wisely observed the channel slope, banks, freeboard, and general conditions, and set the flume accordingly. In channels where loss rates appeared to be potentially highest, flumes were set with the least head loss. In sections where slope was sufficient and the channel was in good condition, the flumes were set with greater head loss so that flume accuracy would be increased. This biasing effect of flume setting would reduce the total flume effects on loss rates below the amount calculated.

The flume effects can be very significant in watercourses where loss rate varies greatly with depth of flow. Much greater inaccuracies will probably be caused by this perturbation of the system than from the inaccuracies of flume measurements. It is important to minimize this perturbation by measuring losses in as long sections as possible and creating as little head loss as possible through the flumes --i.e., always setting them near 90% submergence.

Loss measurements at one point in time on a watercourse may not be representative of other times. For example, after a channel is cleaned, its roughness coefficient, flow depth, and loss rate will decrease. The plant growth in and general condition of the channels do change with season and cleaning operations (although canal cleaning and maintenance operations were not evident on the studied watercourse). There may be seasonal fluctuations in the farmer's needs for water and, as a consequence, the care with which he irrigates. Johnson (1977) indicates that the value of water in crop production reaches its peak near the time of these measurements. Also, the canal was scheduled to be closed for annual maintenance soon after the study ended. Consequently, the farmers were probably as careful with their water at this time as they are likely to be at any time during the year. Another partial set of loss measurements was made on the same watercourse system during August of 1975 (Early and Lowdermilk, 1975). This data indicated conveyance efficiencies varying from 17% to 72% for various locations on the watercourse with a mean efficiency of 47%. The study also found an average loss rate of 12.4% or about 0.35 csc/1000 ft. Although the two studies are not directly comparable, the similarity of their results do lend credence to the findings and indicate that the different seasons in which the two studies were made has not greatly affected the conveyance efficiencies.

The authors do not contend that this watercourse is representative of all Pakistan watercourses, and that all losses are as high. Tubewell 81-R watercourse was in fact chosen for the study and the impending improvement program because it appeared to be poorly built and maintained. But other studies previously mentioned have indicated that conveyance losses are high, especially in SCARP areas. It is believed that the types and degrees of losses measured on this watercourse can be a first step at indicating more generalized problems and solutions.

Although most of the lost water enters the groundwater, and in the study locality, part of it can be reused by pumping, the cost of that water to Pakistan is increased by about Rs. 50 per acre foot. The groundwater can potentially be used as an efficient storage reservoir, but unless its resource is available when needed most, on the demand of the farmers, a tubewell system is at best an inefficient recycling system, and at worst a stopgap method of preventing destruction of the soil resource through waterlogging and salinity.

It is inherently more efficient to solve a problem by attacking the problem directly rather than trying to relieve the effects of the problem. The problem behind waterlogging and salinity is the large volume of water entering the groundwater. A primary contributor to this problem, as indicated by this and previously referenced studies, is conveyance losses from watercourses. A second problem is the constraint on crop production in Pakistan posed by inadequate water supplies. This problem is also directly affected by the high conveyance losses.

Once a source and the magnitude of that source of the problem has been identified, solutions must be sought. In order to intelligently seek solutions, the system must be understood. That was the second goal of this study.

Not only is total watercourse loss a problem; the uneven distribution of those losses is also a problem. Some farmers are hurt by conveyance losses much more than others. Figure 7 is a cumulative distribution curve of delivery efficiencies to the various farmers. The curve is nearly linear from a low of 17% to a high of 68%. Any program designed to decrease conveyance losses should also attempt to even out some of the inequities in water availability.

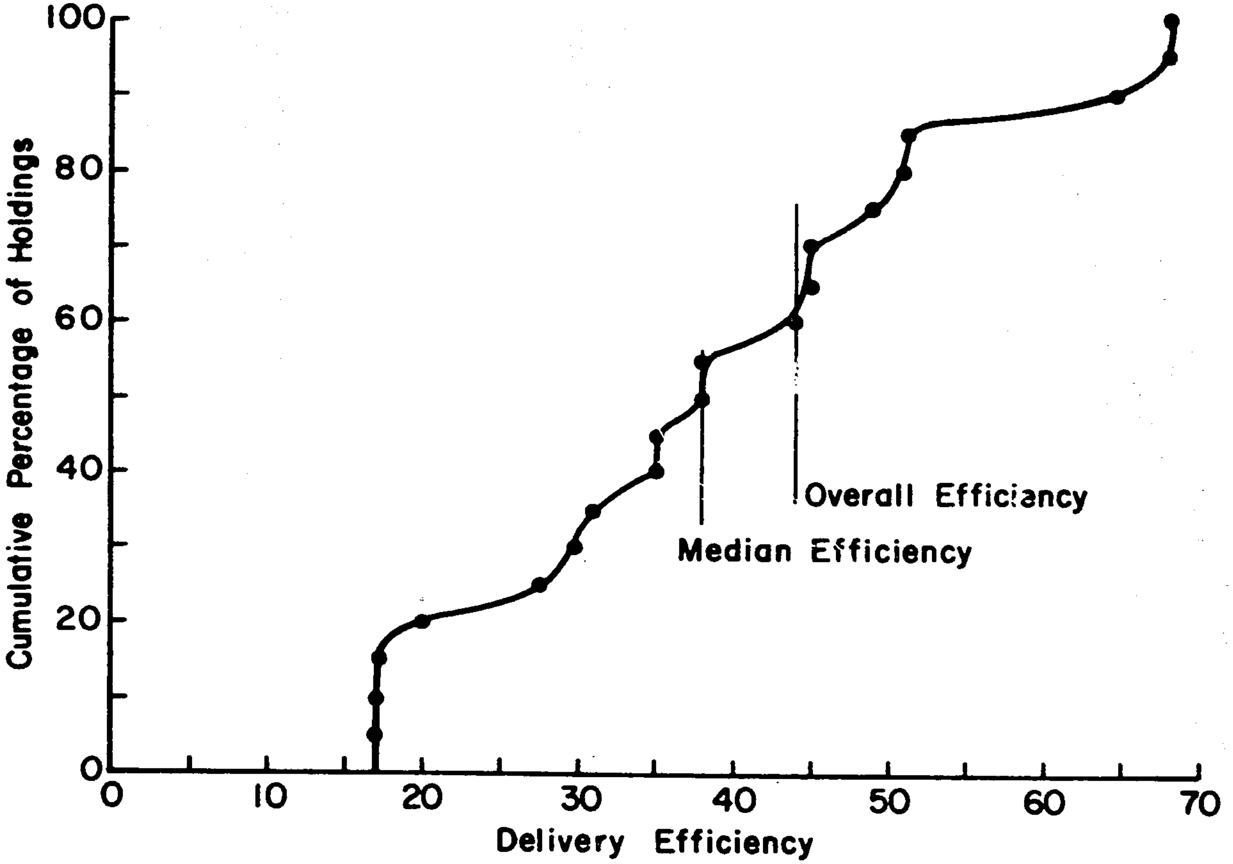


Figure 7. Cumulative Number of Farms vs Delivery Efficiency

Three physical factors were indicated by the study to significantly affect the amount of water available to the farmer at his fields. The first and most important is the distance of his fields from the mogha. The second factor is the elevation of his fields relative to other fields on the watercourse. The third factor is the number of feet of channel he must fill to reach his fields.

This third factor is affected by where he comes in the warabundi rotation, how scattered his fields are, and how much trading from one area to another takes place. If he is forced to fill sections of sarkari khal, and the time allowance in the warabundi does not fully account for the required time, he will lose water. If his holdings are scattered, or if the fields he irrigates are spread out and he must use more channels, or if his holdings are small and his warabundi turn short, a higher proportion of his water supply will be absorbed in operational losses.

Trading of water, unless between neighbors, also increases operational losses. The minimum possible number of total feet and feet-hours of channel are utilized on a given watercourse layout with the warabundi rotation. Conveyance losses will increase whenever the farmer deviates from the warabundi turn rotation. Although water can be used more efficiently for crop production when it is available on demand, and free trading of water is the closest approximation of a demand system in constant flow systems, the trading, unless done carefully, will increase total conveyance losses. This is especially true in a system where field sizes are small and the topography is flat. When the increased value and field application efficiency of water available more on demand through trading is known, it can be compared with the costs of the conveyance losses involved and operational procedures can be proposed.

Where watercourse flows are large, it has also been proposed that splitting of the water into two branches simultaneously might lead to more efficient overall water use. Steady state loss rates will decrease since the depth of flow will be less, and perhaps because more of the used channels are full a higher percentage of the time, discouraging plant growth and rodent activity. But operational losses will be more than double the previous operational losses since the lower flows will require more time to fill empty channels. So steady state loss rates at 50% flow must be less than 50% of the full flow rates. Again this trade off can be evaluated and operational procedures recommended.

As stated in the previous section, a significant portion of these operational losses are due to dead storage water which will not drain from channels. However, dead storage was a small percentage of the overall losses (5%), and is not as important as farmers generally believe. It is the form of loss that remains visually apparent to them, since the infiltration from the bottoms of the watercourse is very slow.

Minimizing dead storage losses is inherent in the warabundi turn system in which the water is progressively moved to the tail end of the watercourse, allowing it to be finally drained into the lowest fields at the tail of each branch. It is when the tail fields are not low, such as in the case of Branch A, that dead storage losses are large. It was observed on Branch A that two farmers with low fields in the intermediate sections of the branch had, after the turn ended, opened their nuccas and irrigated nearly one acre of total land with the otherwise wasted water. Farmers on other watercourses have been observed to maintain a low field, usually planted to rice, for the purpose of utilizing all potential dead storage water.

It is possible to construct a watercourse that would eliminate dead storage losses by constructing it all above the level of the ground so that the channel bottom is on the field level. However, since leakage through watercourse banks tends to be greater if the water level is higher above the field level, the overall losses would probably increase. Again, this is a trade off in watercourse design which can be optimized for a given set of conditions if the relationships between the factors and the loss rate is known.

Although farmers will walk the watercourse checking for leakage during their irrigation turn, they seldom will attempt to plug small leaks through the bank, assuming that the resulting loss is very small. Measurement indicated that, except for a couple of big leaks and one bad 200 foot section, visible leakage was a small percentage of total leakage. It takes 100 ant holes each leaking 0.001 csc to total 0.1 csc net loss. However, if a farmer will spend three hours plugging 100 ant holes in a channel which runs 3 days a week, he will be saving half an acre foot of water during the week. When water is needed, the activity is well worth the time, although not the time of an individual farmer who uses the channel only for a few hours.

The second cost of leakage onto the surface of surrounding fields is in crop damage. If it is assumed that the farmer of the adjoining field had adequately irrigated his crop, the excess water will be wastage, will probably leach nutrients, and often causes crop damage. If crops adjoining the watercourse are superior to those in the rest of the field it might be assumed that benefit is derived from the leakage. This situation has not been observed. It is often observed, however, along leaky main branches that crops are inferior or even destroyed. If on the studied watercourse, the crop value was reduced an average of 40% on the one acre of flooded land, the cost to the farmers would be (assuming a rabi fodder crop worth Rs. 1300/ac and kharif fodder crop worth Rs. 500/ac was raised on the land) Rs. 720 per year. Farm labor, whose time is worth Rs. 8/day, could afford to invest 7 1/2 days per month only to save damaged crops.

Another finding from this study which has an influence on design procedures is that farmers' branches have higher loss rates than the sarkari khal. On Tubewell 81-R watercourse, an improvement program which reduces the loss rate in the sarkari khal by 50% will reduce total conveyance losses by only 30%, since one-third of the conveyance losses are in the farmers' branches. In addition, if losses are reduced in the sarkari khal, the inflow to the farmers' branches will increase, increasing the flow depth and further increasing the loss rates. This was evidenced in the Early and Lowdermilk study (1975) which indicated that the mean conveyance losses on Tubewell 78 watercourse, where most of the sarkari khal had been lined, were still high (53%). But, the farmer branches involved 6 times more total feet of channel than the sarkari khal on the studied watercourse, so reducing 1/3 of the total losses would involve 6 times the effort. This, coupled with the fact that these branches are located on farmers' private land and often serve only one or two farmers would preclude their being included in most community improvement programs, at least in the initial stages.

However, since the length of farmers' branches are generally fairly short (the average utilized length of farmer branch in this study was 1080 ft) slope and design criteria are not so important for them. It is critical that their cross sections be enlarged to handle increased flows and that leakage is reduced by strengthening banks and increasing the freeboard. These are improvements that farmers could carry out without assistance on their own branches. They should be encouraged, or even required, to do this prior to any agreement to assist with sarkari khal improvement.

It was learned from the socio-economic survey that farmers' yields do not vary as much as would be expected considering the variability of conveyance efficiencies. This is pointed out especially well by the lack of correlation between normalized yields and distance from the mogha. The average farmer near the tail is getting total yields from his land (output per acre owned) equivalent to those at the head, while the farmers at the head are receiving 30 to 50% more water. This fact could be used to dispute the validity of the loss measurements.

But, there are factors which can help explain this discrepancey. First, it is possible that tail farmers have learned to utilize their limited water supplies more wisely. Measurements indicated that they apply less depth of irrigation water per irrigation. Perhaps head farmers overirrigate.

Tail farmers cultivate less of their land but achieve slightly higher average yields. Also, the water table is shallower near the tail of the watercourse, which is a common situation, and it is possible that some crops are getting a substantial portion of their required water directly from the groundwater. It has also been observed that tail farmers who own land on the adjoining watercourse will borrow water from that watercourse to help irrigate their land. Further study will have to be done before it will be fully understood why the tail farmers can achieve higher output per unit of water input.

SUMMARY

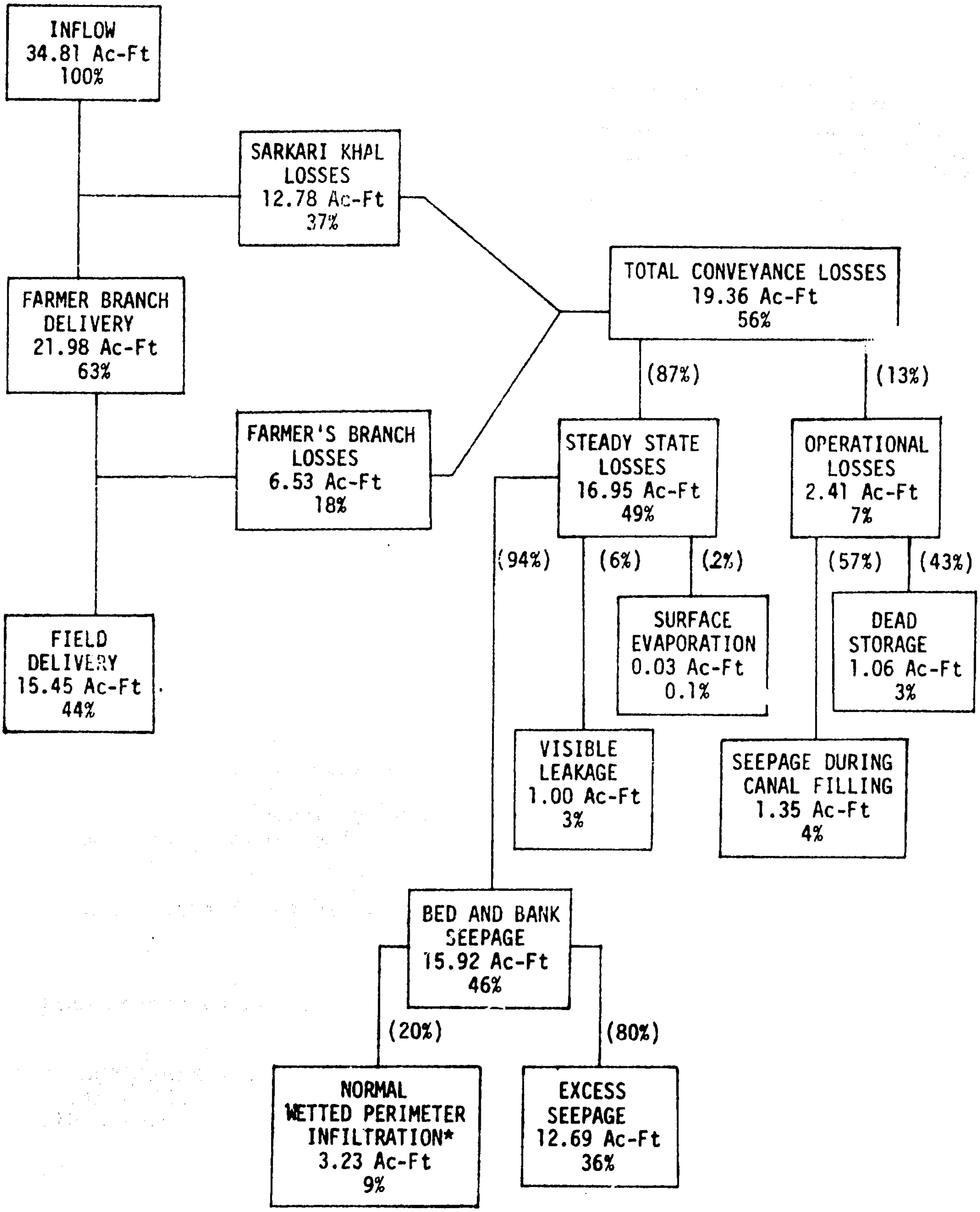
Figure 8 is a flow chart depicting where the water went that flowed into Tubewell 81-R watercourse during the week of December 8, 1976. The data is not necessarily representative of all Pakistan watercourses, but does give an indication of where some of Pakistan's most limiting agricultural resource is going. It is interesting to point out that the portion going to normal wetted perimeter infiltration, 9%, represents what may be the minimum achievable steady state losses without channel lining. The excess bank and bed seepage is a result of the high permeability of the porous banks and the high effective wetted perimeter resulting from the network of rodent and insect holes.

CONCLUSIONS

On Tubewell 81-R watercourse:

1. Conveyance efficiency was measured to be 44%.
2. The increased losses caused by flume installation could account for an increase in real efficiency to as much as 54%.
3. Two-thirds of the losses occur in the sarkari khal.
4. Losses were higher by 5% at night.
5. Thirteen percent of the losses are due to operational conditions.
6. Farmers who fill sections of the sarkari khal lose 45 minutes' worth of water per 1000 feet filled and are compensated for only 15 minutes in the warabundi.
7. 2700 ft^3 of water was lost per 1000 ft of watercourse filled.

FIGURE 8. FLOW CHART DEPICTING WATER MOVEMENT OUT OF THE TW 81-R WATERCOURSE.



*Assuming a normal field soil intake rate of 0.3 in/hr (Precision Land Leveling Project "Irrigation Guide," 1974).

8. Dead storage accounts for nearly half of the operational losses, but amounts to only 5% of the total losses. Thirty percent of the dead storage lies in the sarkari khal.

9. Total visible leakage is a small percentage of total inflow, but its prevention presents an economical means of saving water for the farmers.

10. If losses could be reduced to seepage through the wetted perimeter at the normal soil intake rate, a conveyance efficiency of 90% could be achieved.

11. Farmers perceive that they need 50% more water.

12. Conveyance losses cause a very unequal distribution of the water resource across a watercourse.

13. Farmers with less water achieve higher crop outputs per unit of water input.

ACKNOWLEDGEMENTS

In a study of this scope, many trained personnel are required to carry out the field measurements and data analysis. Most of the actual flume data was collected by Mohsin Wahla's extension staff field assistants including Ahmed Sher, Muhammad Afzal, Lal Khan, Muhammed Baqir Khan, Abdul Rahim, Muhammad Nazir and Habib Ullah. Also Mona Engineers Muhammad Akram, Muhammad Latif, Muhammad Iqbal, and Muhammad Saeed Shah assisted in the data collection. Socio-economic data was collected by Mohammad Hussain and his Mona Economics Section Agricultural Assistants. The interest and support of Mohammad Munir, Mona Project Director, and Mohammad Ashraf, WAPDA Chief Engineer, were also appreciated.

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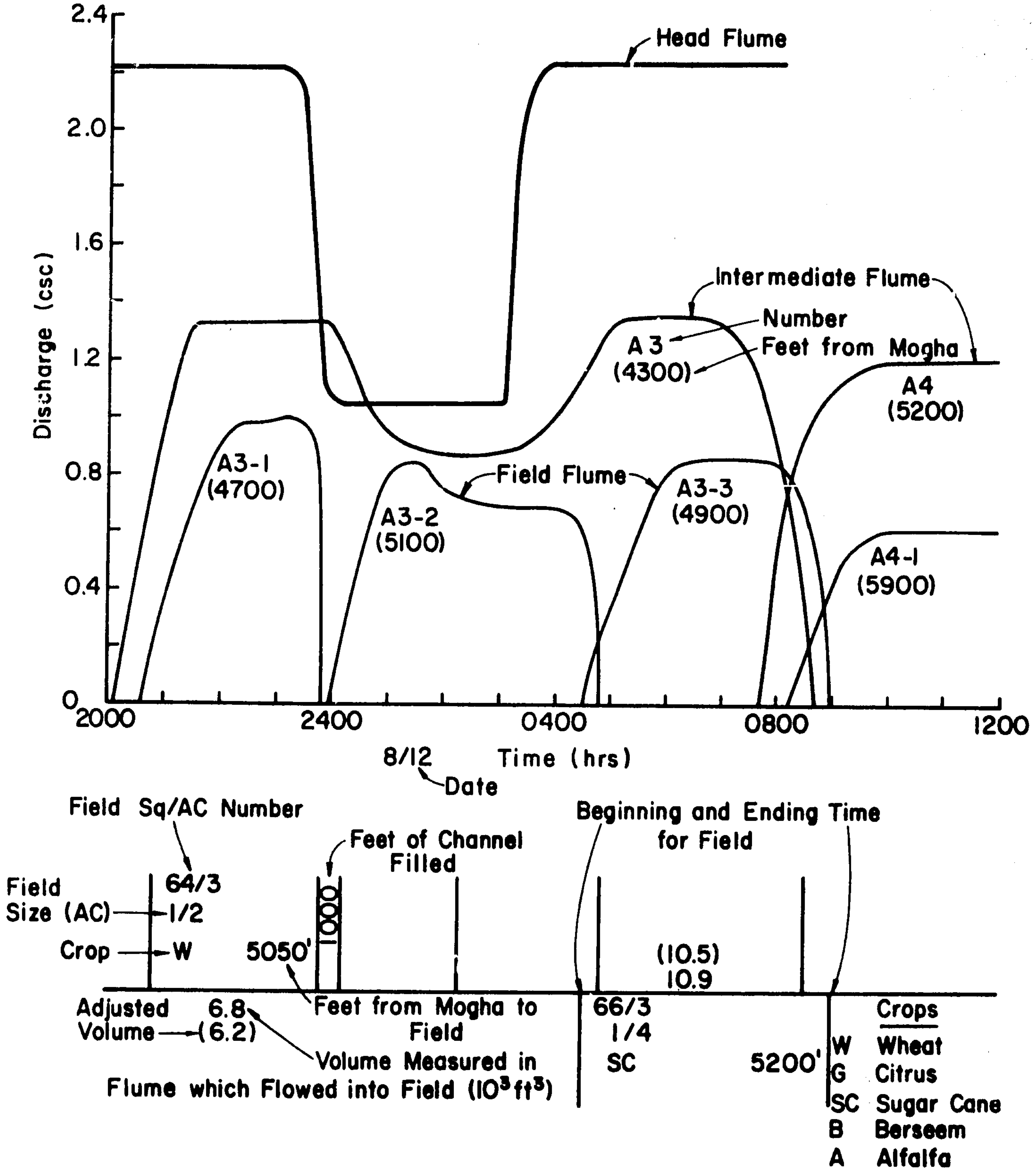


Figure A1. Explanation of Figure A2 Notation.

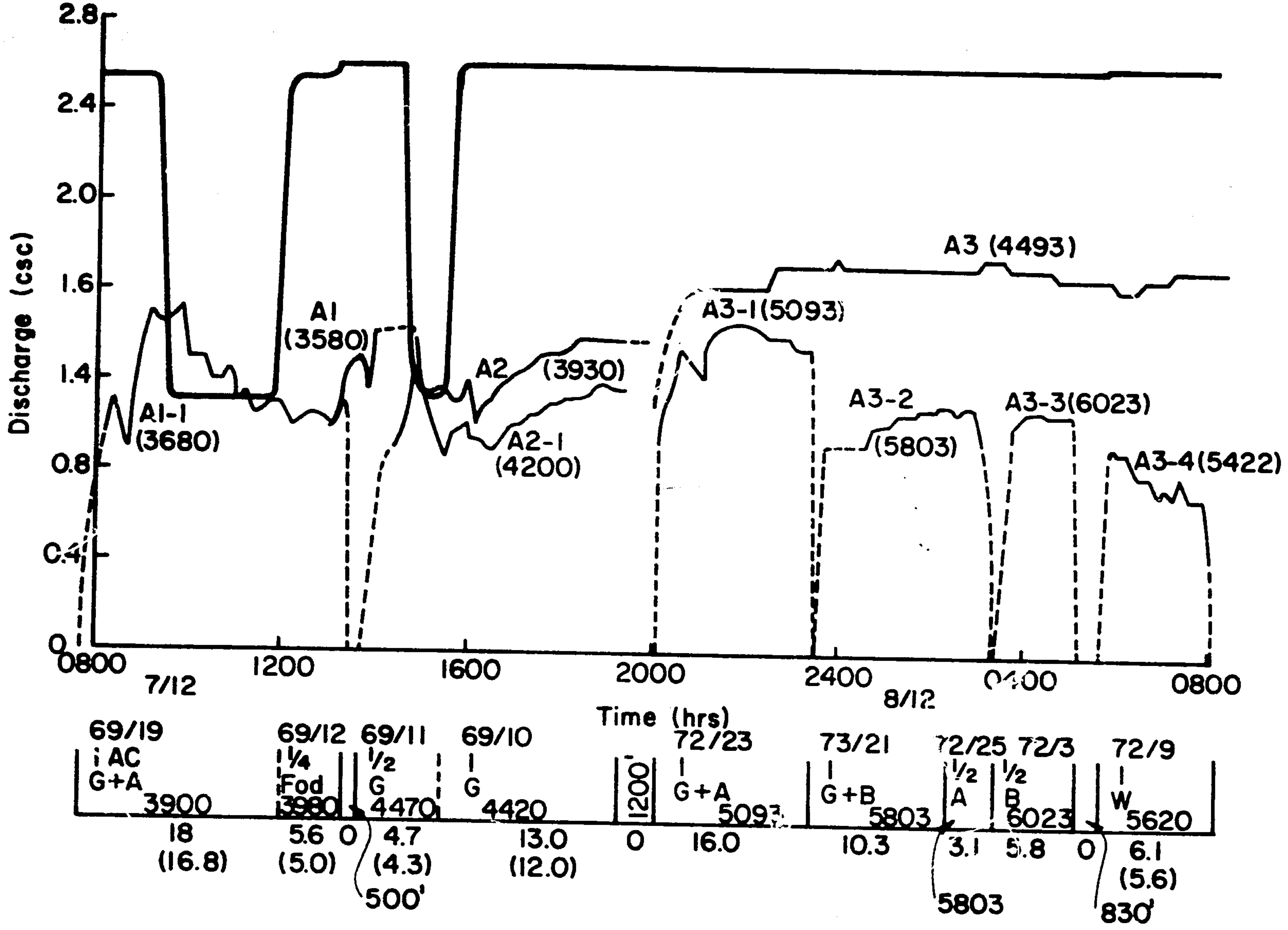
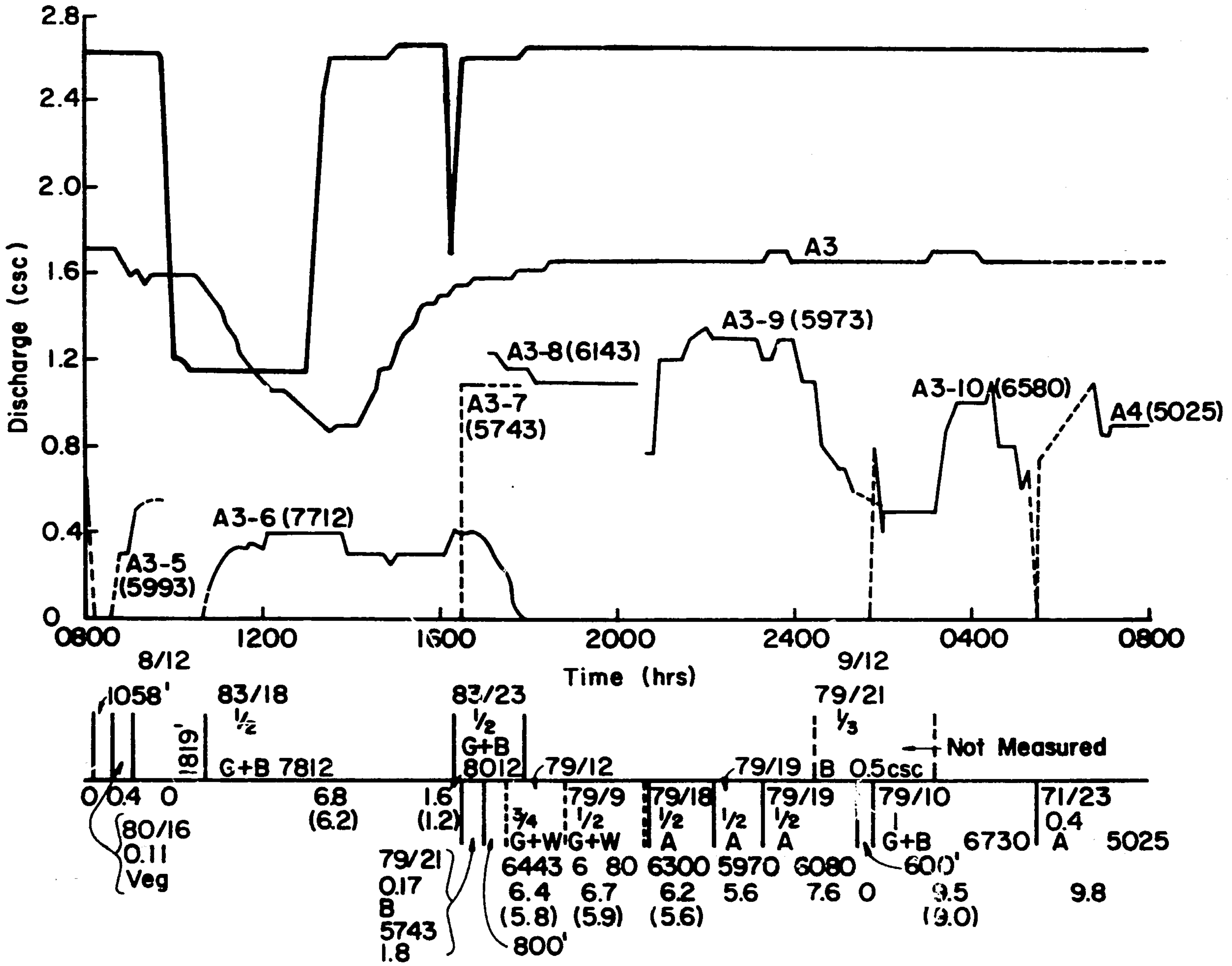


Figure A-2. Flume and Field Data Summary.

Figure A-2 (contd.). Flume and Field Data Summary.



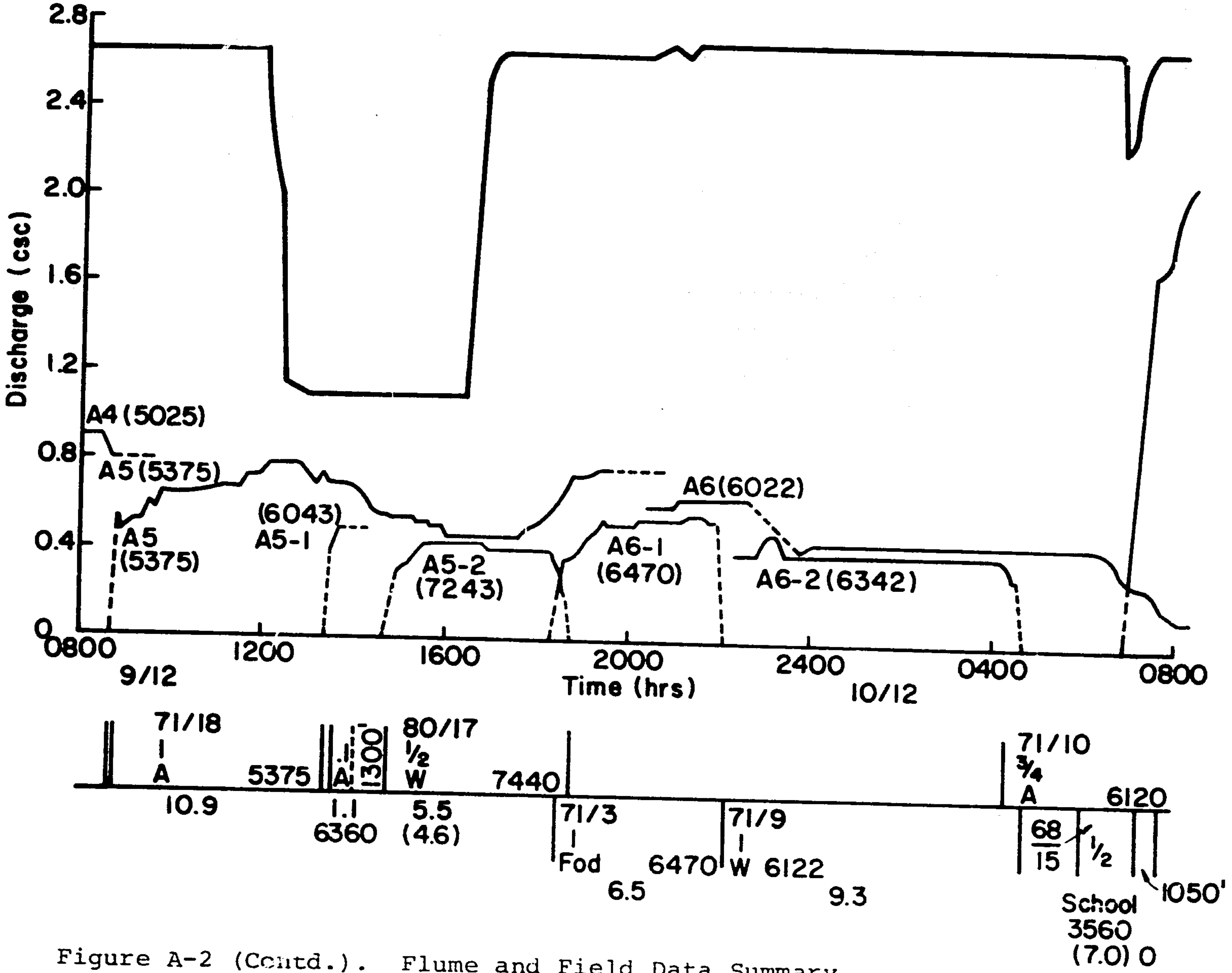


Figure A-2 (Contd.). Flume and Field Data Summary

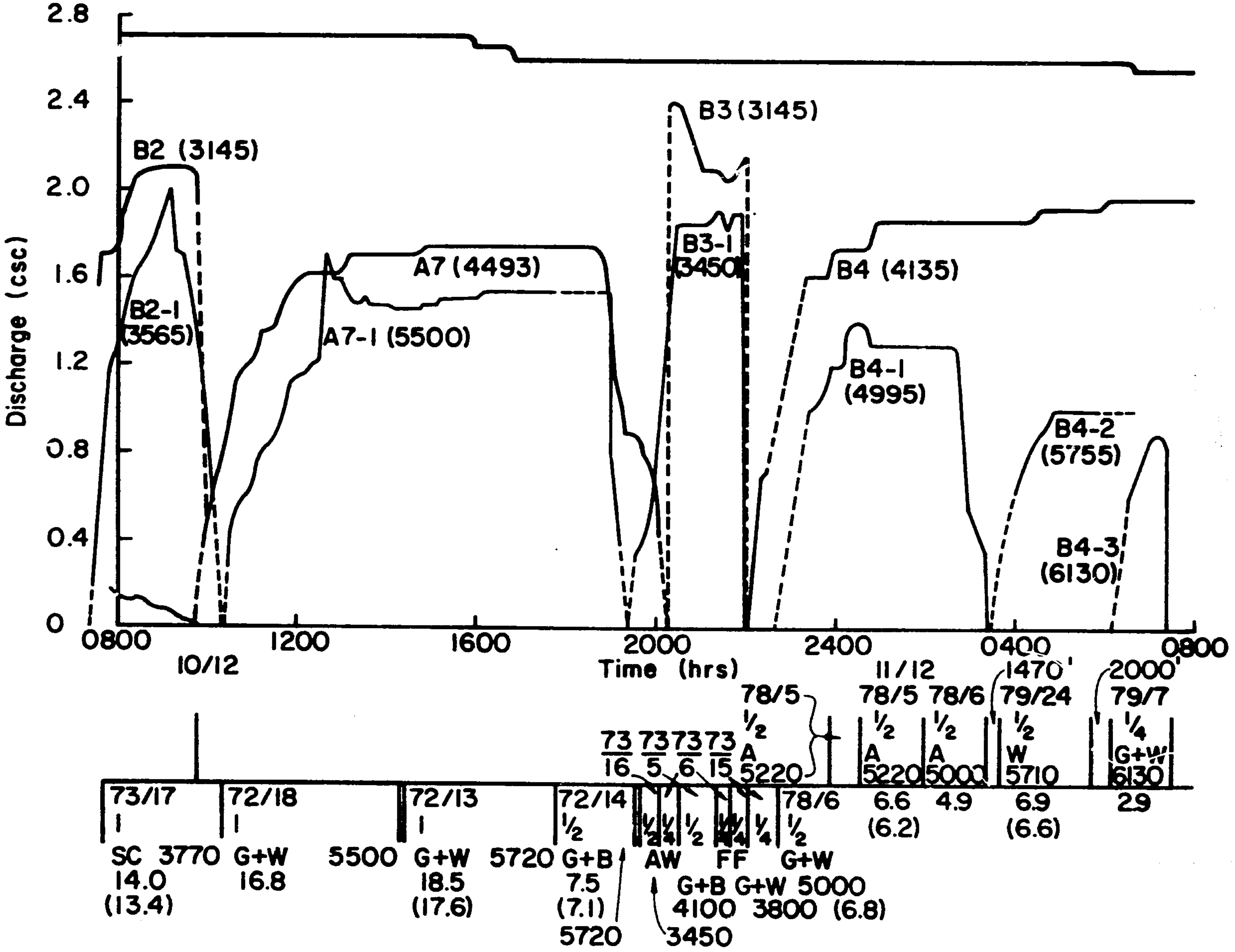


Figure A-2 (Contd.). Flume and Field Data Summary.

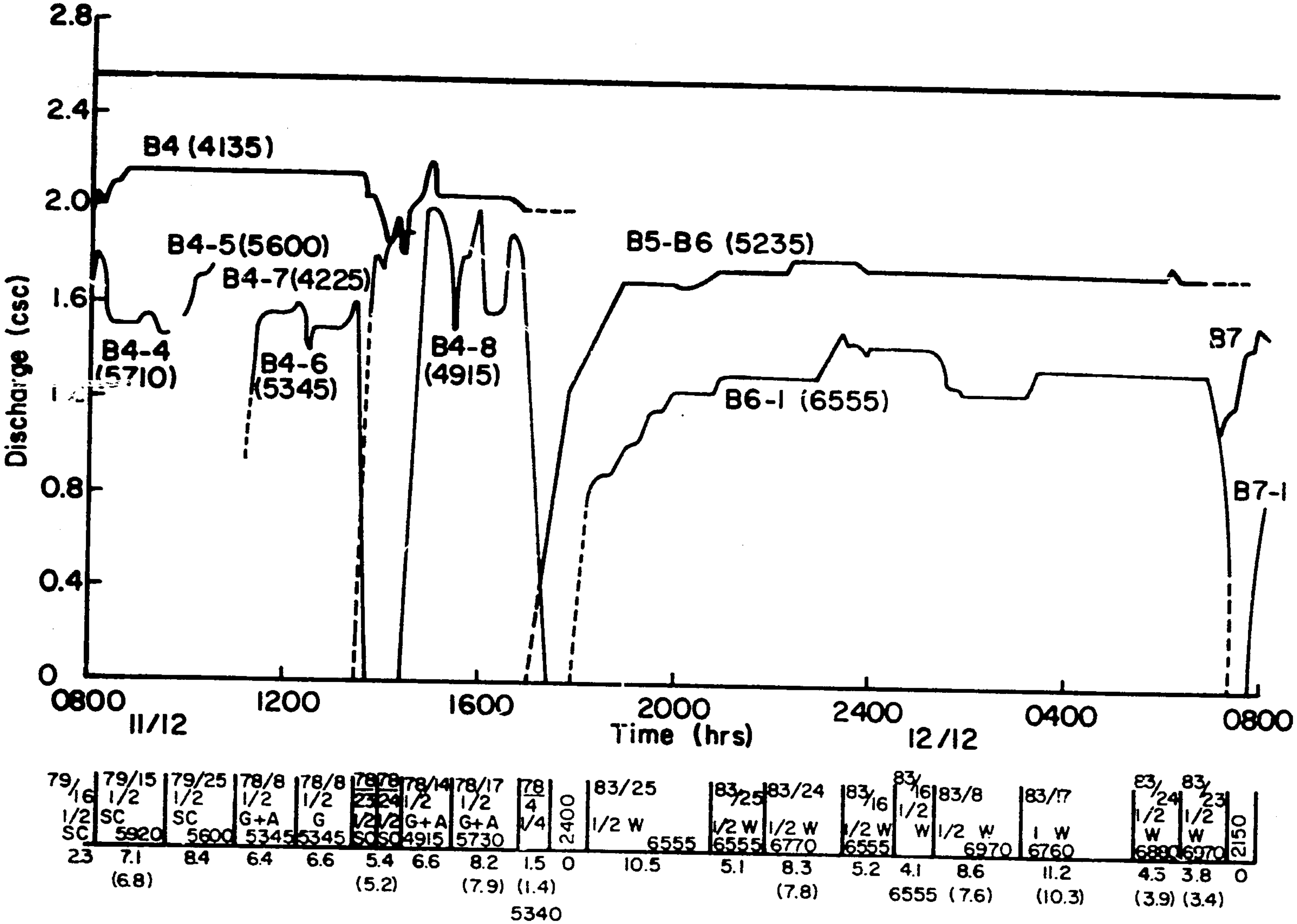


Figure A-2 (Contd.). Flume and Field Data Summary.

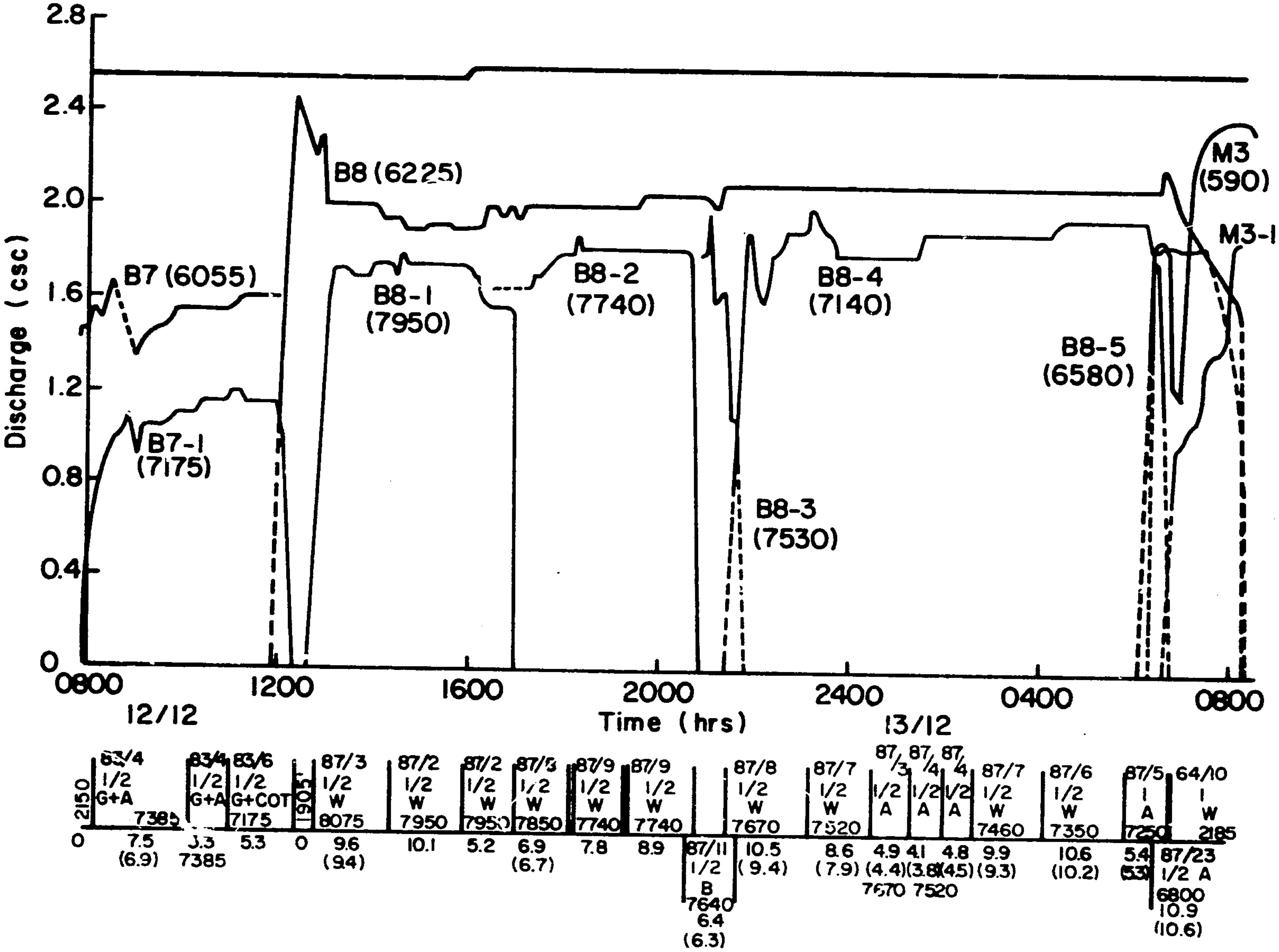


Figure A-2 (contd.). Flume and Field Data Summary.

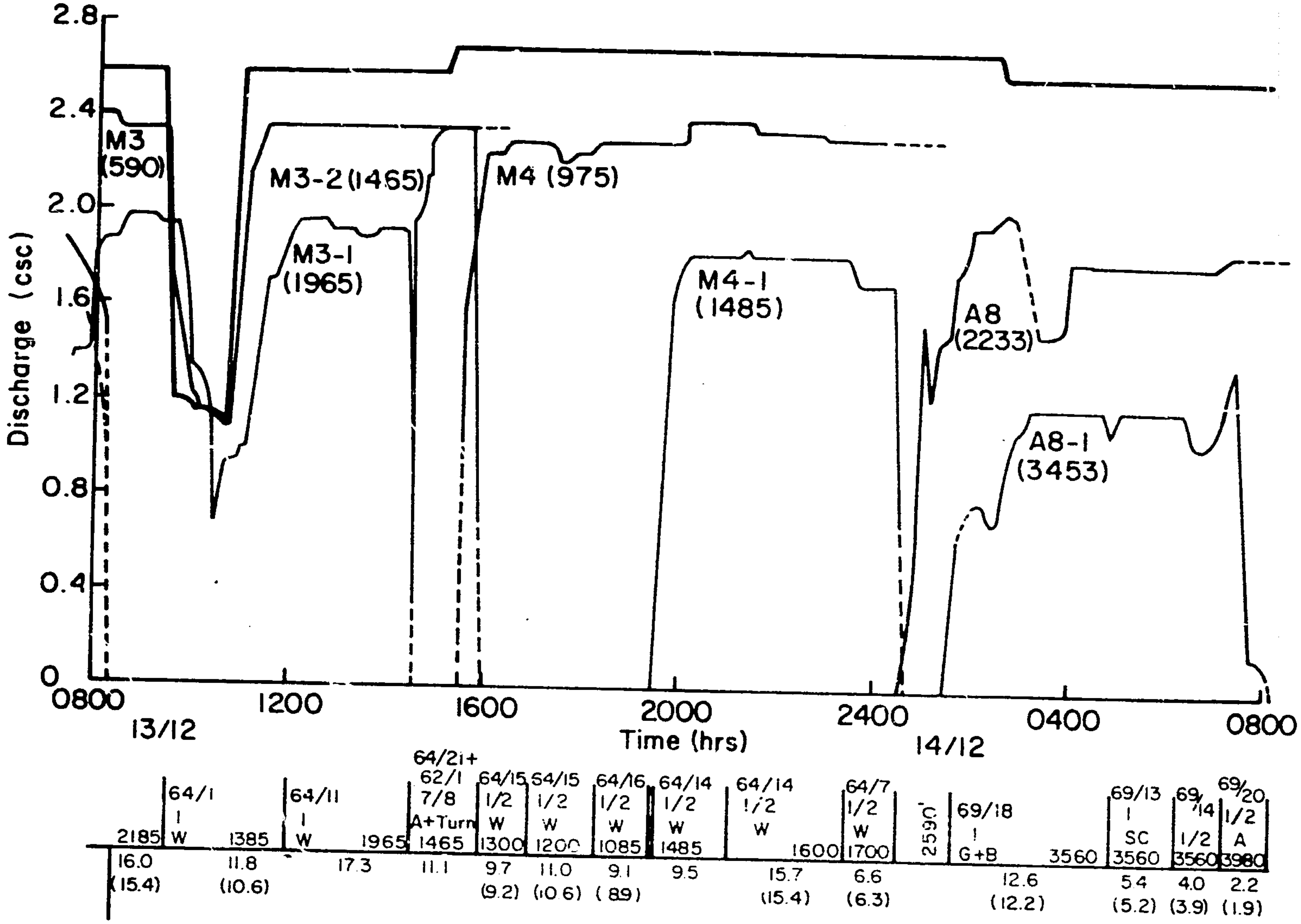


Figure A-2 (Contd.). Flume and Field Data Summary.

APPENDIX 11

WATER CONVEYANCE LOSSES ON TUBEWELL 81-R WATERCOURSE AFTER IMPROVEMENT [1]

By

S.A. Bowers and Mohsin Wahla[2]

One criteria for evaluating the effectiveness of watercourse improvement is the increase in water delivery to the field. On previously improved watercourses the increased delivery was calculated from a series of steady-state loss measurements made at various places on the watercourse, both before and after improvement. Kemper, et al. (3) recognized that steady-state measurements fail to account for losses such as wetting-up dry channels, dead storage, etc. On the basis of a 15 hour loss study which measured the volumes of water into the watercourse and out to the fields, they concluded that these operationa losses equalled 17 percent of the inflow to the watercourses.

Trout et al. (5) selected watercourse TW 81-R (mogha 31574/R) of the SCARP-II area for a complete warabundi loss study. Through out an irrigation turn of one week (168 hours) the water was followed from field to field and flow rate measurements made simultaneously at the mogha (distributary outlet), in the authorized channels, and at the farmer's field. By integration of the resulting flow rate-time curves and analysis of other collected data Trout concluded that the overall watercourse conveyance efficiency was 44 percent; 13 percent of the loss was operational. Two-third of the resulting loss occurred in the Sarkari Khal (government authorized channels).

Following the warabundi study, watercourse TW 81-R was renovated. This included a complete rebuilding of banks, junctions, cross sections, etc. according to new design criteria. In addition, concrete pipe culverts and brick and concrete check and turnout structures were installed. The complete Sarkari Khal was improved plus one farmers' branch (Branch C, Figure 1).

Of concern was the water savings due to watercourse improvement and could this savings be estimated using steady-state inflow outflow procedures. To find this answer, another complete warabundi loss study was initiated on April 25, 1977 and continued until May 2, 1977.

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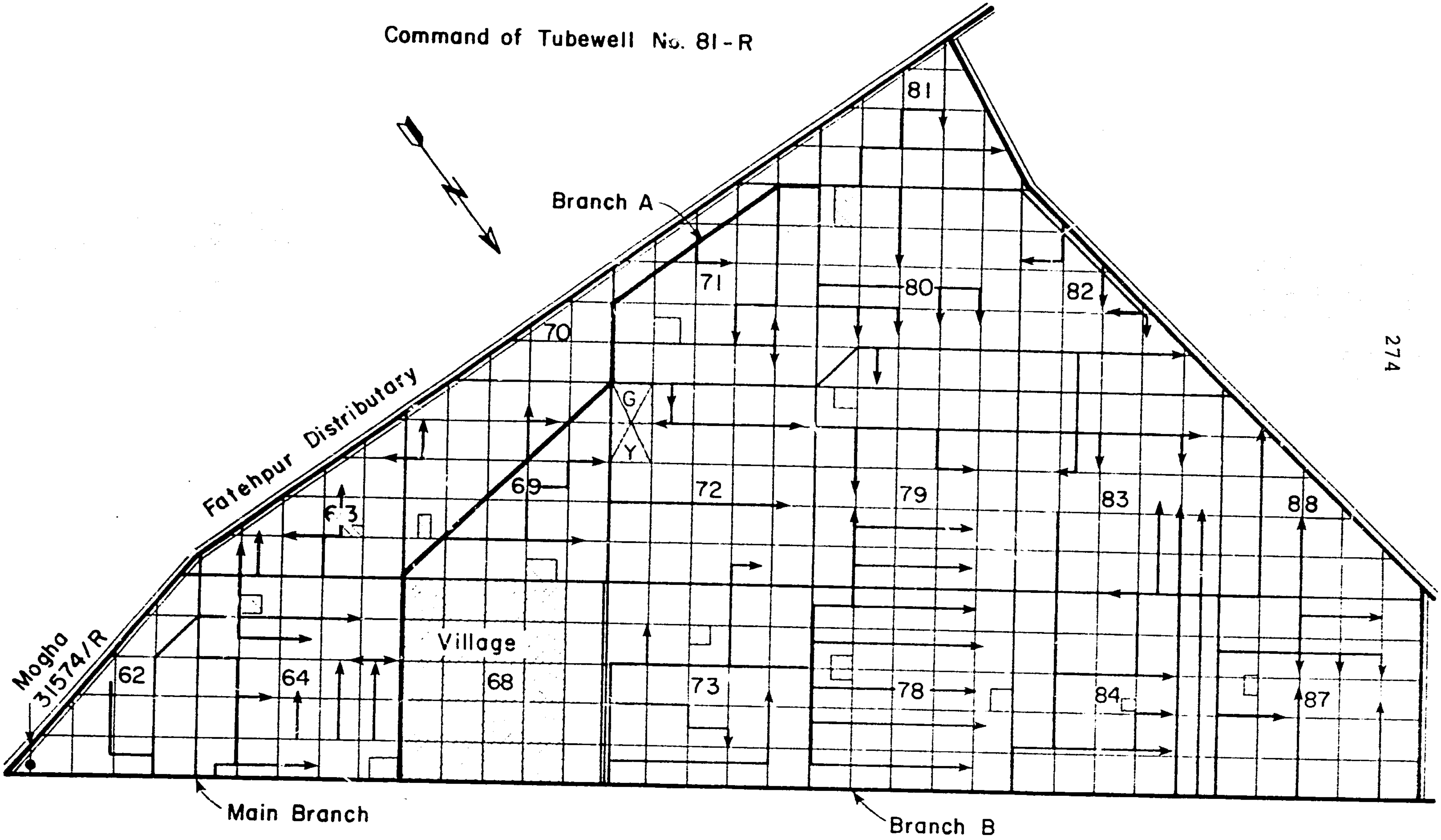
[1] Cooperative investigation with Colorado State University and Mona Reclamation Experimental Project, WAPDA.

[2] Soils Advisor, CSU and Senior Research Officer, MREP, WAPDA respectively.

Figure 1. Layout of Tubewell 81-R Watercourse.



PROCEDURE

Figure 1 shows the map of watercourse TW 81-R. It consists of 366 acres served by approximately 75,000 ft. of watercourse of which 11,500 ft. are government authorized. The watercourse includes a 2000 ft. main channel and two branches designated A and B, which are respectively 4200 and 5300 ft. in length. The authorized flow into the watercourse is 2.60 cusecs; 1.1 cusecs comes from the distributary and 1.5 cusecs comes from the tubewell. The flow is frequently less due to power failures and a daily tubewell scheduled rest period.

Loss was determined by an inflow-outflow procedure using Cutthroat flumes (4) where loss in any section was equal to the integrated discharge difference between successive flumes. One flume was installed at the head of the watercourse just below the confluence of tubewell and mogha. Here flow was recorded every 10 minutes for 168 hours. A second flume was set in the Sarkari Khal near the point at which water was diverted into farmer field channels. A third flume was set in the farmers' field channels near the field irrigated. The Sarkari Khal and field flumes moved with the water. Generally, the flumes were moved sequentially down channel. However, in a few instances, the movement was up channel. Wherever possible, flow rates were recorded every 10 minutes throughout the 168 hour turn.

Unexpected travel restrictions prevented supervisory personnel from participating in the study. Consequently, Sarkari Khal and field flumes were occasionally placed at excessive distances from the fields irrigated or the turnout from the Sarkari Khal. In such cases the loss was linearly extrapolated to the site at which the flume should have been set. Also when water diversions required installation of Sarkari Khal and field flumes at other locations the previously installed flumes were withdrawn before drainage was complete.

Both time and labor limitations prohibited setting a flume for each individual field; consequently, each field flume served two or more fields. Here, the average distance from flume to fields was calculated and loss linearly extrapolated to that distance. The distance from field flume to field irrigated varied from a few feet up to, in one case, 790 ft. The average distance from the field flume to the fields was 233 ft. The field irrigated, its elevation, the time at which the flume was installed and removed, and the distance of each flume from the mogha were also recorded.

All recorded flows were plotted with time and areas under the curves integrated. On the basis of these integrated values, average total water delivered, average flow rates, loss, and conveyance efficiencies were calculated.

From the "before" and "after" improvement flow rate-time curves, steady-state loss rates were selected during flow to most irrigated fields. For each steady-state condition the initial flow rate (Q_O), the distance from the mogha to the field flume (D), the difference in elevation (E) between the mogha and the field irrigated and the conveyance loss between the mogha and the field flumes were recorded.

Previous investigations (1, 2) showed a curvilinear relationship between initial flow rate and loss and distance from the mogha and loss. Similarly because of its influence on depth of water in a trapozoidal or parabolic channel, field elevation difference was believed curvilinearly related to loss. Using Q_O, Q_O^2, D, D^2, E, and E^2 as independent variables and steady-state loss rate as the dependent variable, conveyance loss rate prediction equations were developed (using linear regression techniques) for both the "before" and "after" improvement phases. Steady-state loss rates for the "before" condition were taken from the flow rate-time curves recorded by Trout <u>et al</u>. (5).

Following equation development, 100 acres were randomly selected from the watercourse map. The elevation difference (E) and conveyance distances (D) were calculated for each field. These data were successively entered into the "before" and "after" predictive equations as one set of 100 acres, two sets of 50 acres, four sets of 25 acres, five sets of 20 acres, and 10 sets of 10 acres. Conveyance loss rate to each acre of each set was calculated for a flow rate (Q_O) of 2.5 cusecs. For the two sets of 50 random acres, conveyance loss rates were calculated for flow rates (Q_O) varying in increments 0.25 cusecs over the range of 1.25-2.75 cusecs. For each set, at each flow rate and for each improvement condition, the arithmetic average loss rate was calculated. The average loss rates resulting from an initial flow rate (Q_O) of 2.5 cusecs were compared to those derived from the integration of flow rate-time curves. To observe the effect of "weighting", the weighted averages, where weighting factors were distance from the mogha (D) and elevation difference (E), were also calculated.[1]

RESULTS

Table 1 shows the integrated water volumes delivered, the conveyance losses, and the distances between flumes and mogha,

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[1] The arithmetic average loss rate = $\frac{\sum_{i=1}^{i=n} L}{n}$

The weighted average loss rate = $\frac{\sum_{i=1}^{i=n} DEL}{\sum_{i=1}^{i=n} DE}$

Table 1. After improvement Flow and Loss Measurements on TW 81-R

(1) Field Flume No.	(2) Head Flume Delivery (ac-ft)	(3) SK Flume Delivery (ac-ft)	(4) Loss To SK Flume (2-3) (ac-ft)	(5) Distance SK Flume To Mogha (1000 ft)	(6) Field Flume Delivery (ac-ft)	(7) Loss SK-Fld Flume (3-6) (ac-ft)	(8) Distance SK-Fld Flume (1000 ft)	(9) Field Delivery (ac-ft)	(10) Field Channel Loss 3-9 (ac-ft)	(11) Distance Fld-Fld Flume (1000 ft)	(12) Distance Fld-SK Flume (1000 ft)	(13) Total Loss 2-9 (ac-ft)	(14) Irrigation Time (min)	(15) Acres Irrigated
M-1-1	1.438	1.326	0.112	0.642	1.076	0.250	1.005	1.009	0.317	0.305	1.310	0.429	565	3.5
M-2-1	0.409	0.430	-0.021	0.942	0.316	0.114	0.660	0.301	0.129	0.310	0.970	0.108	120	1.0
M-2-2	1.477	1.381	0.096	0.942	1.244	0.137	0.500	1.213	0.168	0.325	0.865	0.264	420	2.0
Total	3.324	3.137	0.187		2.636	0.501		2.523	0.614			0.801		6.5
A-1-1	1.301	0.828	0.473	3.106	0.744	0.084	0.200	0.693	0.135	0.305	0.505	0.608	340	2.0
A-1-2(a)	1.636	1.177	0.459	3.740	1.177	0.0	0.0	1.152	0.025	0.135	0.135	0.484	430	2.5
A-1-2(b)	0.926	0.692	0.234	4.092	0.692	0.0	0.0	0.679	0.013	0.235	0.235	0.247	250	1.5
A-1-3	0.269	0.212	0.057	3.432	0.208	0.004	0.240	0.208	0.004	0.060	0.300	0.061	120	1.0
A-2-1	2.168	1.217	0.951	4.550	0.843	0.374	0.985	0.786	0.431	0.425	1.410	1.382	630	4.0
A-2-2	0.374	0.241	0.033	4.550	0.213	0.128	0.510	0.206	0.135	0.170	0.680	0.168	120	1.0
A-2-3	0.842	0.510	0.332	4.550	0.269	0.241	2.640	0.243	0.267	0.320	2.960	0.599	230	1.5
A-2-4	0.781	0.468	0.313	4.550	0.262	0.206	2.290	-.262	0.206	0.090	2.380	0.519	210	2.0
A-2-5	0.360	0.232	0.128	4.550	0.216	0.016	1.450	0.216	0.016	0.065	1.515	0.144	100	0.5
A-2-6	1.695	1.064	0.631	4.550	1.038	0.026	1.515	1.001	0.063	0.150	1.675	0.694	520	3.0
A-2-7	0.949	0.481	0.468	4.928	0.460	0.021	0.370	0.460	0.021	0.140	0.510	0.489	260	2.0
A-3-1(a)	0.620	0.202	0.418	5.130	0.202	0.0	0.0	0.202	0.0	0.0	0.0	0.418	170	1.0
A-3-1(b)	0.633	0.265	0.368	5.350	0.265	0.0	0.0	0.265	0.0	0.0	0.0	0.368	170	1.25
A-4-1	1.320	0.458	0.862	6.072	0.458	0.0	0.0	0.458	0.0	0.0	0.0	0.862	430	2.0
A-4-2(a)	0.663	0.165	0.498	6.380	0.165	0.0	0.0	0.165	0.0	0.0	0.0	0.498	215	1.5
A-4-2(b)	0.210	0.098	0.112	6.618	0.098	0.0	0.0	0.095	0.003	0.165	0.165	0.115	125	1.0
A-4-3	0.598	0.135	0.463	6.204	0.115	0.020	0.260	0.102	0.033	0.190	0.450	0.496	240	1.0
A-4-4	0.575	0.114	0.461	6.618	0.114	0.0	0.0	0.076	0.038	0.540	0.540	0.499	165	1.0
Total	15.920	8.659	7.621		7.539	1.120		7.269	1.390			8.651		29.75

Table 1. (cont.)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
B-1-1	1.200	1.032	0.168	3.080	1.000	0.032	0.350	0.984	0.048	0.195	0.545	0.216	325	3.0
B-1-2	1.307	1.196	0.111	3.080	1.077	0.119	0.150	1.066	0.130	0.950	1.245	0.241	380	2.75
B-1-3	0.596	0.541	0.055	3.080	0.496	0.045	0.510	0.496	0.045	0.130	0.640	0.1[illegible]	160	2.0
B-2-1	2.345	1.933	0.412	4.136	1.662	0.271	0.345	1.578	0.355	0.615	0.960	0.767	4.60	5.0
B-2-2	0.495	0.469	0.026	4.136	0.338	0.131	0.540	0.328	0.141	0.370	0.910	0.167	640	1.0
B-2-3	0.374	0.329	0.045	4.136	0.249	0.080	0.925	0.243	0.086	0.290	1.215	0.131	100	1.0
B-2-4	0.959	0.835	0.124	4.136	0.531	0.304	1.540	0.505	0.330	0.380	1.910	0.454	280	1.5
B-3-1	1.999	1.385	0.614	5.324	0.979	0.406	0.545	0.928	0.457	0.295	0.830	1.071	540	2.0
B-3-2	1.154	0.764	0.390	5.324	0.681	0.083	0.695	0.664	0.100	0.205	0.900	0.490	310	2.0
B-4-1	0.896	0.523	0.373	6.116	0.408	0.115	0.985	0.408	0.115	0.025	1.010	0.488	250	1.0
B-4-2	0.977	0.563	0.414	6.820	0.545	0.018	0.070	0.537	0.026	0.130	0.200	0.440	260	2.0
B-4-3	0.900	0.655	0.245	6.468	0.658	-0.003	0.370	0.649	0.006	0.270	0.640	0.251	290	1.00
B-4-4	1.971	1.247	0.724	6.468	1.076	0.171	0.750	1.016	0.231	0.435	1.185	0.955	530	4.0
Branch B Drainage	0.0	0.332	-0.332	6.468	0.344	-0.012	0.750	0.340	0.008	0.790	1.540	-0.340	180	1.0
Total	15.173	11.804	3.369		10.044	1.760		9.742	2.062			5.431		30.25
Grand Total	34.417	23.600	10.817		20.219			19.534	4.066			14.833	10.140	66.50

etc. Flume locations and sequence are identified by letters and numbers. M, A, and B designate the main channel, Branch A, and Branch B respectively. The first number designates successive locations of the Sarkari Khal flumes while the second number designates the successive field flume installations associated with each Sarkari Khal flume. The Sarkari Khal flume was occasionally located so near the field irrigated that no field flume was required.

Table 1 shows that of 34.42 acre ft. delivered to the watercourse, 20.22 acre ft. were delivered to the field flumes. The watercourse average delivery efficiency to the field flumes was 58.7 percent. Trout et al. (5) determined a delivery efficiency to the field flumes of 45.7 percent before watercourse improvements. Thus improvement increased the average delivery to the field flumes by 13.0 percentage points. Since the "before" and "after" initial average flow rates were comparable, 2.51 and 2.48 cusecs respectively, improvement increased the average delivery to the field flumes by approximately 0.31 cusecs. By volumetric measurement the increased delivery to the field flumes after improvement was 4.32 ac-ft.[2] Discounting the small loss between field flume and field, this is sufficient saving to irrigate an additional 13.3 acres[2] per complete turn with 3.5 inches of water each. Actually a total of 66.5 acres were irrigated during the turn; this is 13.5 acres more than were irrigated in the "before" improvement study reported by Trout et al. (5)

Slight errors in the calculated water delivery to the fields are possible. As noted in the procedures section above, flumes were not always set adjacent to the irrigated fields; losses from field flume to field were calculated by linear extrapolation. An additional source of error concerns storage and drainage. Field flumes were usually removed before channel drainage into a field was complete and installed at the next sites after the arrival of some water. Trout et al. (5) estimated that of the 82,000 ft^3 required to fill the Sarkari Khal, 30 percent drained into the fields. Table 1 shows that at least 14,500 ft^3 were recovered at the tail of Branch B from drainage. Even assuming improvement increased the drainage potential 100 percent, the mean delivery efficiency to the field would only increase approximately 2 percent. The total adjusted field delivery was 19.53 acre ft. or a 56.7 percent delivery efficiency. Thus improvement increased the field delivery efficiency by 12.3 percentage points approximately 26 percent more water was delivered to the fields {(0.567 x 2.48)/0.444 x 2.51)}.

How well do steady-state losses estimate the mean loss for the entire watercourse? Predictive loss equations 1 and 2 below were developed by regression techniques from steady-state loss data "before" and "after" improvement respectively (Tables 2 & 3).

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[2] In this report the internationally recognized acre foot (43,560 ft^3) is used. However, the acres referred to are locally defined as 220' x 220' (48,400 ft^2) and known as a "killa".

Table 2. Steady-state Loss Data at Field Flumes Before Improvement

Square & Acre No.	L Loss Rate (cusec)	Q_o Initial Flow Rate (cusec)	D Distance From Mogha (1000 ft)	E Elevation Difference (ft)
		Main Branch		
64/1	0.62	2.60	2.185	1.09
64/10	0.45	1.20	2.185	1.12
64/11	0.64	2.60	1.965	1.12
64/21	0.24	2.60	1.465	1.11
64/14	0.87	2.70	1.485	0.91
64/14	0.88	2.70	1.600	0.91
64/7	1.00	2.70	1.700	0.89
		A Branch		
68/19	1.50	2.55	3.690	0.39
69/10	1.60	2.55	4.200	0.45
69/10	1.40	2.60	4.200	0.45
72/23	1.14	2.60	5.093	1.51
73/21	1.54	2.60	5.803	1.53
72/25	1.50	2.60	5.803	1.50
72/3	1.52	2.60	6.023	1.86
72/9	1.80	2.60	5.422	1.86
83/18	0.84	1.16	7.712	2.22
83/23	1.49	2.65	6.143	2.21
79/12	1.51	2.60	6.143	2.13
78/19	1.34	2.64	5.973	2.02
79/18	1.64	2.64	6.580	2.13
71/23	1.75	2.64	5.025	1.18
71/18	1.99	2.64	5.375	1.19
80/17	0.69	1.10	7.243	1.75
71/3	2.09	2.64	6.470	1.44
71/9	2.24	2.64	6.342	1.24
71/9	2.30	2.70	6.342	1.23
71/10	2.25	2.70	6.022	1.23
69/18	1.50	2.70	3.453	0.34
69/14	1.40	2.60	3.453	0.33
		B Branch		
73/17	0.70	2.70	3.565	1.71
72/18	1.22	2.70	5.500	1.59
72/13	1.16	2.70	5.500	1.64
72/14	1.11	2.65	5.500	2.74
73/5	0.73	2.60	3.450	1.97
78/6	1.20	2.60	4.995	2.08
78/5	1.30	2.60	4.995	1.98
79/24	1.60	2.60	5.775	2.01
79/15	1.05	2.55	5.710	2.22
78/8	1.00	2.55	5.345	2.11
78/8	1.05	2.55	5.345	2.11
78/17	1.00	2.55	4.915	1.93
83/25	1.32	2.55	6.555	2.17
83/24	1.25	2.55	6.555	2.27
83/16	1.11	2.55	6.555	2.16
83/18	1.31	2.55	6.555	2.22
83/17	1.20	2.55	6.555	2.14
83/4	1.40	2.55	7.175	3.00
83/6	1.40	2.55	7.175	2.22

Table 3. Steady-State Loss Data at Field Flume After Improvement

Square and Acre No.	L Loss Rate (Cusecs)	Qo Initial Flow Rate (Cusecs)	D Distance (1000 ft)	E Elevation Difference (ft)
		MAIN BRANCH		
64/22	0.55	2.75	1.675	1.34
64/19	0.30	1.17	1.675	1.08
64/20	0.20	1.17	1.675	1.16
64/11	0.40	2.60	1.675	1.12
64/13	0.55	2.75	1.600	1.03
64/17	0.32	2.72	1.440	1.03
64/18	0.45	2.80	1.440	0.99
64/7	0.40	2.80	1.440	0.89
		A BRANCH		
63/6	0.95	2.85	3.300	1.20
63/15	1.10	2.80	3.300	1.28
63/14	0.90	2.80	3.300	1.30
69/17	0.55	2.80	3.670	0.31
69/18	0.65	2.75	3.670	0.38
69/19	0.60	2.75	3.670	0.39
69/9	0.75	2.75	3.670	0.49
69/2	0.55	2.70	3.670	0.47
72/25	1.55	2.72	5.500	1.50
73/21	1.43	2.72	5.500	1.53
72/16	1.48	2.65	5.500	1.58
72/15	1.30	2.65	5.500	1.73
82/16	1.40	2.65	7.170	2.16
82/25	1.50	2.70	6.864	2.11
82/24	1.55	2.70	6.864	2.04
80/16	1.05	2.70	5.980	1.80
79/22	0.90	2.55	6.030	2.01
79/20	1.25	2.65	6.030	2.10
79/22	1.10	2.65	6.030	2.00
71/23	1.65	2.65	5.100	1.18
71/18	1.40	2.65	6.070	1.18
71/19	1.47	2.72	5.100	1.19
71/16	1.97	2.65	6.070	1.23
81/25	0.67	1.17	6.380	1.21
80/21	2.10	2.75	6.380	1.28
81/17	0.67	1.22	6.380	1.21
71/3	0.80	1.22	6.380	1.44
81/14	2.00	2.75	6.380	1.22
		B BRANCH		
73/13	0.50	2.75	4.225	1.75
73/9	0.57	2.72	4.225	1.88
73/16	0.37	2.72	3.650	1.66
78/24	0.72	2.72	4.460	1.94
78/17	0.65	2.72	4.460	1.93
78/18	0.62	2.72	4.460	2.00
78/8	0.47	2.72	4.460	2.11
78/6	0.57	2.72	4.770	1.95
78/7	0.45	2.70	5.060	2.07
79/17	1.16	2.71	5.675	1.87
79/18	1.02	2.71	5.675	2.13
84/15	1.32	2.72	5.760	2.02
84/14	1.22	2.72	5.760	2.10
84/23	1.12	2.72	5.920	2.08
84/19	0.92	2.72	5.920	2.10
84/10	1.25	2.75	7.130	2.16
87/15	1.20	2.75	6.850	2.47
87/14	1.02	2.71	6.850	2.52
87/23	0.80	2.75	6.820	2.08
87/21	1.30	2.70	7.215	2.20
87/22	1.20	2.70	7.215	2.23
84/20	0.95	2.70	7.215	2.20
87/11	1.20	2.70	7.215	2.32
84/14	1.22	2.72	5.760	2.10

"Before"

$$\begin{aligned} \text{Loss(cusecs)} = 0.72297 &- 1.33664\ Q_o + 0.50462\ Q^2 \\ &+ 0.30272\ D - 0.00228\ D^2 \\ &- 0.49874\ E - 0.00271\ E^2 \end{aligned} \tag{1}$$

$r^2 = 0.75816$

STD Error of Estimate = 0.2415 cusecs

"After"

$$\begin{aligned} \text{Loss (cusecs)} = -1.64017 &+ 0.49080\ Q_o - 0.00432 Q^2 \\ &+ 0.07375\ D + 0.02232 D^2 \\ &+ 1.29190\ E - 0.58641\ E^2 \end{aligned}$$

$r^2 = 0.73726$

STD Error of Estimate = 0.2446

Where
Q_o = initial flow rate in cusecs
D = distance from mogha to field flume in 1000 ft.
E = elevation difference between mogha and field irrigated in ft.

To check the above two equations, the distances (D) and elevation differences (E) associated with the measured steady-state losses (Tables 2-3) were successively entered into these same equations and losses recalculated for an initial flow rate (Q_o) of 2.5 cusecs. The weighted average (D and E as weighting factors) of these calculated losses for "before" and "after" improvement were respectively 1.27 cusecs and 1.03 cusecs which are reasonable approximations to the 1.36 and 1.02 loss rates derived from integration of flow rate-time curves. The arithmetic average of these same "before" and "after" calculated loss rates were respectively 1.20 cusecs and 0.93 cusecs. In this instance the arithmetic averages underestimated the weighted averages by 6-10 percent.

Table 4 makes a comparison between various computational procedures for the "before" and "after" loss rates to the field flumes. If we accept procedure 1 (based on integration and subtraction of flow rate-time curves) as the most correct then all other procedures provide answers which are probably satisfactory for engineering estimates. Procedures 2, 3, 4, and 5 (Table 4) are too circuitous to be of present practical use but they do demonstrate that mean watercourse loss rates can be estimated on the basis of certain physical data associated with the watercourse and the commanded acres.

The data of Table 4 does not resolve the question of whether or not the steady-state loss averages include estimates of operational losses. However, weighting procedures are compared to arithmetic averaging the weighted averages tend to be 3-12

Table 4. Water Loss (in cusecs) to Field Flumes on TW 81-R as computed by Various Procedures for 2.5 Cusec Initial Flow Rate (Q_o).

	AVERAGE LOSS (Cusecs)	
COMPUTATIONAL PROCEDURES	BEFORE	AFTER
1. Integration and subtraction of flow rate-time curves.	1.36	1.02
2. Develop prediction equations; using D and E from original steady-state data compute the weighted average loss.	1.27	1.03
3. Develop prediction equations; using D and E from original steady-state data compute the arithmetic average loss.	1.20	0.93
4. Develop prediction equation; using D and E from two randomly selected 50 acre sets calculate the loss for each acre and compute the weighted average loss.*	1.36	1.11
5. Develop prediction equations; using D and E from two randomly selected 50 acre sets calculate the loss for each acre and compute the arithmetic average loss.*	1.28	1.02
6. Arithmetic average of steady-state losses.	1.29	0.97
7. Steady-state loss weighted average with D and E as weighting factors.	1.33	1.09
8. Steady-state loss weighted average with D as a weighting factor.	1.36	1.07

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*Distances used with randomly selected acres was the channel distance, as taken from the watercourse map, from the mogha to the particular acre.

percent higher. This partially compensates for under estimation of conveyance losses attributed to steady-state procedures.

Table 5 lists the predicted loss rates which result from entering the distances (D) and elevation differences (E) associated with the 100 randomly selected acres into equations 1 and 2 above and solving for an initial flow rate (Q_o) of 2.5 cusecs. Data was entered in acre sets varying in size from 100 to 10. Predicted loss rates from individual sets as small as 20 acres appear as acceptable approximations to the watercourse mean loss rate derived from flow rate-time integration. The implication is that the loss rate status of TW 81-R could have been characterized by as few as 20 randomly selected steady-state loss measurements.

In addition, distances (D) and elevation differences (E) from two randomly selected 50 acre sets were entered into equations 1 and 2 and losses determined for various flow rates. Figure 2 is a plot of the weighted average calculated loss versus initial flow rate. From the figure, at 2.50 cusecs initial flow rate, the losses "before" and "after" were respectively 1.36 and 1.10 cusecs, the corresponding delivery efficiencies 45.6 percent and 56.0 percent. Both these values reasonably estimate the integrated values.

Figure 2 also predicts a water delivery increase to the field flumes of 0.26 cusecs at Q_o equal to 2.5 cusecs. This approaches an actual 0.31 cusecs increase {(2.48 - 1.02) - (2.51 - 1.36) = 0.31)}. The "before" and "after" curves approach one another at a flow rate of 1.75 cusecs. The possible physical explanation is that at 1.75 cusecs the "before" water level would be below the degraded bank portions and overtopping and excessive seepage through the porous upper bank could not occur. It is not understood why the curves diverge at 1.50 and 1.25 cusecs but it probably results from the very few data points available for equation development at these low flow rates. The equations are obviously valid over a limited flow rate range since they do not predict a 0 loss when the initial flow rate (Q_o) is 0.

From Table 1 it was calculated that approximately 73 percent of the water was lost in the government authorized channels (Sarkari Khal) and 27 percent in the farmers' field channels. The average irrigation time weighted conveyance distance in the authorized channels was 4445 ft. The average loss rate was 0.20 cusecs/1000 ft. This is 5 percent less than the 0.21 cusec/1000 ft. rate reported by Trout et al. (5) before improvement. In the farmers' field channels, the irrigation time weighted average distance from the SK flume to the field was 1005 ft; the average loss rate was 0.35 cusecs/1000 ft. This is 0.08 cusecs/1000 ft less than that reported by Trout (5) before improvement. Logically, one might expect the loss rate in farmers' field channels to increase after improvement since

Table 5. Predicted Watercourse Mean Loss Rates for an Initial Flow Rate (Q_o) of 2.5 Cusecs and Randomly Selected Acre Sets

Improvement Condition	Acres Set	Number Of Sets	Loss Rate Averaging Methods	Set Number										Mean of Loss Rate Averages
				1	2	3	4	5	6	7	8	9	10	
Before	100	1	Weighted	1.361										1.361
			Arithmetic	1.277										1.277
After			Weighted	1.092										1.092
			Arithmetic	1.013										1.013
Before	50	2	Weighted	1.368	1.356									1.362 ± 0.008
			Arithmetic	1.265	1.289									1.277 ± 0.017
After			Weighted	1.129	1.061									1.095 ± 0.048
			Arithmetic	0.997	1.030									1.014 ± 0.023
Before	25	4	Weighted	1.373	1.362	1.372	1.339							1.362 ± 0.016
			Arithmetic	1.295	1.234	1.308	1.270							1.277 ± 0.033
After			Weighted	1.097	1.167	1.106	1.021							1.098 ± 0.060
			Arithmetic	0.987	1.006	1.100	0.959							1.013 ± 0.061
Before	20	5	Weighted	1.381	1.390	1.343	1.330	1.359						1.361 ± 0.025
			Arithmetic	1.263	1.322	1.274	1.235	1.291						1.277 ± 0.032
After			Weighted	1.155	1.087	1.103	1.074	1.055						1.094 ± 0.038
			Arithmetic	1.017	0.968	1.021	1.072	0.987						1.013 ± 0.040
Before	10	10	Weighted	1.364	1.391	1.410	1.302	1.356	1.310	1.377	1.306	1.416	1.358	1.359 ± 0.042
			Arithmetic	1.211	1.314	1.455	1.127	1.216	1.255	1.328	1.220	1.390	1.254	1.277 ± 0.096
After			Weighted	1.171	1.146	1.068	1.096	1.172	1.049	1.117	1.026	1.136	0.959	1.094 ± 0.069
			Arithmetic	0.978	1.056	1.034	0.903	1.012	1.030	1.133	1.011	1.094	0.880	1.013 ± 0.078

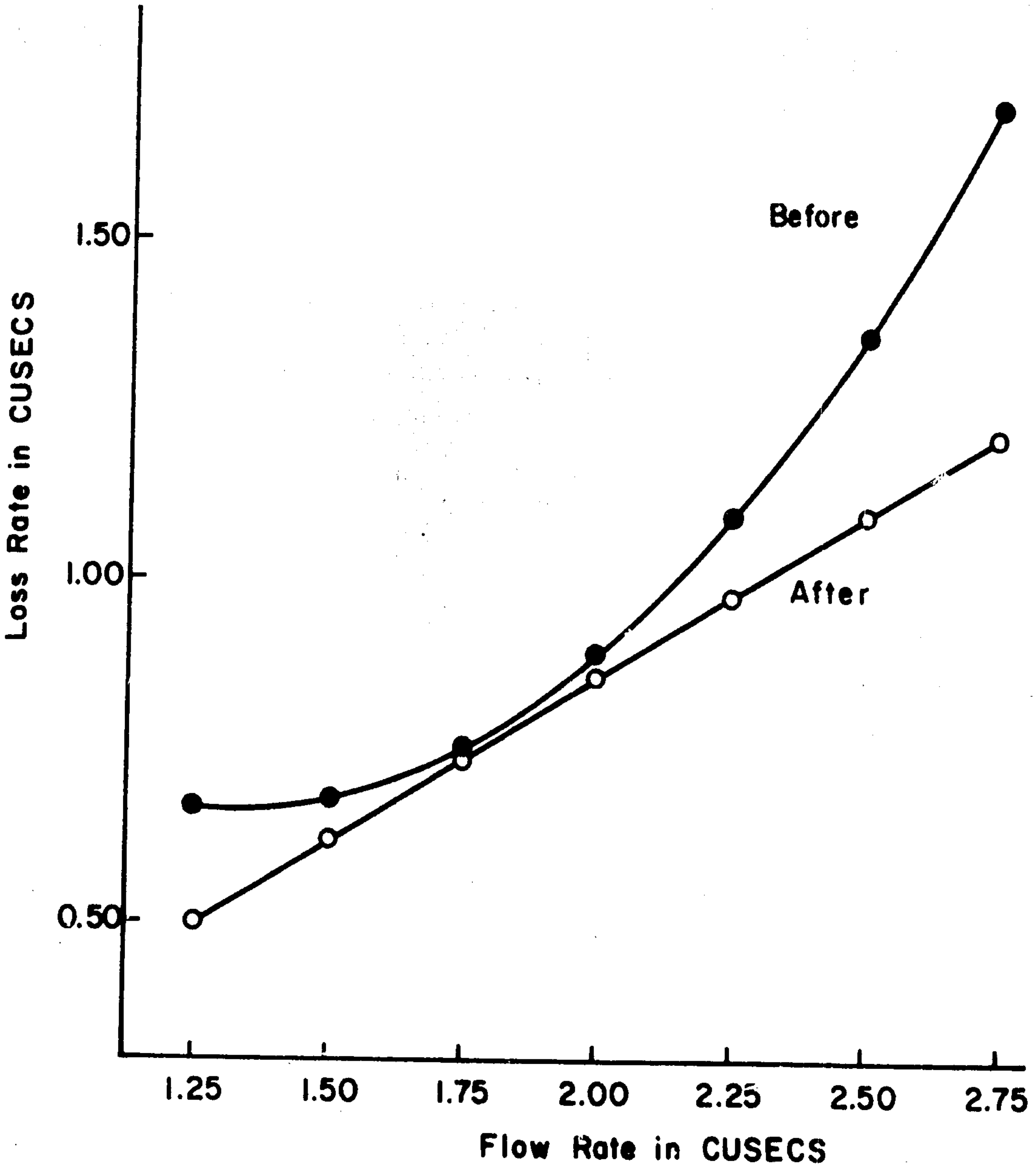

Figure 2. Predicted Loss Rate "Before" and "After" Improvement For Various Initial Flow Rates. Each Point Represents An Average Of Two 50 Acre Sets.

a greater water load would be carried in unimproved farmers' channels. In this instance, however, at least a 1000 ft. section (Channel C in Figure 1) was improved and check structures and nakkas installed. This may have partially contributed to a decreased loss rate.

Both Kemper (3) and Trout (5) reported greater losses at night (6pm - 6am) than in the day (6am - 6pm). After improvement, night losses accounted for 51 percent of the total and day losses, 49 percent; statistically, this difference was not significant (F 1, 12 = 0.038). Previously reported higher night losses were attributed to less attentive irrigators and greater difficulty in detecting leakage, etc. In this study both channel improvement and longer daylight hours due to season may have eliminated a significant night-day loss difference. Longer daylight hours also help to explain the decreased loss rate/1000 ft in field channels.

CONCLUSIONS

Based on integrated flow volumes into the watercourse and out to the field the mean watercourse delivery efficiency was 56.7 percent or 1.40 cusecs. This is a 12.3 percentage point increase in delivery efficiency due to improvement.

By measurement, improvement increased delivery to the watercourse field flumes by 4.32 ac-ft. (4.08 ac-ft. to fields) during the complete warabundi. This extra water allowed irrigation of 13.5 additional acres.

Seventy-three percent of the loss occurred in the Sarkari Khal; the average loss rate was 0.20 cusecs/1000 ft. Twenty-seven percent was lost from farmers' field channels where the loss rate was 0.35 cusecs/1000 ft.

Significant differences between night and day losses were not detected.

Based on steady-state data watercourse conveyance losses both "before" and "after" improvement, were mathematically described by the equations of the following form:

$$\text{Loss (cusecs)} = a + bQ_o + cQ_o^2 + dD + eD^2 + fE + gE^2$$

Where Q_o = initial flow into the watercourse

D = distance in 1000 ft to field flume

E = elevation differences in ft between mogha and irrigated field.

Using the developed equations both the weighted and arithmetic average loss rate based on randomly selected acre sets varying in size from 100 acres to 20 acres estimate the measured rates (derived from integration of flow rate x time curves) with sufficient accuracy to satisfy engineering requirements. The implication is that the mean loss for the TW 81-R could have been estimated with steady-state loss measurements to as few as 20 randomly selected acres.

Solutions to the loss equations for various flow rates predict that watercourse mean loss rates "before" and "after" improvement are almost equal for an initial flow rate of 1.75 cusecs.

Weighted average loss rates where distance and elevation were weighting factors were always greater than the arithmetic averages.

The loss data analysis did not clearly separate operational losses from total losses. This possibly resulted from procedural deficiencies in data collection.

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APPENDIX 12

OPERATIONAL CONVEYANCE LOSSES ON TWO PUNJAB WATERCOURSE SYSTEMS[1]

Tom Trout and Sidney A. Bowers[2]

INTRODUCTION

In an effort to increase, or even maintain, the nutritional standards of an ever growing population, Pakistan agriculture must increase its production. In order to increase production, present constraints to production must be alleviated. One of the most limiting physical constraints in the semi-arid Indus Basin is the water resource. Land availability, labor availability, and climate is such that, with an increased water supply, more crops could be grown.

The water supply at the farmers' fields can be increased by either increasing the supply of water entering the irrigation system, or by increasing the efficiency of that system in getting the water to the crop. In a country such as Pakistan, where the need for food and increased agricultural output is growing so rapidly, both methods must be exploited.

Recognizing the general lack of knowledge about the workings and efficiency of the Indus Basin irrigation system after it enters the cultivator's domain below the "mogha" (distributary outlet), studies have recently been carried out to better understand and evaluate the on-farm irrigation system.

Colorado State University Water Management Research Project personnel and their Pakistani cooperators are working to determine means to improve on-farm water management in Pakistan. An important component of this system is the network of small watercourses which convey the water from the mogha to the field being irrigated. Though the primary portion (the "sarkari khal") of this conveyance system is authorized by the government, all practical upkeep and maintenance of the entire system is left to the farmer.

In the past four years, many measurements of water loss from these village watercourses have been made. These

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[1] Joint effort of Mona Reclamation Experimental Project, Bhalwal; Agricultural University, Faisalabad and Colorado State University Water Management Research Project. Funding was provided by USAID research contract No. AID/ta-C-1411.

[2] Agricultural Engineer and Agronomist, respectively, Colorado State University, Fort Collins, Colorado.

measurements have indicated that from 30 to 50 percent of the water available to the farmers at the mogha is lost from this conveyance system on most watercourses (Clyma et al., 1975; Early et al., 1975; Early et al., 1976; Ashraf et al., 1977). However, all of these measurements have essentially been taken while the system was in steady state, or flowing at a constant rate. This type of measurement fails to measure the additional transient losses from the watercourse system while it is under operating conditions. Operational losses include, in addition to steady state seepage, water initially infiltrated into dry channel banks, water seepage during movement of water from one field to another, dead storage water left in the bottom of channels after their use, and losses resulting from short term breaks or leaks in the watercourse.

The objectives of this study are three:

1. To add further evidence that is thorough and well documented to the existing data that evaluate the watercourse conveyance losses in Pakistan.
2. To determine the amount of transient water losses so that past steady state measurement findings can be adjusted accordingly; and
3. To thoroughly study watercourse conveyance systems so that a better understanding of the factors causing inefficiencies and losses can be determined, and improved designs can be made.

In order to strive towards these objectives, operational loss studies were completed on two Punjab watercourses. These studies involved measuring all of the water entering the watercourse from the mogha or public tubewell and all of the water which passes through "nuccas" (field outlets) and enters farmers' fields during a one week "warabundi" (water allocation rotation). On both watercourses, as is the case on most Punjab systems, water is allocated to all farmers on a weekly turn rotation. Additional measurements of water flow and losses were also made, enabling a distribution of the losses to different categories.

SITE DESCRIPTIONS

The two watercourse systems studied were selected to represent different conditions. One is served by a SCARP (Salinity Control and Reclamation Project) tubewell, the other is in a non-SCARP area. One has predominantly larger farmers; the other, small. One appeared to be poorly maintained by the farmers, while the other appeared to be in relatively good condition. By choosing contrasting conditions, it was hoped that, where comparable results were found between the two systems, the results from the small sample could be more confidently generalized to other watercourse systems.

Tubewell 81-R Watercourse

One of the chosen watercourses was located in the Mona Reclamation Project area near Bhalwal. It is part of the SCARP II area, is served by part of the flow of Tubewell 81, and will be called Tubewell (TW) 81-R watercourse. The canal inflow (through mogha #31574/R) to the watercourse was about 1.1 cubic feet per second (csc). The tubewell added 1.5 csc to the system, giving a combined inflow of 2.6 csc.

The watercourse commands 366 culturable acres. There is one csc of inflow for each 140 cultivated acres. Primary crops in the area are wheat, fodder, sugarcane and citrus. The cropping intensity for the past year (two seasons) had been 174%, higher than the average in the Mona area of 138%.

There are a total of 75,000 feet of watercourses in the command area (205 ft/acre) of which 11,000 ft are sarkari khal. Figure 1 shows the layout of TW 81-R watercourse command area.

There are 20 land holdings listed on the watercourse warabundi list. Land holding sizes varied from 6.4 to 46.6 acres with a median size of 15 acres.

There was little indication of maintenance or cleaning of the watercourse channels, although the farmers had shown an interest in and later did complete, a watercourse earthen improvement program proposed by the Mona staff. There was evidence of more than 50 nucca cuts through the sarkari khal banks, or one for about every 200 ft. of length. There was usually one irrigator present during a farmer's irrigation turn. He generally was a hired laborer.

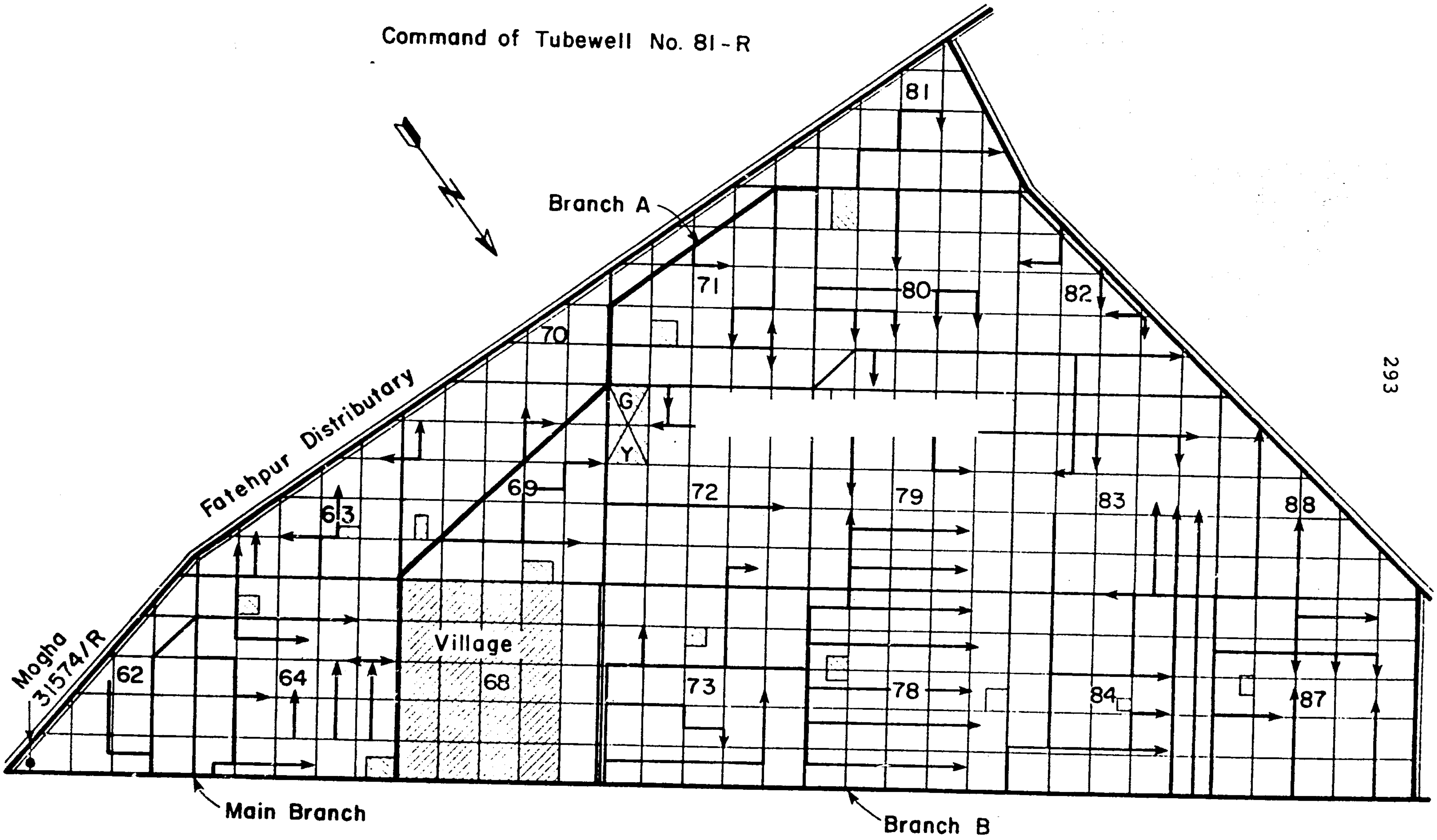
In response to questioning on the number of irrigations required by their crops, the farmers indicated that they needed 54% more water to fulfill their crop irrigation needs (without increasing their cropping intensity).

The operational loss study was carried out from the 7th to the 14th of December, 1976. Much of the irrigation water was applied to newly germinated wheat. The canal was scheduled to be closed one week after the study ended, for cleaning and maintenance.

Tikriwala #1 Watercourse

The second watercourse system studied was that served by mogha #RD89480/L of the Jhang branch. It serves the farmers

Figure 1. Layout of Tubewell 81-R Watercourse.



of Tikriwala village, located 11 miles from Faisalabad on the Jhang road, and will be called Tikriwala #1 (Tik #1) watercourse.

The canal inflow to the watercourse varied between 1.35 and 1.60 csc and averaged 1.45 csc during the week it was being studied. The design inflow to the watercourse was 1.23 csc based on requirements for a 75% cropping intensity (according to district irrigation department personnel), but the mogha had recently been enlarged.

There were two private tubewells located near the head of the watercourse, each jointly owned by groups of about 10 cultivators. The tubewells, which each pumped 1.4 csc, were reported to have good quality water. They are run extensively, but never mixed with the canal water. All farmers bought tubewell water for Rs. 4/hr. (about Rs. 35/acre-foot (ac-ft)) but during high use periods, non-owner farmers sometimes expressed difficulty getting tubewell water. During the studied week, one tubewell was out of order and the other ran every day during the daylight hours.

The watercourse commands 410 culturable acres (about 280 acres per csc inflow). Major crops are sugar cane, wheat and fodder. The cropping intensity for the past year was 174%. The exceptionally high intensity was made possible by the presence of the private tubewells, and is much higher than is generally found in the Faisalabad area.

A total of 98,000 ft of watercourses lead from the mogha to the fields (238 ft/ac) of which 16,000 ft are sarkari khal. The layout of Tikriwala #1 is shown in Figure 2.

There are 91 land holdings in the watercourse command area. The average holding size is about 4.5 acres, the largest holding size is 13 acres, and only 6 farmers own more than 8 acres of land on the watercourse.

The farmers indicated they needed to give 15% more irrigation water to their crops in order to adequately irrigate them. In response to a question regarding their use of a 50% increase in water supply, the replies were evenly divided between cropping more land, getting higher yields, and utilizing less tubewell water, with many farmers giving two of the responses.

The watercourse had been relatively well maintained and cleaned. Farmers often cleaned their branches before their irrigation turn began. Half of the time, two men were present during the irrigation, one of which was nearly always the cultivator, and much time was spent patrolling the watercourse checking for leaks. There were only 23 nuccas cut into the sarkari khal, or one for each square (land division containing about 25 acres) as was authorized in the original

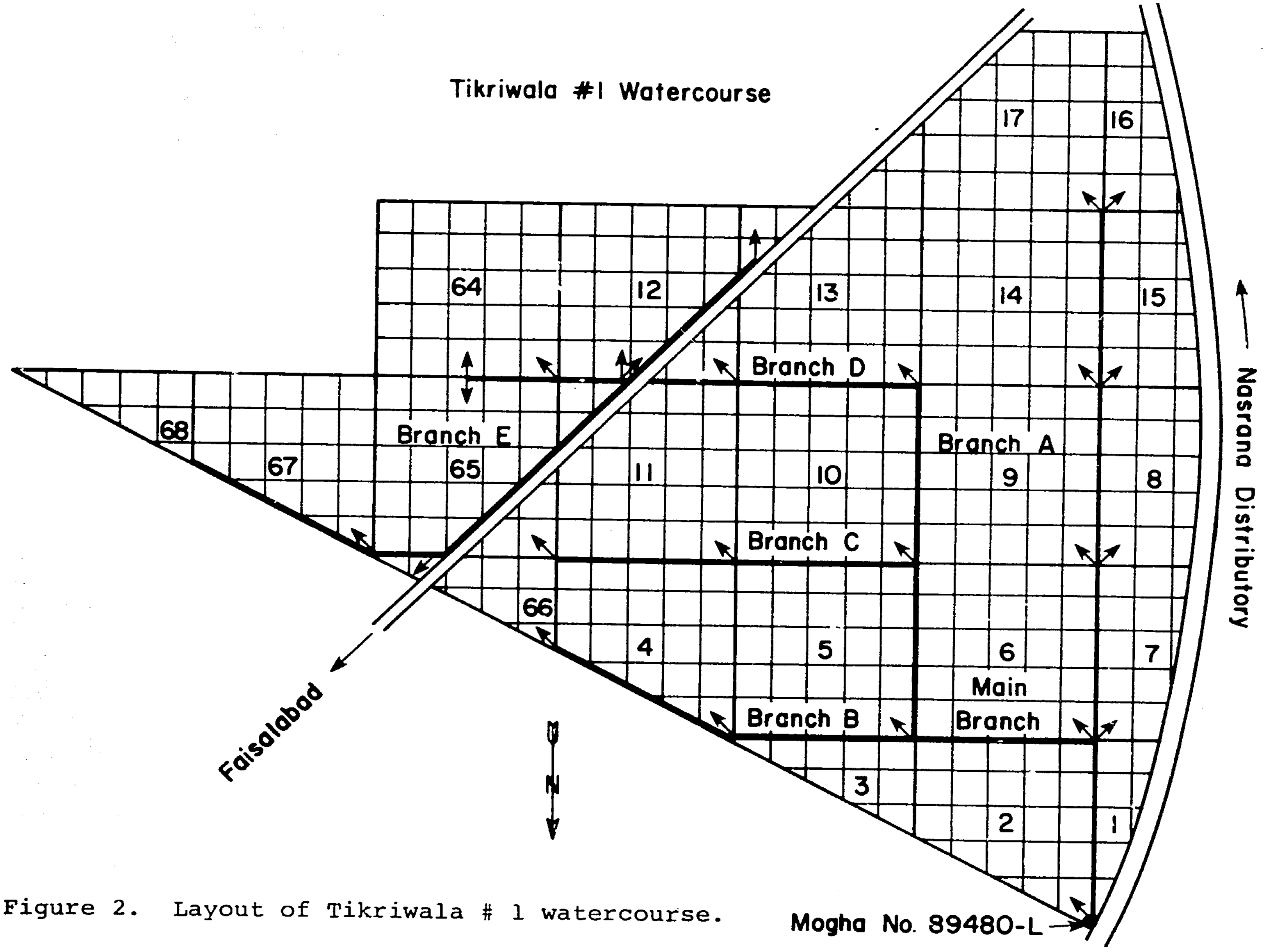


Figure 2. Layout of Tikriwala # 1 watercourse.

design. As a result sarkari khal leakage was reduced but longer farmer branches were required. Farmer branch banks were often very thin and freeboards were almost non-existent, the result of carving away the bank soil in order to enlarge the field sizes slightly. The farmers showed an interest in, and later did rebuild their sarkari khal sections on the design of the On-Farm Water Management Watercourse Improvement Program.

The watercourse was studied from March 21 to 28, 1977. Most of the sugar cane had been harvested, and fodder, wheat, and new sugar cane received most of the irrigation water.

PROCEDURE

(Only a summary of the experimental procedures will be given here. A more complete explanation is available in Trout et al. 1977.)

Flow rates were measured with Cutthroat flumes (Skogerboe et al. 1973) set at the watercourse head (below the mogha and public tubewell inflow), at the end of the sarkari khal section being utilized and upstream of the nucca through which water was flowing into the field being irrigated. The flumes were normally set before the water arrived and left in place until the flow ceased or a flume further downstream was set. In this way, all water which flowed during the week passed through three measurement flumes. Flume readings were normally taken at least every 10 minutes until the flow became steady, and then at least every 15 minutes. Times at which water entered fields or nuccas were opened or closed were recorded.

The flume flow rate data was graphed versus time, as is shown in Figure 3. The graphs were then integrated numerically (TW 81-R) or graphically with a planimeter (Tik #1) to determine the total volume of water passing each point in a given time.

Summing up the volume of water which entered the head of the watercourse, passed from the sarkari khal into the farmers' branches, and entered the fields, allowed a direct volumetric calcuation of the losses and conveyance efficiencies in each section of the watercourse.

Transient conveyance losses were defined as the difference between the losses which would have occurred had the system flowed constantly at steady state and the actual measured losses. They were calculated by taking the difference between the product of the steady state flow rate into a field and the rotation turn time utilized in irrigating that field, and the actual volume of water which entered the field. This calculation is shown graphically in Figure 4.

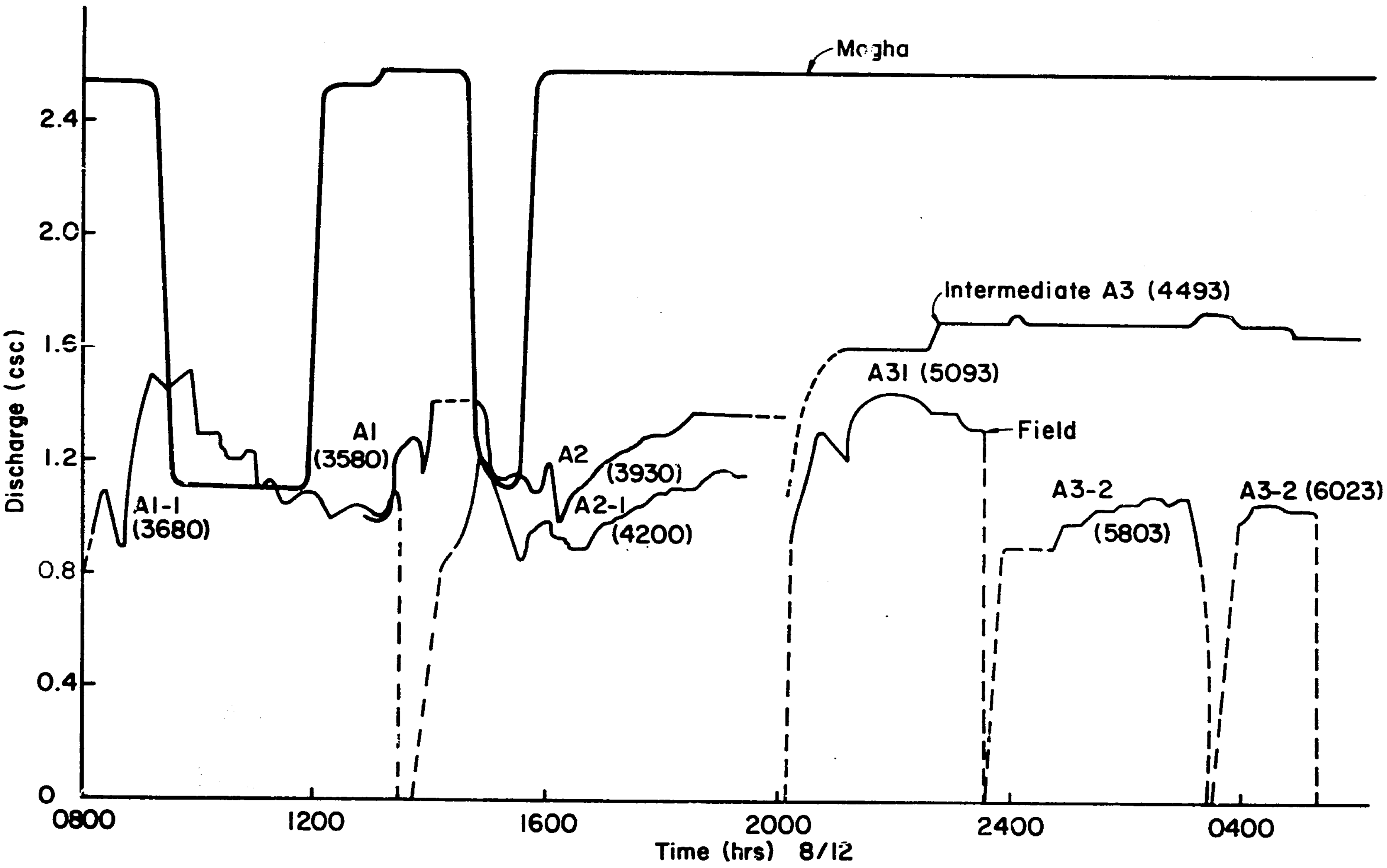


Figure 3. Discharge through the mogha, intermediate and field flumes over time.

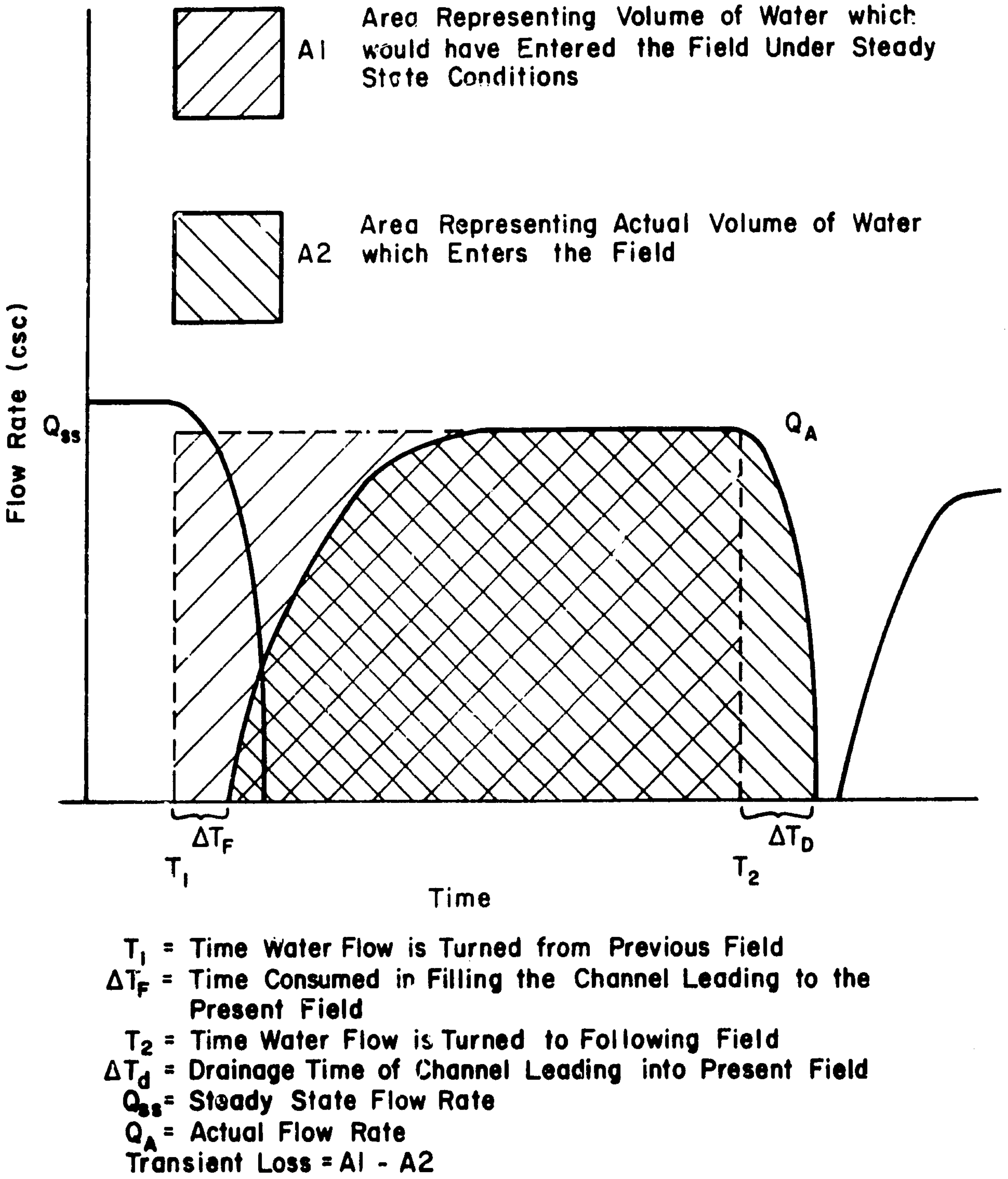


Figure 4. Graphical explanation of the transient loss calculation.

One type of transient loss, dead storage water which remains in the channel after a channel has ceased to be used, was physically measured (see Trout et al., 1977).

Leakage from the watercourses which was visible on the soil surface outside the watercourse was measured volumetrically on TW 81-R watercourse. Leakage through rodent and insect holes or leaky nuccas was collected in a container of known volume for a known period of time so that leakage rate could be determined. On Tikriwala #1 watercourse, visible leakage was small and was only estimated.

RESULTS

During the weeks when the two watercourses were studied, 44% and 63% of the inflow passed through the farmers' nuccas into their fields on Tubewell 81-R and Tikriwala #1 watercourse respectively. About half of their water resources was lost from the village level conveyance system. Table 1 summarized the volumetric inflows and outflows for the two systems.

Tikriwala watercourse is a more efficient water conveyor than TW 81-R, especially in the sarkari khal sections, where less than half as much of the inflow is lost. Both sets of farmers' branches leak badly, losing about 25% of their inflow per 1000 ft length.

More than twice as many farmers' branch channels were utilized to reach the 83 acres (150 bunded units) irrigated on Tikriwala watercourse, than was used to irrigate 56 acres (99 bunded units) at TW 81-R. However, the weighted average length from the mogha to the field was 5383 ft on TW 81-R and 4740 ft on Tik #1. In both cases, 80% of the watercourse usage was sarkari khal, or the average farmer utilized 4 times more sarkari khal than farmers' branch to get the water to his field.

On TW 81-R watercourse conveyance efficiency decreased by 5% (47% vs 42%) during the night. There was little difference at Tikriwala. This probably reflects the importance of the careful monitoring done by the Tikriwala farmers, especially during the night when darkness makes watercourse monitoring more difficult.

Steady State Losses

Table 2 summarizes steady state losses on the two watercourses.

TABLE 1. Conveyance efficiencies and losses, and channel usage on TW 81-R and Tikriwala #1 watercourses during the studied weeks.

	TW 81-R			Tik #1		
	Sarkari Khal	Farmers' Branches	To Fields (total)	Sarkari Khal	Farmers' Branches	To Fields (total)
Volume of Inflow (ac-ft)	34.81	21.98	15.45	20.23	16.97	12.83
Conveyance Efficiency (%)	63%	70%	44%	84%	76%	63%
Loss Volume (ac-ft)	12.83	6.55	19.38	3.26	4.14	7.40
Distribution of Losses (%)	66%	34%		44%	56%	
Length of Channels Utilized (ft)	11,000	26,000	37,000	16,000	55,000	71,000
Channel Usage (10^3 ft-hrs)	722.3	182.0	904.3	636.5	159.6	796.1
Distribution of Usage (%)	80%	20%		80%	20%	
Weighted Average Channel Length Utilized (ft)	4,300	1,083	5,383	3,790	950	4,740

TABLE 2. Steady state conveyance losses on Tubewell 81-R and Tikriwala #1 watercourses.

	TW 81-R	Tik #1
Total Steady State Losses (ac-ft)	16.95	5.71
Percent of Total Losses (%)	87	77
Weighted Average Steady State Loss Rate-Total (csc/1000 ft)	0.23	0.08
(% of section inflow/1000 ft)	8.8	5.9
Weighted Average Steady State Loss Rate-Sarkari Khal (csc/1000 ft)	0.20	0.06
(% of section inflow/1000ft)	7.7	3.8
Weighted Average Steady State Loss Rate-Farmers' Branches (csc/1000 ft)	0.31	0.17
(% of section inflow/1000 ft)	19.6	14.0

On both watercourses, the loss rates from the farmers' branches were much higher than from the sarkari khal. The farmers' branches lost one-fifth and one-seventh of their branch inflow per thousand feet on TW 81-R and Tik #1 watercourses respectively. On Tikriwala sarkari khal which was well maintained and had few nuccas, the steady state loss rate was only 0.06 csc/1000 ft. The ranges of values determined in these studies are consistent with steady state loss rates measured in previous studies (Ashraf et al., 1977).

The weighted average values given in Table 2 fail to indicate the wide variation in loss rates found on different branches of both watercourses. The variations have led to further studies to determine the factors which effect steady state loss rates. These studies, which will be detailed in another report in preparation by the authors, found that steady state loss rates:

1. increased when relatively higher fields were being irrigated

2. increased when inflow to a section increased

3. decreased farther from the mogha

The first two relationships are primarily a result of the extreme sensitivity of loss rates on the flow depth in a given channel (found from ponding loss measurements to be exponentially related). The third relationship may indicate that loss rate is related to flow rate.

One type of steady state loss which can be estimated is surface evaporation. The average potential evapotranspiration in the Mona area the first week of December is 0.63 inches/week (Reuss et al. 1976). The average channel top width on TW 81-R watercourse is 4.7 feet. If we assume free surface evaporation is about equal to potential evapotranspiration, then the evaporation rate would be 0.0004 csc/1000 ft. or about 0.2% of the average loss rate.

Pan evaporation at Faisalabad from March 21 to 28, 1974 was measured to be 1.63 inches. If we assume an average top width of 4 ft, the average surface evaporation rate was 0.0009 csc/1000 ft. or about 1.1% of the average loss rate. In both cases, the surface evaporation is a very small percentage of the conveyance losses and less than 0.3% of the watercourse inflow was evaporated from the surface of the conveyed water.

On TW 81-R watercourse, although on some sections there were many observable leaks where water passes through or over the banks and appeared on the adjoining field surface, the total volume of visible leakage was still not large. In one 200 foot section, 0.1 csc (0.5 csc/1000 ft) of water was volumetrically measured as it emerged from 20 visible leaks. About one-third of the adjoining field was flooded.

Most observed leaks were from about 0.4 inch diameter ant holes which leak about 0.001 csc each. These holes often interconnected inside the banks with major complexes of rodent burrows. About half of the total volume of visible leakage was through earthen nuccas which had not been adequately closed. Because these earthen bunds or checks are made from loose soil, a small leak through them will quickly wash out into a larger hole. One nucca leak of about 0.2 csc was observed. It was later closed by a farmer.

Total measured visible leakage from the sarkari khal sections varied up to 0.3 csc, depending upon the time measurement was made. From these measurements, it was estimated that about 1.00 ac-ft of water or 3% of the total inflow was lost through sarkari khal leaks which ran onto the surface of surrounding fields. Farmers' branch leakage was not measured. A total of one acre of land along the main channels was flooded by the leakage.

On the sarkari khal sections of the Tikriwala watercourse, very little leakage was passing through or over the channel banks and appearing in the fields. Only 14 small visible leaks were noted. They resulted in about 1400 square feet of standing water area. Crops were visibly damaged in about half of that wet area. Several farmers' branches were observed to leak badly through and over the thinly trimmed banks which had little freeboard. This leakage (which was not measured), because of its intermittent nature, seldom caused crop damage; but often was observed to wet fields which were in preparation and interfere with the cultivation process. It was estimated that about 0.1 ac-ft or 0.3% of the inflow was lost to visible leakage from the sarkari khal during the week.

The remaining steady state losses primarily infiltrate into the watercourse banks. The rate of this seepage can be calculated on a per unit area basis to make it comparable to field irrigation intake rates. The average wetted perimeter on the TW 81-R watercourse was 5.9 ft. and the average infiltration rate would be 0.75 in/hr. In both areas, the silty loam soils have a normal field soil intake rate of about 0.3 in/hr (Precision Land Leveling Project, 1974), so the watercourse wetted perimeters have infiltration rates 5 and 2 1/2 times larger than the infiltration rates of the surrounding fields. Since water will stand on the silt covered watercourse beds, which comprise perhaps 50% of the wetted perimeter, for several days, the infiltration rate into the banks must be as much as 10 times larger than the field intake rates. Actual calculations from ponding loss measurements have found average infiltration rates into the upper portion of some banks in the range of 12 to 15 inches per hour. Watercourse banks may be the most porous soils in all the Indus Basin.

Transient Losses

On the two studied watercourses, 7% and 8% of the inflow was lost to transient type losses. On TW 81-R watercourse where 7% of the inflow was lost to transient losses, 13% of the total operational losses were transient. On Tikriwala #1 watercourse, 8% of the inflow and 23% of the total operational losses were transient. This means that steady state type loss measurements would have measured losses to be 49% and 28% while true operational losses were 56% and 37% on the two watercourses. These preliminary findings indicate that steady state watercourse conveyance loss measurements should be adjusted upward by about 7 or 8 percentage points to estimate operational conditions. It should be noted that the transient losses tended to vary with the inflow rate rather than with the total losses.

Transient losses varied with feet of channel filled or drained. Multiple linear regressions were run between transient loss volume, length of channel filled and length of channel drained. The regression equation for TW 81-R watercourse, run on a per holding basis, was:

$$\text{Transient Loss } (\text{ft}^3) = -530 + 3.29\,(L_w) - 1.12(L_d)$$

$r^2 = .58$

Where L_w = length of channel wetted (ft)
L_d = length of channel drained (ft)
r^2 = coefficient of determination

The equation for Tikriwala #1 watercourse, which was run on an individual field basis (similar results were found when holding basis was used) was:

$$\text{Transient Loss } (ft^3) = 110 + 1.51 (L_w) - 0.67(L_d)$$
$$r^2 = .52$$

Over half the variation in transient losses can be explained by the length of channel wetted and drained. Other important factors would include steady state loss rates, previous wettness of the channels, and remaining dead storage. On the two studied watercourses, transiet loss can be predicted on a per unit inflow basis by:

$$\frac{\text{Transient Loss } (ft^3)}{\text{Inflow Rate (csc)}} = 1.14(L_w) - .43(L_d) + 17$$
$$r^2 = .58$$

From this equation, it can be predicted that a farmer on a watercourse which has a 2 csc inflow will, by irrigating a field which requires him to fill and drain 800 feet of channel, have 1220 ft^3 (0.3 ac-in) of transient loss. If a 2 inch irrigation is given on a 1/2 acre field, 30% of the inflow will be lost to transient conditions. If a trade is made and 2000 feet of channel is filled, while 1000 feet is drained, 3700 ft^3 (1 ac-in) of extra water is lost. On TW 81-R watercourse, one farmer traded water which involved filling and draining 3600 feet of extra channel. He irrigated 2 1/2 acres of his land and lost 3.2 ac-in of water to transient losses. This is greater than predicted value because of excessive dead storage in the channels drained. On Tirkiwala #1 watercourse, only trades between neighboring farmers were made.

A special type of transient loss of concern to the farmers is the filling of the sarkari khal. The first farmer to irrigate from a sarkari khal nucca is forced to fill the upstream section but has no chance to drain it. Consequently, time allowance is made on the warabundi timings for this filling process. On TW 81-R watercourse, about 15 minutes/1000 ft filling time was allowed. However, the farmers lost the equivalent of 45 minutes worth of water in filling 1000 feet of sarkari khal, and so were losing 30 minutes worth of their irrigation water. On Tikriwala, the time allowance is 25 minutes per 1000 feet, and the actual time requirement was 25 minutes, so the allotment was correct.

Likewise, the last farmer to irrigate on a major branch will drain the sarkari khal filled by the previous farmers, so time is normally subtracted from this turn to allow for this. On TW 81-R, no time was deducted from the farmer who drained 4000 foot Branch A, but he gained the equivalent of 2 hours worth of water. On 7000 foot Branch B and main, 27 minutes was deducted from the last farmer's time, and he also drained the equivalent of 2 hours worth of water after his turn ended and the flow had been diverted upstream. On Tikriwala #1 watercourse, the drainage allotment was again accurate with 15 minutes per 1000 ft of time deducted and about 15 minutes worth of water gained per 1000 ft drained. Over or under estimates of sarkari khal filling and draining time allowances lead to an inequitable water distribution between farmers.

Twenty-four percent of the transient losses on TW 81-R watercourse and 16% of the transient losses on Tikriwala #1 watercourse occurred in the sarkari khal. This indicates that the transient losses on a length basis are larger on the farmers' branches by 20 to 40%, possibly because of the larger amount of dead storage and higher steady state loss rates found there.

Of the several types of transient losses, dead storage water left lying in the watercourse after a branch has been drained is the easiest to measure. This water is a result of channel bottoms lying below the level of the last field irrigated, or by a channel which has an uneven bottom. Total dead storage water was measured in both watercourses. A summary of the findings are given in Table 3.

TABLE 3. Dead storage losses on TW 81-R and Tikriwala #1 watercourses.

	TW 81-R	Tikriwala #1
Total Dead Storage (ac-ft)	1.06	1.04
Total Channel Drained (ft)	41,000	71,000
Dead Storage/ft (ft^3/ft)	1.1	0.8
% of Dead Storage in Sarkari Khal (%)	32	10
Dead Storage/Inflow (%)	3	5
Dead Storage/Losses (%)	5	14
Dead Storage/Transient Losses (%)	43	62

Dead storage accounted for about half of the transient losses, but only about 3-5% of the lost inflow.

A second type of transient loss which can be roughly estimated, is the high infiltration rate involved in wetting dry banks. A mass balance equation (Trout et al., 1977) was used to estimate the average infiltration rate during channel filling. When it was applied to several sections of TW 81-R watercourse, it was concluded that the average infiltration rate into watercourses being filled must be greater than the steady state infiltration rate by a factor of about two.

Transient losses resulting from temporary major breaks through watercourse banks or bunds were recorded on both watercourses. On TW 81-R, nucca breaks leaking 0.1-0.2 csc were observed. One or possibly two cases of intentional (maliciously so) leaks were observed. All were eventually closed. Such major leaks on Tikriwala watercourses were few and were repaired quickly because of the constant monitoring by the irrigator.

DISCUSSION OF THE FINDINGS

The operational loss determinations described in this report were the most thorough watercourse conveyance loss measurements yet tried in Pakistan. They involved 5000 readings from 140 measurement flume settings by 25 people including 12 engineers.

The accuracy of the results depends of course upon the precision of the measuring devices and the care with which they were used. Generally, Cutthroat flumes under field conditions measure correct flow to within $\underline{+}5\%$, if installed correctly. Assuming errors are random and normally distributed, the accuracy of the total loss figure should be within 1% (Trout et al., 1977).

One factor in flow rate measurement which is not randomly distributed is the induced losses resulting from flume installations. Measurement flumes create an elevation drop (head loss) in the water surface which forces the depth of flow upstream of the flume to increase, and, as previously stated, losses increase in watercourses as flow depths increase. The head loss in the flume normally varies between 0.1 and 0.3 ft. The induced losses depend upon the channel hydraulic characteristics, slope, and the dependence of losses on flow depth. A theoretical analysis of TW 81-R, assuming all flumes were set at an average head loss of 0.2 ft, estimated that the real steady state loss rates would have been increased by about 25% by the flume (Trout et al., 1977), or that real loss rates were 20% less than measured. Since 87% of the measured losses were steady state, the induced loss could be 10% of the inflow and real conveyance losses, 46% instead of 56%. However, a regression analysis of section length and flume head loss with loss rates indicated that loss rates decreased as flume head loss increased, contradicting the above analysis. This seeming contradiction was caused by the fact that in sections where slopes were small and channels were in poor condition, the engineers set the flumes with the least head loss and thus minimized the flume induced losses.

On Tikriwala #1 watercourse where the average slope was larger, and steady state losses were a smaller percentage of operational losses, the flume induced losses will be less. The author estimates that on both watercourses, the presence of the measurement flumes have increased real losses by three to six percentage points.

The flume induced losses will be greater in shorter sections (such as farmers' branches and fields near the mogha) flat sections (such as in channels serving high fields) and in undersized channels (such as farmers' branches).

Regardless of the adjustments, the watercourse conveyance losses are still large, and these findings support the previously referenced studies. In fact, these findings indicate that previous steady state measurements have underestimated total operational losses by 7 or 8 percentage points.

Watercourse conveyance losses are much higher than the 10% proposed in several planning reports in the 1960's (MacDonald & Partners, 1966; Gibb & Partners, 1966; Tipton and Kalmback, 1967; Lieftnick et al., 1967) upon which much of the present water resource planning is based. Planners must take into consideration that nearly 50% of the water supplied at the mogha, or about 40% of the total water diverted or pumped into the irrigation system is being lost in the watercourse system. Saving just half of this loss would provide an additional 25 million acre feet of water to the fields of Pakistan.

Not only is total losses a problem, but the distribution of these losses causes inequities in the water availability between farmers. On watercourses where steady state sarkari khal losses are high, farmers at the tail of the watercourse will get less than half as much of their valuable water resource input as those at the head. On TW 81-R watercourse, tail farmers were getting about 25% as much water as head farmers.

Once a problem is identified, and its magnitude determined, it must be studied further to determine the components and causes so that solutions can be proposed. That was the third objective of this study.

First, it was determined that if conveyance losses could be reduced to normal wetted perimeter infiltration (at the same rate as water infiltrates into surrounding fields) plus water surface evaporation, plus the infiltration into the dry banks and seepage during filling and draining processes, the conveyance losses could be reduced to about 15% of the inflow. In fact, steady state infiltration should be reducible to less than field intake rates as a result of silt deposition on the channel bed. This would not involve any physical reordering of the watercourse system, or expensive channel linings; only earthen design improvements to bring the system up to its potential.

Losses could then be further reduced without lining by reordering the field and watercourse layout. Fields could be irrigated in long (660-1100 ft) border strips, and the average length of farmers' branch required to reach the field could be reduced from about 1000 ft to less than 500 feet, reducing channel wetted and potential steady state infiltration by about 10%, and transient losses by 50%, making a 90% watercourse conveyance efficiency feasible.

Although these are attainable levels, more realistic estimates of conveyance efficiencies which can be maintained in a well designed village conveyance system are probably about 75-80%. But even at these levels, half of the present losses will be saved.

It has often been questioned whether the water could not be more effectively utilized if it were available to the farmers on demand. This is the way irrigation systems are operated in most western countries. When a farmer needs water, he informs the controller of the distributary outlet gate who adjusts the watercourse inflow accordingly. This system allows for higher application efficiencies and cropping intensities, since the water is available in the desired amounts when required. But in such a large integrated irrigation system built on a large, flat plain, where lag times between request and response must be large, operation of such a system on a macro scale would be difficult if not impossible. It would be feasible only if demand within a canal commanded area could be relatively distributed over time, which would return the system essentially to its present constant flow state.

It is possible that a partial demand system could be tried on the watercourse level, involving not necessarily rate of flow but at least the timing of deliveries. This system is being practiced on a local level by farmers who trade water with one another as their relative needs vary. Trading of water between neighbors was a common occurrence on Tikriwala #1 watercourse where holdings and irrigation timings were small.

But, the warabundi system presently in practice is the most efficient method of moving water through the present watercourse system. It involves filling and draining the least amount of channel possible, and any deviation from it will increase transient losses. There is a trade-off involved, between application losses and conveyance losses, and trials should be made to determine practicable alternatives and the corresponding total losses.

Perhaps the most practical solution is to legalize trading of water between farmers within the same area or whose turns falls sequentially in the warabundi, so that a minimum of extra channel is filled or drained. When trades are made between distant fields, transient losses are high.

Of course, if watercourses are improved and fields are reorganized to permit less field channel utilization, the costs of such water movement is greatly reduced. If sarkari khal channels were lined and fields reorganized, the extra transient losses created in a full trading system would be minimal.

The other condition under which a local partial demand system is practical is where there is a locally controllable water supply, such as a public tubewell. If the tubewell could be operated on the farmers' demands, up to a limited total number of hours in a given period of time, it would add much greater flexibility to the system. The private tubewells on Tikriwala #1 watercourse are used effectively on the farmers' requests, making a proportionately greater supply of water available when it is needed most.

A decision that will have to be made in any watercourse conveyance loss reduction program is, how much of the system should be improved. Costs are based on feet of channel improved, but benefits are based upon the hours of usage of the channels. As improvement is taken farther from the head, the usage decreases and the footage increases. There are more than six times more farmers' branches on both studied watercourses than sarkari khal. However, 80% of the usage is in the sarkari khal. This means that if loss rates were the same in both sections, the payoffs in the sarkari khal would be 30 times greater. On the other hand, operational loss rates are higher in the farmers' branches by 2 times on TW 81-R and 5 times on Tikriwala #1 watercourse, and this loss rate will increase after sarkari khal improvements when inflows to the branches will increase. Although the payoff will still be larger within the sarkari khal, total delivery efficiency achievable will be reduced from nearly 85% to perhaps 75%, and a 50% loss reduction in the sarkari khal might lead to only a 25% overall conveyance loss reduction.

Although as thorough of improvement program probably need not be undertaken in the farmers' branches as is proposed in the sarkari khal, some improvement, such as enlarging the flow cross section and strengthening the banks, must be made if the benefits of watercourse improvements are to be fully realized.

SUMMARY

Figures 5 and 6 are flow charts depicting where the water went that flowed into the two watercourses during the weeks they were studied. The data is not necessarily representative of all Punjab watercourses, but the varying conditions found on the two do indicate that concurrence between them should be generalizable. Further operational loss studies which are planned, will support or contradict these initial findings.

CONCLUSIONS

1. These studies concur with past measurements that indicate that watercourse steady state conveyance losses in the Punjab are in the range of 30 to 50%.
2. Transient losses are about 8% of the inflow, and steady state loss measurements should be increased by about 8 percentage points to reflect operational conditions.
3. Loss rates in the farmers' branches are much higher than in the sarkari khal.
4. Measurement flumes may cause 3 to 6% of additional induced losses.
5. Transient losses can be predicted by:

$$\frac{\text{Transient loss (ft}^3\text{)}}{\text{Watercourse Inflow (csc)}} = 1.14 \times \text{length of channel wetted (ft)} - 0.43 \times \text{length drained (ft)}$$

6. About half of the transient losses are dead storage.
7. If losses could be reduced to normal channel wetted perimeter infiltration rates, conveyance losses could be reduced to about 15%.

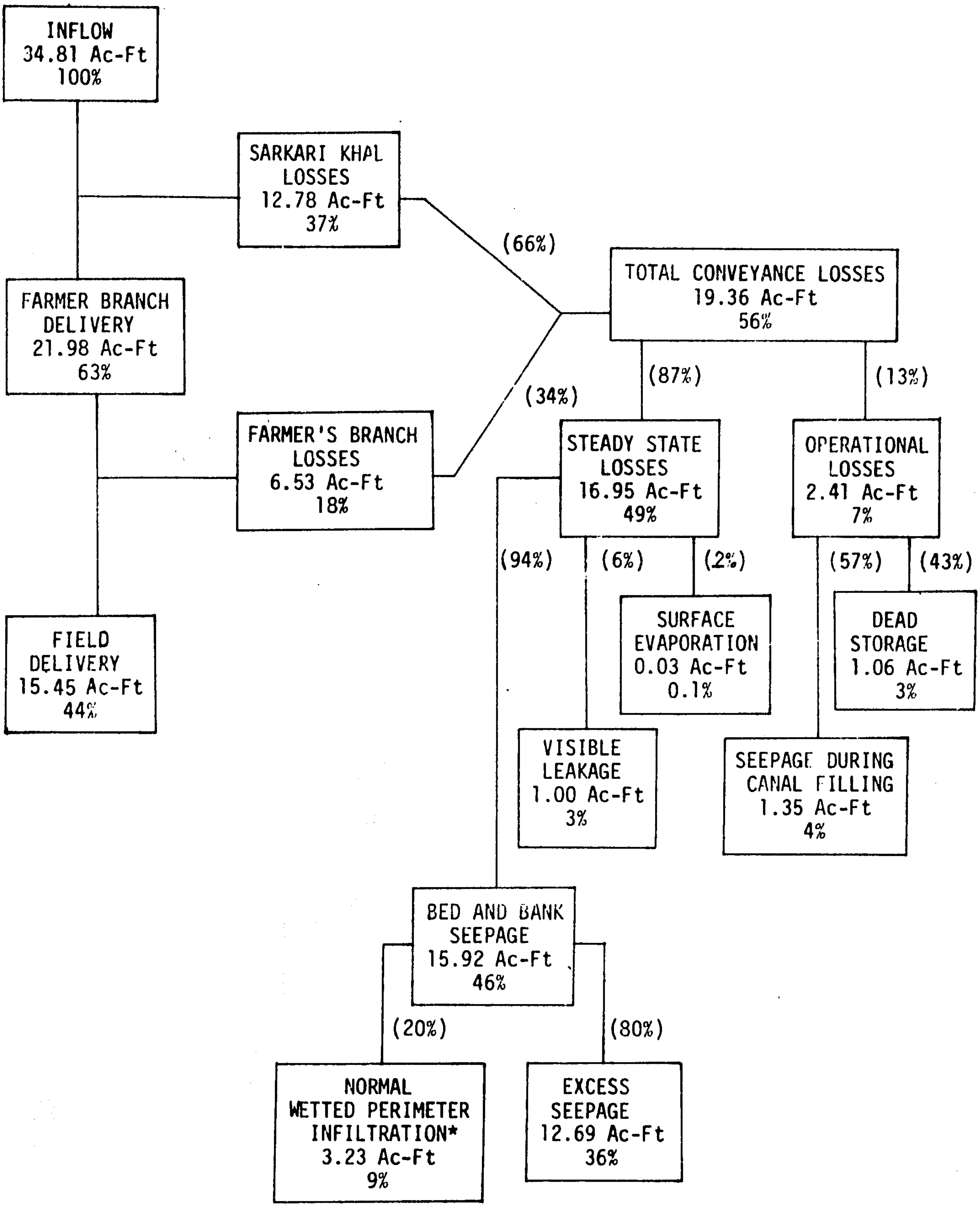


FIGURE 5. Flow chart depicting water movement out of the TW 81-R watercourse.

*Assuming a normal field soil intake rate of 0.3 in/hr (Precision Land Leveling Project "Irrigation Guide," 1974).

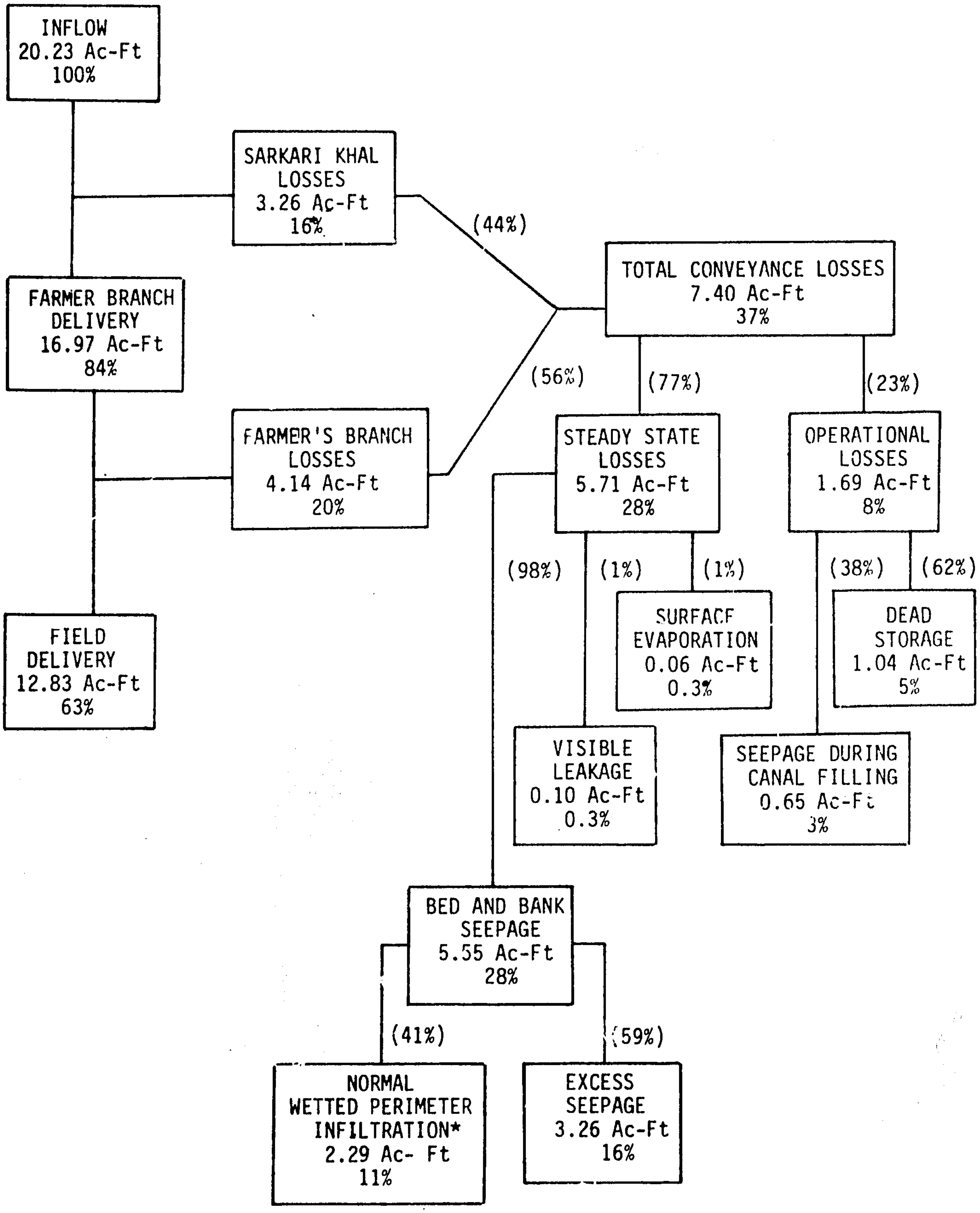


FIGURE 6. Flow chart depicting water movement out of the Trikriwala #1 watercourse.

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APPENDIX 13

SIMPLIFIED DESIGN OF EARTHEN WATERCOURSE IMPROVEMENTS[1]

by
A. C. Early, W. K. Twitty and Hayatullah Khan[2]

I. Introduction

The objective of this paper is an attempt to simplify the design of watercourse improvements to the most basic elements. A discussion of the iterative procedure utilizing Manning's equation and the design charts is presented followed by a detailed outline of the field information required before the design is undertaken. A detailed design procedure is outlined and accompanied by the necessary charts for design using roughness coefficient n=0.04 and side slopes of 1:1 and 1.5 to 1.0 (horizontal to vertical) of an assumed trapezoidal channel cross section. These two combinations of roughness and side slope will potentially cover the major possibilities for watercourses that require renovation in Pakistan. These combinations assume earthen improvements and the current level of watercourse maintenance and the current state of nakka design and construction technology.

Given the generally flat slopes of the land encountered in Pakistan and the poorly structured soils it has been assumed that the range of slopes encountered in watercourse design will be 0.0001 to 0.0030 and that the range of velocities from the minimum necessary to prevent the deposition of silt to the maximum necessary to prevent erosion in the channel to be from 0.15 to 0.45 meters/sec. respectively. The number of cases in which these two upper limits will be approached will be minimal; the lower limits will be encountered frequently. Charts for the head loss through various orifices with common available diameters in Pakistan are borrowed from "Aids for Watercourse Design and Improvement," July 1976 edition.

The overall approach of this design procedure is a backward plotting of the design water surface elevation from

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the highest field at the tail branch section (farthest from mogha) through each main watercourse section and progressively through an encountered branch section ending at the mogha. The formats for the required data sheets are provided in the text. This paper will conclude with a sample watercourse design, which is part of an actual watercourse encountered near Lyallpur.

Guidelines and a simple pocket calculator program are presented for the determination of the most efficient hydraulic section. The condition for the most efficient cross section is that the bed width is approximately 8/10 of the depth of flow for 1:1 side slopes. This program can be effectively used by the supervisory personnel who will check the watercourse designs.

II. Manning's Equation, Assumptions of Design, Design Charts and the General Procedure

In 1889 the Irish Engineer Robert Manning presented a formula for uniform flow in an open channel based on several previous formulas and incorporating an empirical coefficient n based on the roughness of the channel, and termed Manning's n.

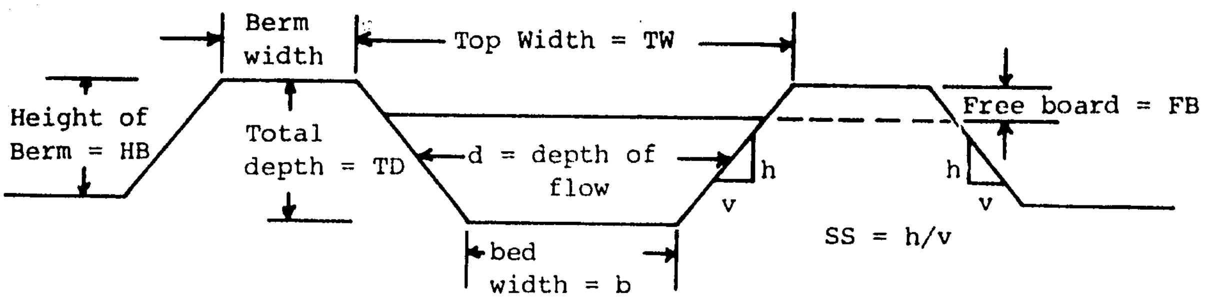
Manning's equation expressed in metric units is $V = \frac{R^{2/3} S^{1/2}}{n}$, where V = Velocity meters per second, R = Hydraulic radius in meters, S = Slope in meters height/meters length.

The hydraulic radius is defined as $R = \frac{A}{W_p}$ where A is cross-sectional area of flow in square meters, W_p is wetted perimeter in meter length.

The cross-sectional area of flow is $A = bd + zd^2$ where b is bed width in meters, d is depth of flow in meters, SS is ratio of horizontal to vertical in side slope (SS = 1 if side slopes are 1:1, SS = 1.5 if side slopes are 1.5:1.0).

The wetted perimeter is calculated as $WP = b + 2d \sqrt{SS^2 + 1}$ for SS = 1, $WP = b + 2d \sqrt{2}$ for SS = 1.5, $WP = b + \sqrt{13d}$

The following sketch illustrates the important x-sectional parameters.



The total depth is: $TD = d + FB$

The top width is: $TW = b + 2SS\ (d + FB)$

The Berme width: $BW = \frac{5-b - 2SS\ (d + FB) - 2SS\ (HB)}{2} \geq .3$

Where HB is the height of the Berme above the field level. The assumptions used in this design procedure are as follows:

ROUGHNESS FACTOR: $n = 0.04$

SIDESLOPES: SS = 1:1 or SS = 1.5:1.0

FREEBOARD MAIN WATERCOURSE: FBM = .24 meter

FREEBOARD BRANCH WATERCOURSE: FBB = .15 meter

WORKING HEAD RANGE: WH = 0.075 to 0.150 meter

VELOCITY RANGE: V = 0.15 to 0.45 meters/second

MINIMUM BERME WIDTH: BW = 0.30 meter

MAXIMUM RIGHT OF WAY: ROW = 5 meters

The general procedure is a backwards iteration of determining water surfaces from the nakka of highest field served in each branch section of watercourse back to the mogha. The general procedure is:

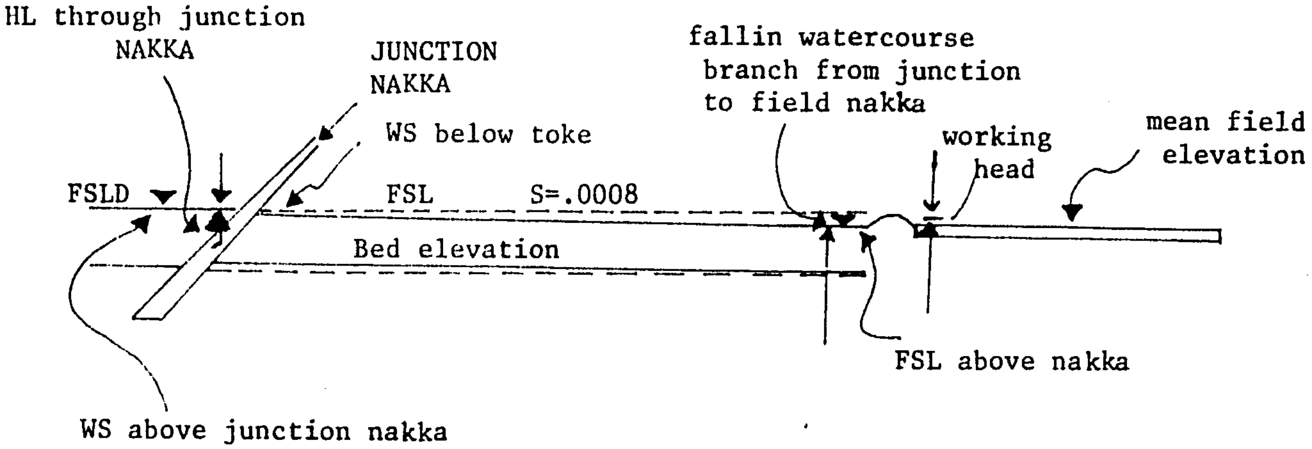
a. Determine elevation of the highest field and distance from the field nakka to the junction nakka.

b. Add working head to get water surface elevation at highest field.

c. Determine fall in watercourse branch from the junction to highest field as the head utilized; add to previous water surface elevation to obtain the water surface elevation at head of branch.

d. Determine head loss through structure and add to water surface elevation to get new water surface elevation above the structure.

The following sketch indicates the major elements of a junction to field design problem.



A careful specification of the water surface elevation throughout the system is the essence of the design procedure.

Generalized step (c) above is the most complicated of the procedure. It is a process of fitting a decline in the water surface profile over the section in question. Given the bed width in common usage, the discharge Q to be carried, and the head required at the nakka of the field, one must choose a slope and read the corresponding velocity and depth of flow for the channel configuration. Generally, one can estimate the head available to be used as fall in the watercourse from the difference in water surface elevations previously determined at some control point upstream as a junction, or a culvert, or the mogha itself. This head available in meters divided by the length of branch being designed in meters provides the approximate slope to be utilized in the chart. Consider Figure 1, a portion of which is sketched below. On the vertical axis is the discharge Q in cubic meters per second called mu secs. On the horizontal axis is the slope in meters per meters.

The chart contains two sets of sloping curves, one set upward to the right and one set upward to the left. The set that slopes up to the right start at the origin of the axis and are the depth of flow curves for that combination of channel cross-section geometry, roughness factor, discharge and slope. Any point on the chart is a solution to Manning's Equation. A point at the intersection of a given Q, discharge (horizontal line) and a given S, slope (vertical line) is the solution for Manning's equation when read (interpolated) with respect to the depth curves.

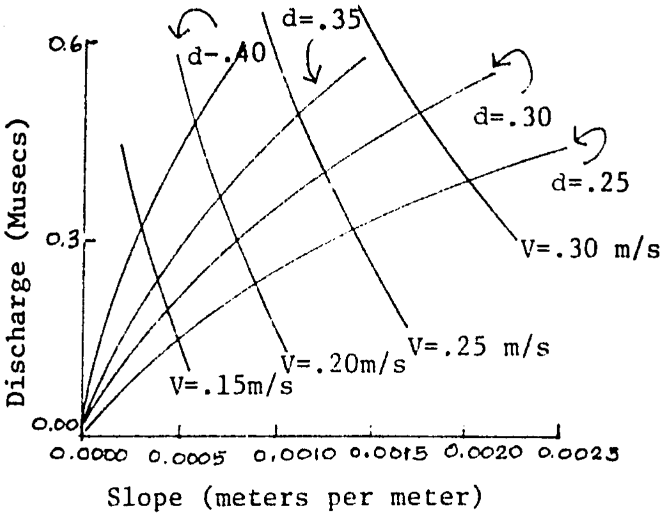


Figure 1. Partial solutions to Manning's Equation for bed width b=0.30, n=0.04, SS=1.0

The curves that slope upward to the left are the corresponding velocity curves. The velocity is kept between the minimum 0.15 meters per second to prevent silt deposition and the maximum 0.45 meters per second to prevent channel scouring or erosion.

The available curves are for bed width from b = 0.30 to b = 0.60 meters in increments of 0.05 meters. Figures 1 through 7 are for roughness factor n - 0.04 and trapezoidal cross-section with 1:1 side slopes, with respective bed widths. Figure 8 is for roughness factor n = 0.04 and trapezoidal section with 1.5:1.0 side slopes.

III. Field Information Required for Design

The following is a check list of field information required for designs.

A. AUTHORIZED FLOW RATE AT MOGHA. FULLY SUPPLY ELEVATION AT MOGHA AND BED ELEVATION AT MOGHA.

B. CROSS COMMAND AREA AND CULTURABLE COMMAND AREA OF WATERCOURSE.

C. WATERCOURSE LAYOUT MAP.

D. BUNDED IRRIGATION UNIT MAP WITH FIELD NAKKAS AND ALL WATERCOURSE BRANCHES.

E. MAIN WATERCOURSE PROFILE INCLUDING WATER SURFACE ELEVATION ON DOWNSTREAM SIDE OF MOGHA.

F. FIELD ELEVATION PROFILE ON BOTH SIDES OF MAIN WATERCOURSE.

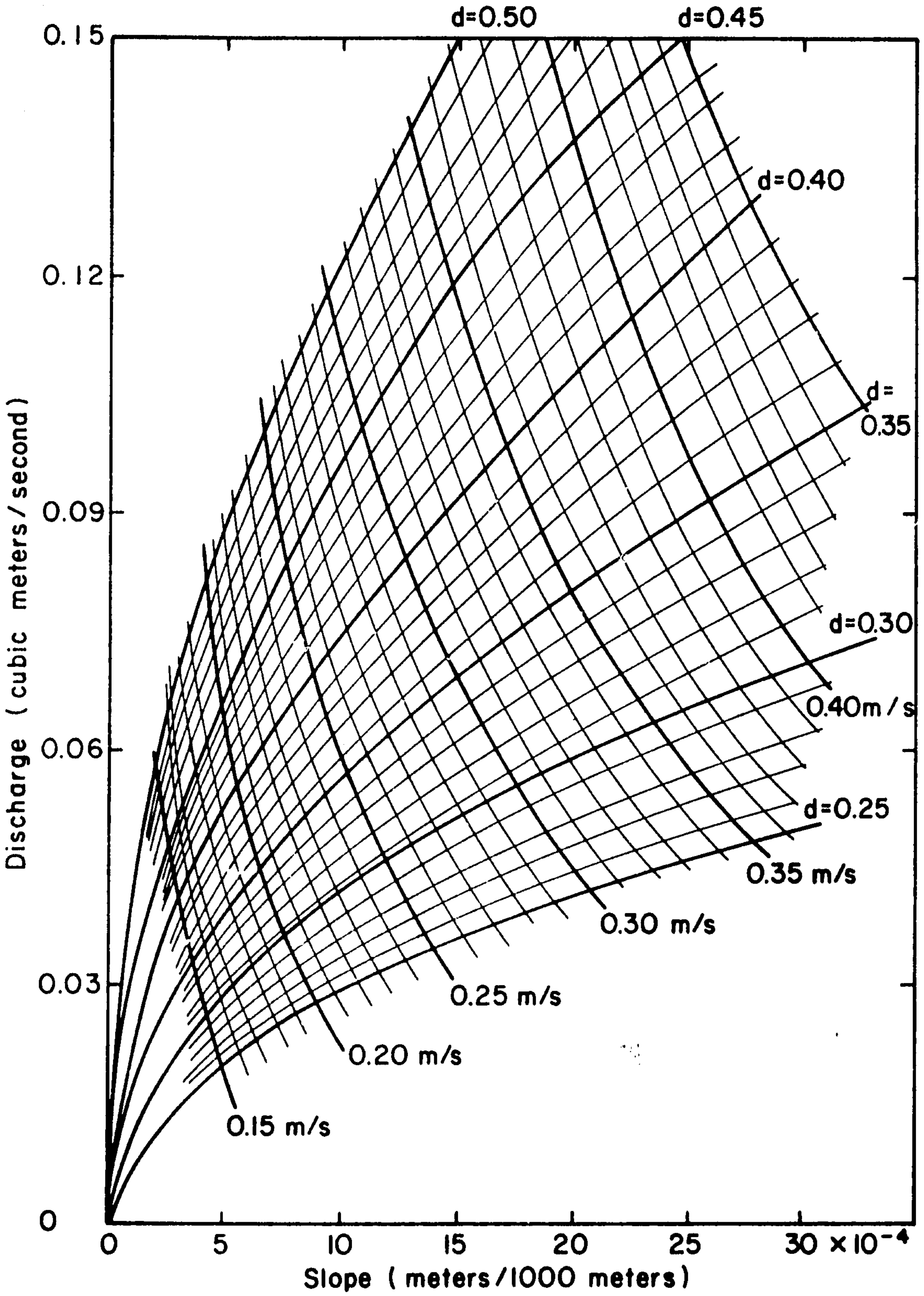


Figure 1. Solutions to Manning's Equation for bed width b = 0.30 meters and roughness n = 0.04.

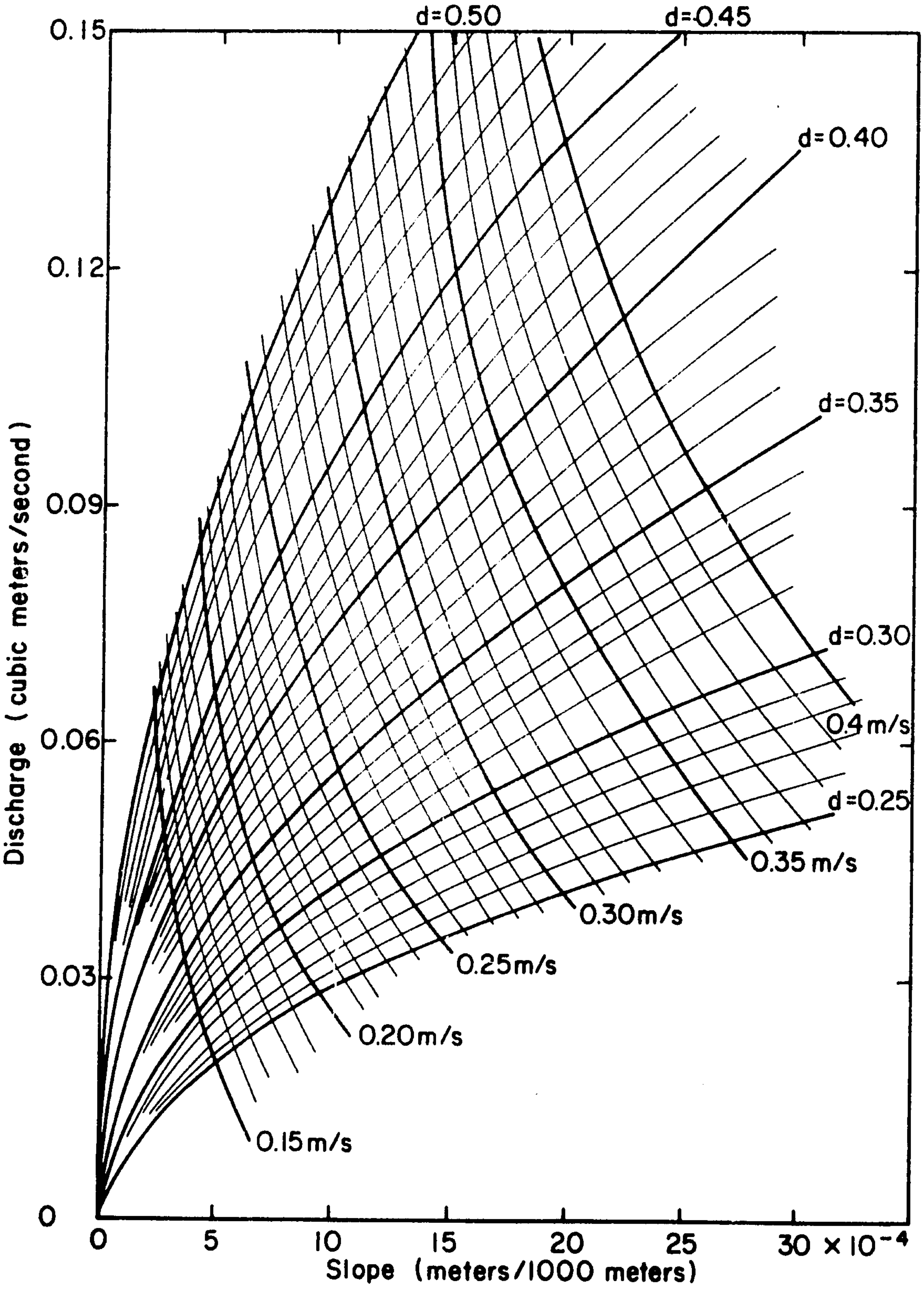


Figure 2. Solutions to Mannings' Equations for bed width b = 0.35 meter and roughness n = 0.04.

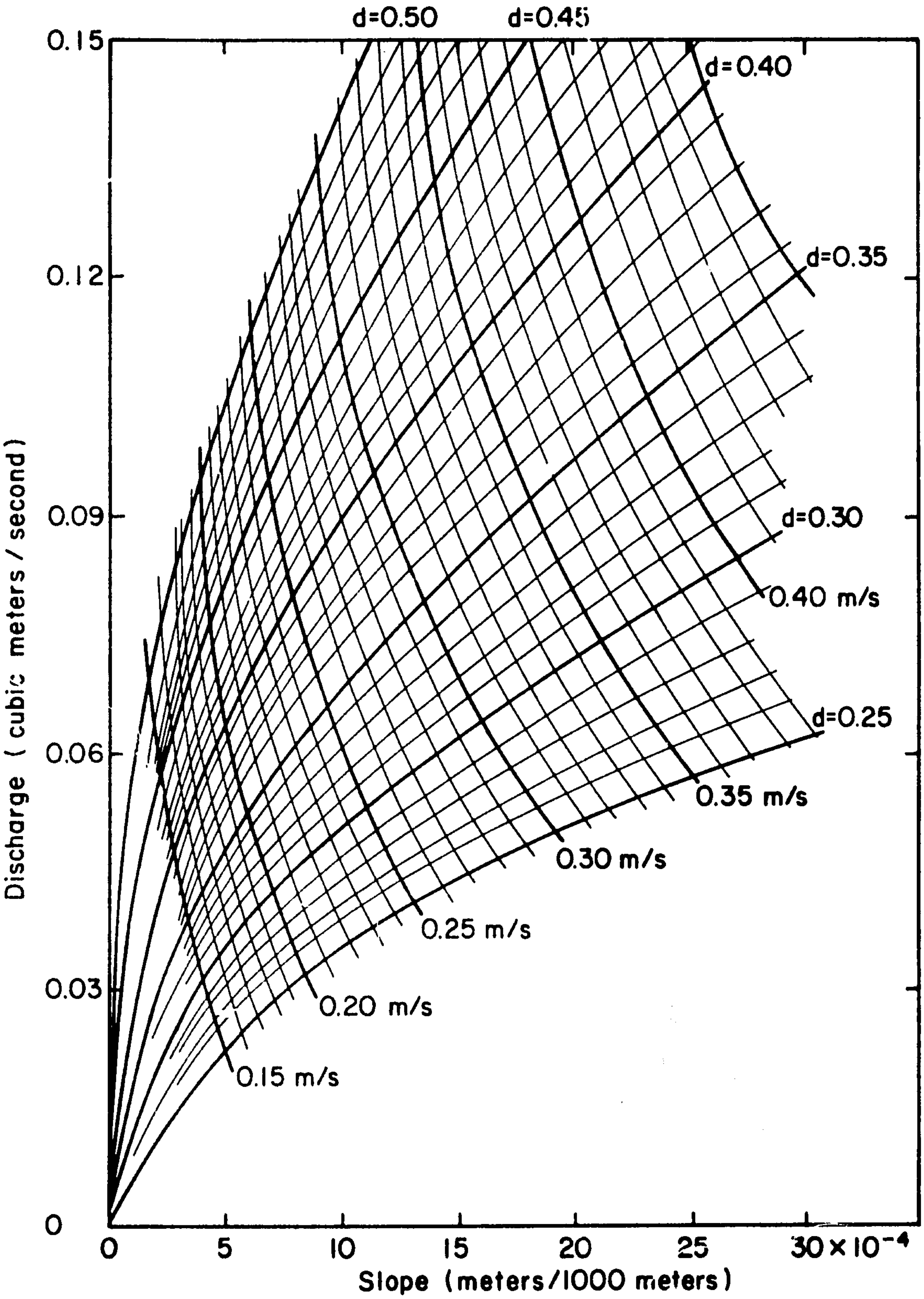


Figure 3. Solutions to Manning's Equation for bed width b = 0.40 meters and roughness n = 0.04.

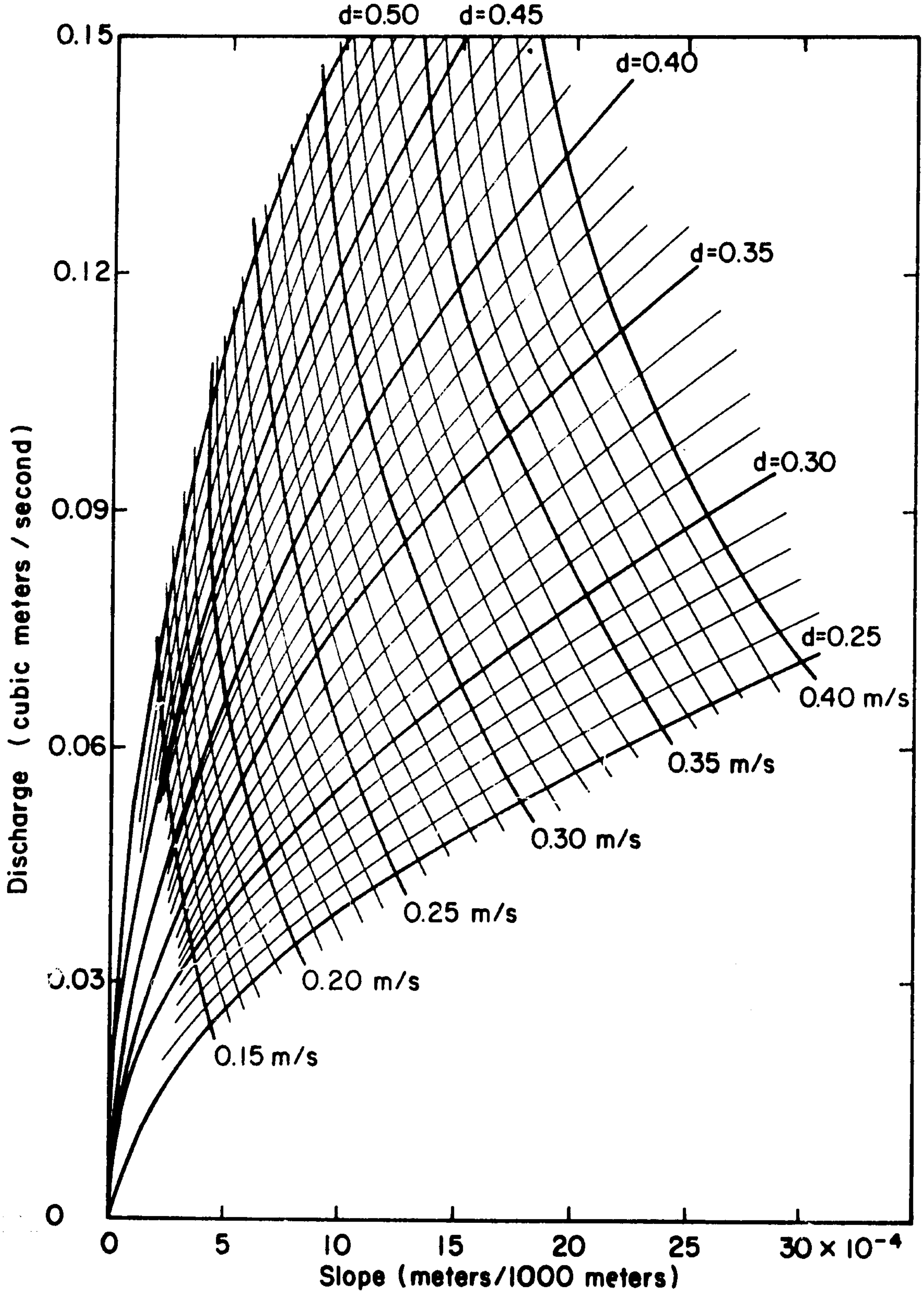


Figure 4. Solutions to Manning's Equation for bed width b = 0.45 meter and roughness n = 0.04.

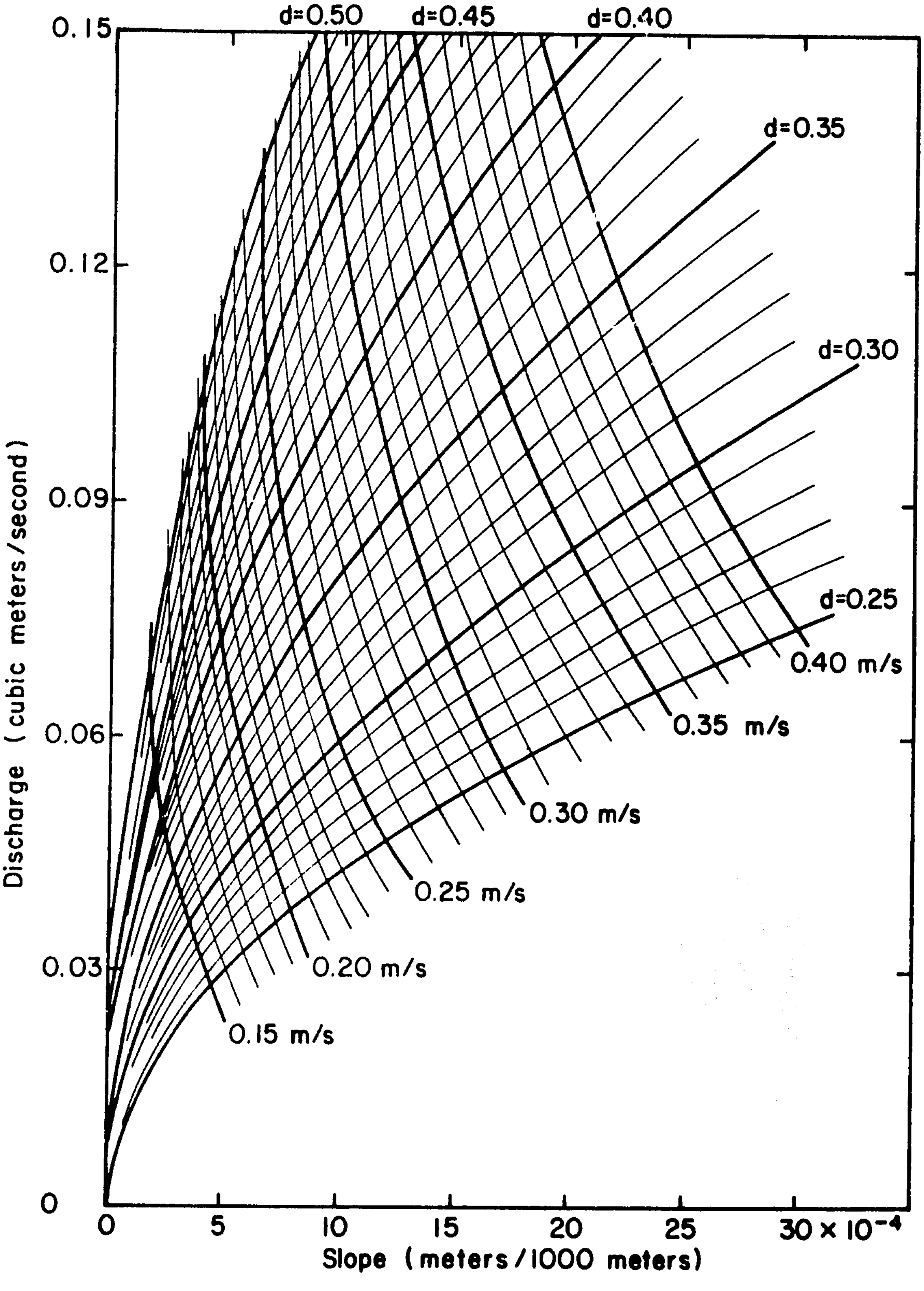


Figure 5. Solutions to Mannings' Equation for bed width b = 0.50 meters and roughness n = 0.04.

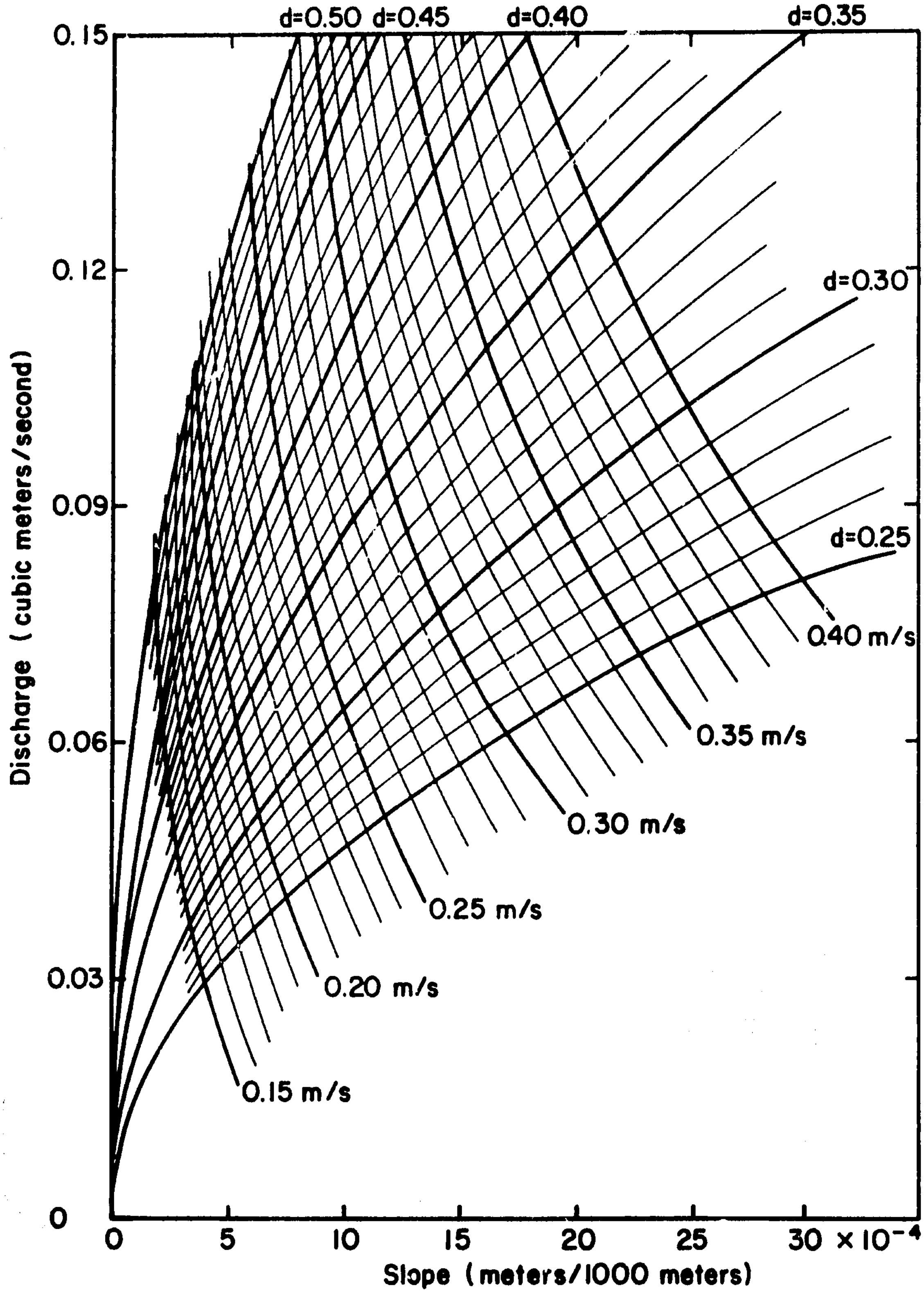


Figure 6. Solutions to Manning's Equation for bed width b = 0.55 meters and roughness n = 0.04.

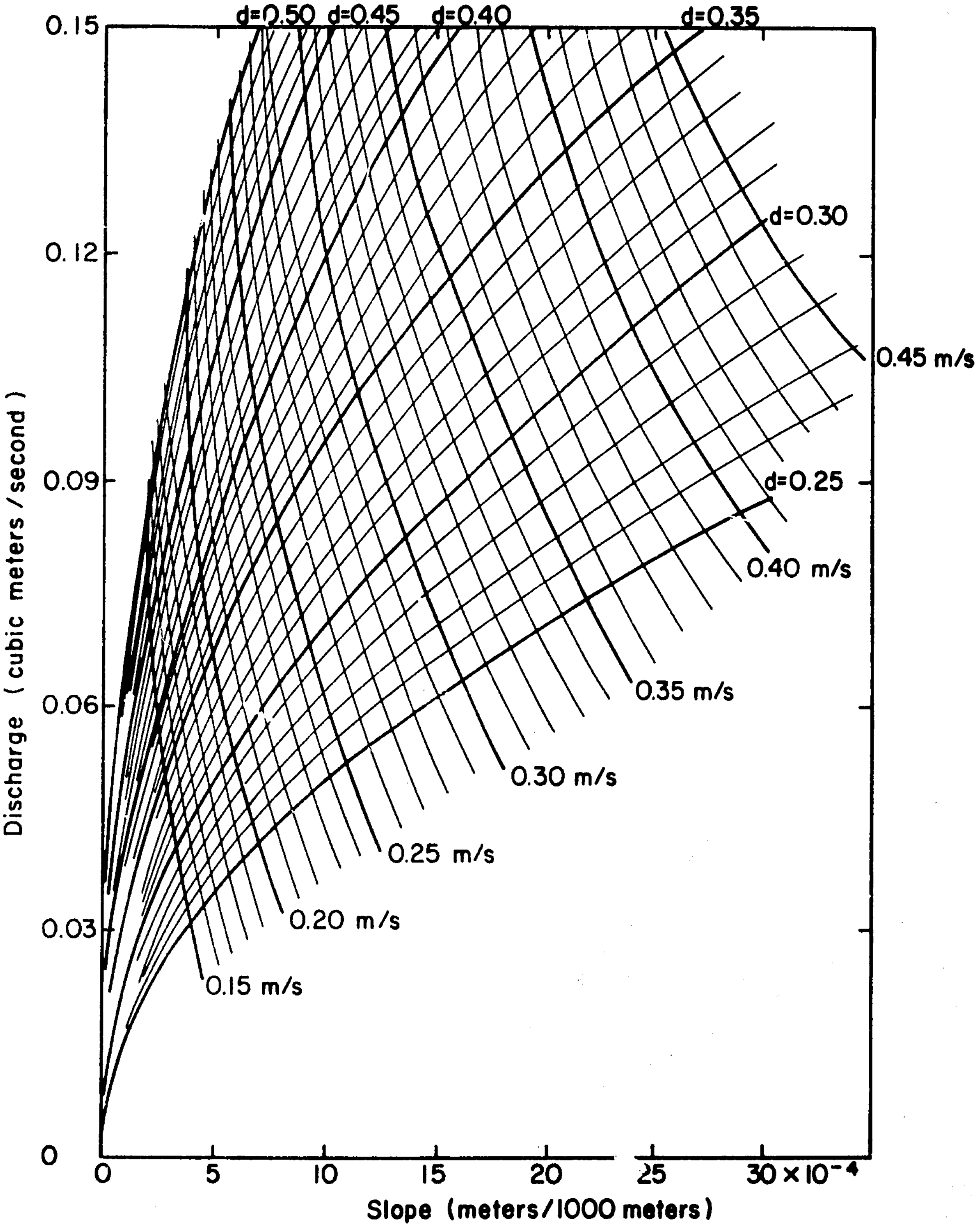


Figure 7. Solutions to Manning's Equation for bed width b = 0.60 meters and roughness n = 0.04.

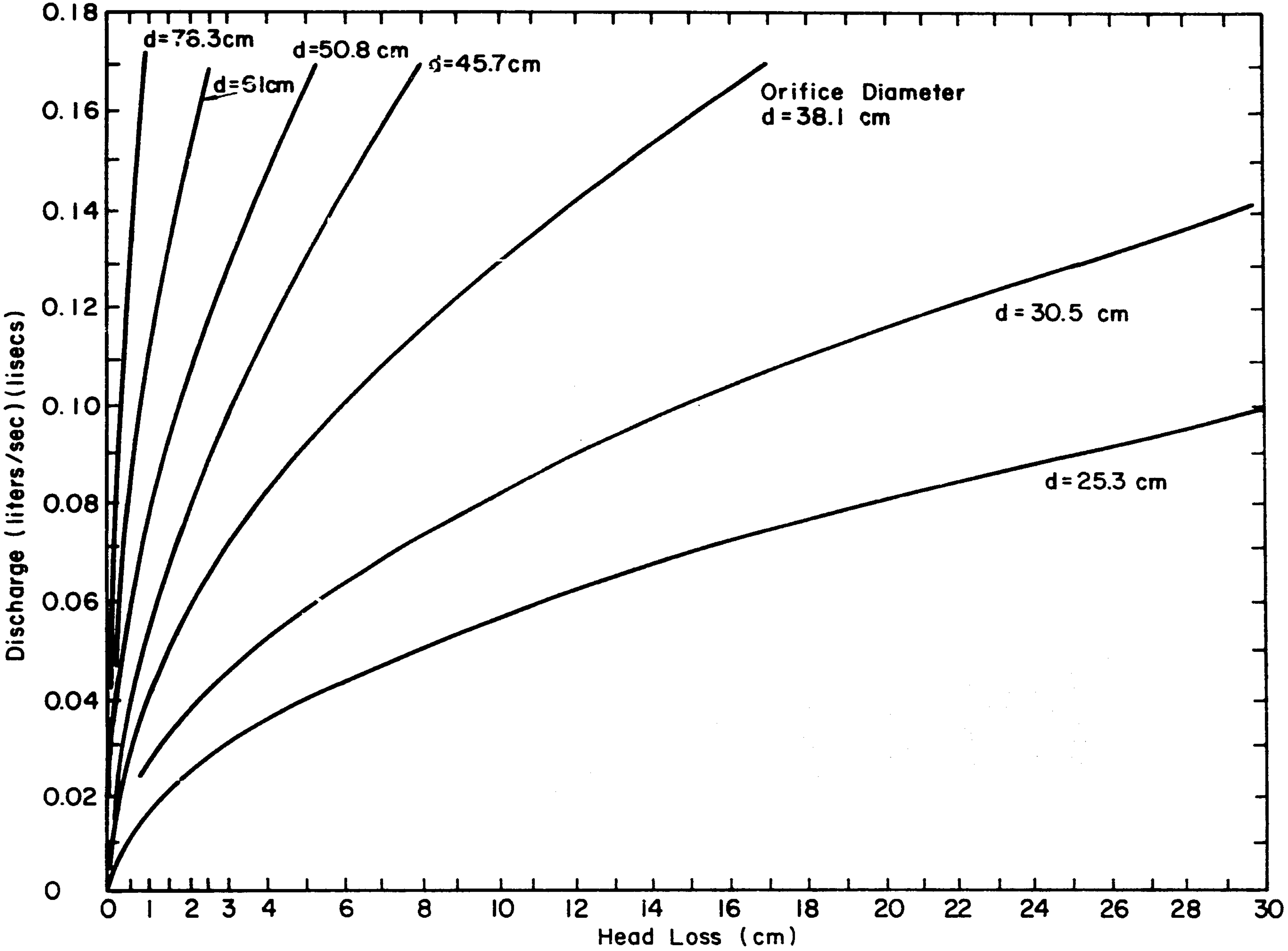


Figure 8. Headloss as affected by discharge and diameter of round openings in control structures such as panel and pipe nakkas or culverts (less than 3M in length).

G. BED ELEVATIONS AND DIMENSIONS OF ALL EXISTING CULVERTS AND PUCCA STRUCTURES IN MAIN WATERCOURSE

H. BRANCH WATERCOURSE PROFILES OF ALL BRANCHES

I. FIELD ELEVATIONS AT THE INTENSITY OF ONE SHOT PER ACRE

J. MEASURED MOGHA DISCHARGE

K. MEASURED LOSS RATES AT HEAD, MIDDLE AND TAIL OF WATERCOURSE

Three types of data are required. They are to be collected from the Canal Patwari or Sub-Divisional Officer of the Irrigation Department, from a survey of the watercourse command area and from a set of watercourse loss measurements. The first three items A, B, and C are collected from an irrigation department official. These are the official statistics on the watercourse. The watercourse layout map should be traced for reference when the grid system is being prepared prior to mapping of the watercourse. If the land is not laid out on a rectangular grid system (Kishtiwar or irregular grid system), then the watercourse plan map will have to be prepared from a plane table survey of the command area or from a tracing of an enlarged aerial photograph if photography is available.

Items D through I are obtained in a detailed survey of the watercourse. First, a grid map of squares and acres (10 hectare and 4/10 hectare units approximately) is prepared based on the map traced from the Patwari. The authorized right of way for the sarkari khal and the authorized nakkas are shown. The second step is to take this map to the field and to add all of the branch watercourses, all of the bunds separating individually irrigated fields (bunded irrigation units) and the location of all nakkas on the branch watercourses. The third step is to make a benchmark survey in a closed circuit starting at the bed elevation of the mogha assumed to be 10 meters elevation and connecting a sequence of pacca nakkas, square stones, hand pump bases, tubewell structures throughout the watercourse command area. Approximately one such pacca benchmark should be obtained per square of land to facilitate further surveying. The survey should be closed on the point of origin and error of closure calculated and proportionately distributed if it is within tolerable limits. The fourth step is to take elevation shots at an intensity between one per acre and one per bunded unit, depending on the time and manpower available. (The elevations are entered as directed on bunded unit map.) The fifth step is the determination of longitudinal profiles of the main and all branch watercourses. Included at this time is the determination of bed elevation and dimensions of all concrete structures occurring in the watercourse. In steps 4 and 5 the surveying must always be started and closed on a point of known elevation. If the error of closure exceeds tolerable limits, the survey must be repeated. The sixth step is the plotting of main watercourse and branch watercourse profiles along with the elevations of all adjacent bunded units to provide a field of profile. Items J and K are determined by using a pair of Cutthroat flumes, one at the mogha and the second at a field nakka. At least three different fields should be irrigated and water measured at each head, middle, and tail of the watercourse, making a total of nine field measurements. The location of the measurements should be noted on the watercourse plan map. Calculations of delivery efficiency and loss rates per 100 meters should be made according to

$$E_d = \frac{Q_{nakka}}{Q_{mogha}} \text{ x } 100 = \text{delivery efficiency}$$

$$LR = \frac{(Q_{mogha} - Q_{nakka})}{\frac{\text{distance in meters}}{100}} = \text{musecs loss rate per 100 meters}$$

IV. Preliminary Design Procedure

The preliminary design steps following the collection of the necessary field information:

A. DIVIDE COMMAND AREA MAP INTO SUBCOMMANDS OF EACH MAJOR BRANCH TAKING OFF FROM MAIN WATERCOURSE

B. INSPECT ELEVATION MAP TO DETERMINE THE LOCATION OF THE HIGHEST ELEVATION BUNDED UNIT OF EACH SUBCOMMAND

C. PREPARE FIRST WORKSHEET: LOCATION AND ELEVATIONS OF: HIGHEST FIELDS IN EACH BRANCH COMMAND OF WATERCOURSE

D. MAKE WATER LOSS CALCULATIONS AND PREPARE FIRST WORKSHEET: DISCHARGE OF DESIGNED SECTIONS THROUGHOUT MAIN WATERCOURSE AT ROAD CROSSINGS, CULVERTS AND STRUCTURES LOCATION (NAKKAS)

The first two steps, A and B, are made by subdividing and marking the location of the highest bunded units in each branch command on the watercourse plan map. The branch commands should be lettered consecutively from the mogha to the tail. Step C is completed by listing these highest field elevations, their location by acre and square number and their distance along the watercourse branch from the junction on the sarkari khal, but the letter designation of the branch A, B, C, D, etc. Step D is made after scrutinizing the water loss rate measurements, and obtaining a mean loss rate for the nine or more measurements. After this rate has been determined a design decision needs to be made. The question which must be answered is what percent of these determined loss rates should be assumed saved due to the watercourse improvement. Generally, a reasonable target is to save 50% of the loss. Other circumstances as well as future technological development might change this decision. Using the 50% loss saved criteria worksheet number two entitled Discharge of Designed Sections Throughout Main Watercourse is completed. It is started on the line labeled mogha with the mogha discharge entered. The next line is for the interval mogha to Nakka (toke) A. The distance in meters and the discharge loss (at 50% savings) is entered. The third line is for the Nakka A station. The discharge is the mogha discharge minus the loss of the line above. The cumulative distance is entered also. The fourth line is for the interval Nakka A to B and each successive line is completed in this alternating pattern to the last branch (tail) section.

V. Iterative Watercourse Design Procedure - Use of the Worksheet

The following section specifies the iterative procedure of design directly to specific lines of the worksheet #3, which are numbered from one at the top of the page.

Line 1 - In the space above the word DESCRIPTION, label the branch that is to be designed. Determine the elevation of the highest field to be irrigated near the end of the major branch at the tail of the watercourse. (In some cases this can be a high field anywhere on the branch from worksheet number 1.) Record the distance from the nearest junction outlet upstream as the design STATION. Determine the location of the outlet that will serve that field with respect to the grid system and record that location in the DESCRIPTION column. Give that location an arbitrary map number (starting with one), label the map likewise, and record in the column labeled No. Record the elevation of that field in meters above the specified datum in the column labeled ELEVATION OR FULL SUPPLY LEVEL.

Line 2 - Determine the working head of water needed to irrigate that field. Ideally this should be 0.15 meter, but compromises often must be made when topography is the limiting factor. Record working head in the column labeled DESCRIPTION. Record the magnitude of this factor in column labeled HEAD LOSS OR UTILIZED.

Line 3 - Add the field elevation to the working head to obtain the water surface elevation at the field outlet, which is listed in column labeled DESCRIPTION. The magnitude of this water surface elevation is recorded in column labeled ELEVATION OR FULL SUPPLY LEVEL.

Line 4 - a. Record the design discharge for the branch under consideration in the column labeled Q. Use the estimate of the full supply level at the junction outlet of the branch under consideration from the second worksheet.

b. Estimate the slope for this section by dividing the difference in full supply level at both ends of the branch under consideration (less than amount of head loss expected through the structures and culverts encountered in the branch) by the length of the branch section. Record this trial slope in column labeled $\underline{Sx10^{-4}}$.

c. For a given estimated bed width required, which is recorded in b column, the design chart to be used is selected from figures 1 through 7, for bed widths from b=0.30 to b-0.60. Read the discharge Q on the vertical axis and the calculated slope S on the horizontal axis to determine the depth of flow, d, and velocity of flow, V, in meters and meters per second respectively. Record in columns d and V, respectively. The velocity should be kept between the design limitations of V-0.15 to V=0.45 meters per second. If the velocity is too great, determine some method to reduce the slope; if the velocity is too low, increase the slope if possible. Attempt to keep the depth of flow, approximately 20% greater than b, the bed width for 1:1 slide slopes, be for 1 1/2:1.0 side slopes.

d. Multiply the design slope times the length of the section recorded in column L to obtain the head utilized. In the DESCRIPTION column record fall in branch lettered A onward from head to tail. In the HEAD LOSS OR UTILIZED column record the magnitude of this quantity.

Line 5 - This line is for the full supply elevation or water surface elevation below junction outlet at the head of this branch section. Record water surface elevation below junction outlet in DESCRIPTION column. Add the head utilized in the previous line (4) as fall in the branch watercourse to the water surface elevation at the field outlet determined in line (3) to obtain the water surface elevation and record in ELEVATION OR FULL SUPPLY LEVEL column.

Line 6 - If a structure is used at the head of this section record head loss through panel nakka or other pucca nakka in DESCRIPTION column. Use the appropriate curve of the orifice in figure 8, chosen, reading horizontally for the discharge Q in this branch of the curve, and then vertically down to the head loss axis and record in column labeled HEAD LOSS OR UTILIZED.

Line 7 - Add the head loss determined through the orifice determined in line (6) above, to the water surface elevation determined in line (5) above to obtain the new water surface elevation above the structure. List in DESCRIPTION column. Record sum in ELEVATION OR FULL SUPPLY LEVEL column. If a culvert is encountered or to be included while working backward to this junction, it should be treated as a design point intermediate to this set of steps to reach the NAKKA at the head of this branch. Care should be taken in calculating the head loss through the existing structures, especially culverts that are submerged and which in effect become inverted siphons. These steps are continued through the last section of the main watercourse backwards (from the direction of water flow) to the next major junction, repeating the steps in line (4) for the main watercourse. This overall procedure is repeated for all encountered branches and main watercourse sections until the source is reached. If all calculations are made correctly then water will flow by gravity in all designed sections within the limits of velocity specified to serve the selected most difficult served fields.

VI. Utilization of Existing Culvert Structures

Virtually every watercourse in Pakistan has existing pucca (concrete) culverts for road crossings of some kind. As a matter of economy, where sufficient slope is available and where the culvert is not placed too high to be efficiently used, it is suggested that these structures remain in place and that they be used as design control points. In a small percentage of cases these culverts will occur at the correct elevation to work as a pucca section in open channel flow. For these free flow cases, if the cross-sectional area of flow is nearly equal to or greater than the area of flow in the improved watercourse, the transition losses can be considered minimal from a trapezoidal channel to a rectangular culvert and the head loss equal to the difference in water surface elevations at inlet and outlet sections of the culvert. If the cross-sectional area of the culvert is much less (less than 90%) of the area of the flow in the improved channel, the difference in velocity head must be calculated for the culvert and channel and used to calculate inlet and outlet transition losses. Total head loss will then be inlet transition convergence loss, plus pipe friction loss, plus outlet transition divergence loss, using the formula and methodology presented in the following section.

For the great majority of cases where the culvert is located too low to function as a free flow channel, head loss calculations must be made so the culvert can be included in the design as an inverted siphon. The equation[3] to be used for this head loss determination is:

$$HL = 1.1 \ (h_i + h_f + h_b + h_o)$$

3/Young, R. B. 1974. "C. Inverted Siphons." Design of Small Canal Structures. U.S. Department of Interior, Bureau of Reclamation.

where h_i is the inlet transition loss

h_f is the pipe friction loss

h_b is the pipe bend loss

h_o is the outlet transition loss

and the 1.1 coefficient provides a 10% factor of safety. The calculation of inlet and outlet transition losses is made complicated by whether the inlet (outlet) is a converging of diverging flow section. This is determined by the relative magnitudes of the cross-sectional areas of the improved trapezoidal sections and the rectangular culvert. To make this comparison, the cross-sectional area of flow in the watercourse and velocity must be calculated from the equations

$$A_{wc} = db + SSd^2 = \text{area of watercourse}$$

Where d is the design depth of flow

b is the bottom width and

SS is the ratio of horizontal to vertical distances for the channel side slopes (equal to 1 for 1:1 side slopes and equal to 1.5 for 1½:1 side slopes)

$$V_{wc} = \frac{Q}{A_{wc}} = \text{flow velocity in watercourse}$$

Where Q is the design discharge in the channel section immediately above the culvert.

This V_{wc} can also be obtained directly from the design charts for the corresponding cross-sections. The V_{cul} is obtained by dividing the design discharge Q by the cross-sectional area of the culvert.

$$A_{cul} = hw = \text{area of culvert}$$

Where h is the height of the culvert and

w is the width of the culvert - assuming it flows full due to submergence. Hence

$$V_{cul} = Q/A_{cul}$$

The inlet and outlet transition coefficients are provided in the following table according to the type of section encountered.

	Diverging Section if $A_{cul} > A_{wc}$ at inlet	Converging Section if $A_{cul} < A_{wc}$ at inlet
B_1: Inlet transition coefficient	1.0	0.5
	if $A_{wc} > A_{cul}$ at outlet	if $A_{wc} < A_{cul}$ at outlet
B_2: Outlet transition coefficient	1.0	0.5

The inlet and outlet transition losses are calculated from the following equations which are based on the change in velocity head Δhv between watercourse and the culvert:

$$h_i = B_1 \ \Delta \ hv$$

$$h_o = B_2 \ \Delta \ hv$$

Where B_1 and B_2 are determined from the table and

$$\Delta hv = \frac{V_{wc}{}^2 = V_{cul}{}^2}{2g} = \frac{V_{wc}{}^2 - V_{cul}{}^2}{19.64} = \text{change in velocity head}$$

Where g is the acceleration due to gravity ($g = 9.82$ meters/sec^2). The friction loss in the culvert is obtained as the product of the pipe length and the friction slope of the culvert calculated

$$h_f = L_{cul} \ S_f = \text{culvert friction loss}$$

Where L_{cul} length of culvert in meters

S_f is the friction slope of the culvert calculated as

$$\frac{N^2 \ V_{cul}{}^2 {}_{4/3}}{S_f - R_{cul}} = \text{friction slope of culvert}$$

Where R is the hydraulic radius of the culvert calculated as

$$R = A_{cul}/sh + 2w$$

Where A_{cul}, h and w were previously determined for the culvert

n is the roughness coefficient for the concrete and brick culvert assumed to be equal to n = .013 and V_{cul} was previously determined for the culvert.

The culvert bend loss is determined from the equation:

$$H_b = 2z \ h_{V_{cul}} = \text{culvert bend losses}$$

Where z is Hind's zeta taken to be z = 0.21 for right angle (90%) bends on the inlet and outlet sections.

and h_v is the velocity head equal to $h_{val} = \frac{V_{cul}{}^2}{2g}$ as previously defined.

The combination of inlet, friction, bend and outlet losses is made to estimate the total loss. The following example is made to clarify the calculations:

Given: Q = .042 mu/secs in watercourse
y = .315 meter depth of flow
b = .3 meter bottom width
S = .0010 meter/meter slope of watercourse
SS = 1.0 (ratio of horizontal to vertical)
L_{cul} = 10 meters
W = .5 meter
h = .5 meter

1. Calculate the cross-sectional area of flow in watercourse

$$A_{wc} = yb + SSy^2$$
$$= (.315)(.300) + (1.0)(.315)^2$$
$$= .0945 + .0992$$
$$A_{wc} = .1937 \text{ m}^2$$

2. Calculate the velocity of flow in the watercourse

$$V_{wc} = Q/A_{wc}$$
$$= 0.042/.1937 = 0.217 \text{ meter/second}$$

3. Calculate the area of flow of the culvert (assumed flowing full):

$$A_{cul} = hw$$
$$= (.5)(.5)$$
$$A_{cul} = .25 \text{ m}^2$$

4. Calculate the velocity of flow of the culvert

$$V_{cul} = Q/A_{cul}$$
$$= 0.042/.25$$
$$V_{cul} = 0.168 \text{ meter/second}$$

5. Calculate the change in velocity head between watercourse and culvert

$$\Delta h_v = (V_{wc}{}^2 - V_{cul}{}^2)/19.64$$

$$= (.217)^2 - (.168)^2/1964$$

$$\Delta h_v = 0.00096 \text{ meter}$$

6. Calculate inlet transition loss for a diverging flow section at inlet of culvert $(A_{cul} > A_{wc})$

$$h_i = B_1 \Delta h_v$$

$$h_i = 0.00096 \text{ meter}$$

$$= 1.0 \ (0.00096)$$

7. Calculate the outlet transition loss for a converging section at outlet of culvert $(A_{cul} < A_{wc})$

$$h_o = B_2 \Delta h_v$$

$$= (0.5)(0.00096)$$

$$h_o = 0.00048$$

8. Calculate the friction loss in the culvert

$$h_f = L_{cul} S_f$$

$$\text{Where } S_f = \frac{n^2 \ V_{cul}{}^2}{R_{cul}{}^{4/3}}$$

$$\text{Where } R_{cul} = \frac{A_{cul}}{2h + 2w}$$

$$= \frac{.25}{1 + 1}$$

$$R_{cul} = .125$$

$$R_{cul}{}^{4/3} = .0625$$

$$n = .0013$$

$$n^2 = .013$$

$$n^2 = (.013)^2$$

$$n^2 = .000169$$

$$S_f = \frac{n^2 \; V_{cul}{}^2}{R_{cul}{}^{4/3}}$$

$$= \frac{(.000169) \; (.02822)}{(0.0625)}$$

$$S_f = 0.000076$$

finally

$$h_f = L_{cul} \; S_f$$

$$= (10) \; (.000076)$$

$$h_f = .00076$$

9. Calculate the culvert bend losses (assuming 90° inlet and outlet bends)

$$h_b = 2_z \; h_{V_{cul}}$$

Where $z = 0.21$

$$h_{V_{cul}} = \frac{V_{cul}}{2g}$$

$$= \frac{(.168)^2}{19.64}$$

$$= \frac{.0282}{19.64}$$

$$h_{V_{cul}} = .00144$$

then

$$h_b = 2_z \; h_{V_{cul}}$$

$$= 2(.21) \; (.00144)$$

$$h_b = .00060$$

10. Combine the loss components to determine the total head loss through the culvert.

$$HL = 1.1 \; (h_o + h_f + h_b + h_o)$$

$$= 1.1 \; (0.00096) + (.00076) + (0.00060) + (0.00048)$$

$$= 1.1 \; (.00280)$$

$$HL = .00308$$

This is the head loss that must be included in the calculations of water surface levels in the design.

VII. After all branches and sections of the main watercourse have been designed the final step is the calculation of designing elevations of bed and berme and the location of bed width, top width and berme width stakes.

The elevations at a 10 meter interval are calculated iteratively from the following:

$$\begin{pmatrix}\text{NEW}\\ \text{BED}\\ \text{ELEV}\end{pmatrix} = \begin{pmatrix}\text{MOGHA}\\ \text{BED}\\ \text{ELEV}\end{pmatrix} - 10\ S$$

Where S is the slope of the newly designed section in meters per meter and

$$\begin{pmatrix}\text{NEW}\\ \text{BED}\\ \text{ELEV}\end{pmatrix} = \begin{pmatrix}\text{PREVIOUS}\\ \text{BED}\\ \text{ELEV}\end{pmatrix} - IS$$

Where I is the interval distance in meters. The berme elevation is

BERME ELEV - BED ELEV. + TD

Where TD is the total depth and equal to the design depth of flow plus freeboard.

Likewise

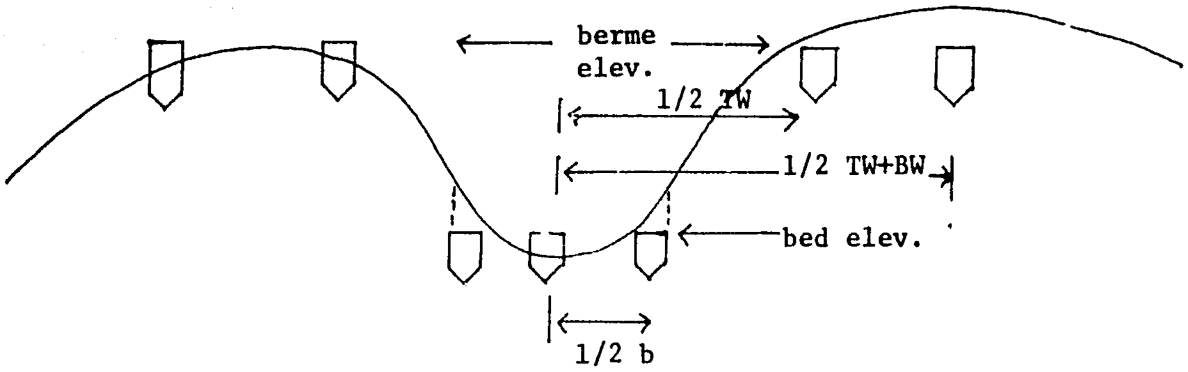
$$\begin{pmatrix}\text{NEW}\\ \text{BERME}\\ \text{ELEV}\end{pmatrix} = \begin{pmatrix}\text{OLD}\\ \text{BERME}\\ \text{ELEV}\end{pmatrix} - IS$$

The location of the bed width stakes is at a distance of one half the bed width (1/2 b).

The location of the top width stakes is at a distance of one half the top width (1/2 TW) from the center line of the new watercourse which is also the inner edge of the berme.

The location of the outer berme stakes is at a distance of one half the top width plus the berme width (1/2 TW + BW) from the center line of the new watercourse.

The stake locations are shown in the following sketch:



The general layout procedure is given the following six steps and the tabulated values are recorded in the following worksheet number 4 (FINAL FIELD LAYOUT TABULATION).

1. Determine location of 5 meter wide ROW.

2. Delineate center line of new watercourse with stakes.

3. Place elevation stake for bed elevation on center line.

4. Place stake at 1/2 b (one half bed width) from center line bed elevation stake on both sides of center line.

5. Place elevation stakes at the berme elevation at 1/2 TW (one half the top width) and 1/2 TW + BW (one half the top width plus the berme width) from the center line on both sides of the center line.

6. Repeat steps (3) through (5) at every 10 meter interval and at all junctions and pucca structures throughout the watercourse sections that will be improved.

WORKSHEET #1

LOCATION AND ELEVATIONS OF HIGHEST FIELDS IN BRANCH COMMAND OF WATERCOURSE

BRANCH COMMAND	HIGHEST ELEVATION	LOCATION ACRE SQUARE	DISTANCE FROM TOKE

WORKSHEET #2

DISCHARGE OF DESIGNED SECTIONS THROUGHOUT MAIN WATERCOURSE

STATION	INTERVAL	DISCHARGE	DISTANCE	CUMULATIVE DISTANCE	DISCHARGE LOSS
MOGHA	XXXXX		XXXXX	0.00	XXXXX
XXXX	MOGHA TOKE →	XXXXX		XXXXX	
	XXXXX		XXXXX		XXXXX
XXXX		XXXXX		XXXXX	
	XXXXX		XXXXX		XXXXX
XXXX		XXXXX		XXXXX	
	XXXXX		XXXXX		XXXXX
XXXX		XXXXX		XXXXX	
	XXXXX		XXXXX		XXXXX
XXXX		XXXXX		XXXXX	
	XXXXX		XXXXX		XXXXX
XXXX		XXXXX		XXXXX	
	XXXXX		XXXXX		XXXXX
XXXX		XXXXX		XXXXX	
	XXXXX		XXXXX		XXXXX
XXXX		XXXXX		XXXXX	
	XXXXX		XXXXX		XXXXX
XXXX		XXXXX		XXXXX	
	XXXXX		XXXXX		XXXXX
XXXX		XXXXX		XXXXX	
	XXXXX		XXXXX		XXXXX
XXXX		XXXXX		XXXXX	
	XXXXX		XXXXX		XXXXX
XXXX		XXXXX		XXXXX	

WORKSHEET #3

WATERCOURSE DESIGN WORKSHEET

Station	Description	Map Number No.	Length L	Depth d	B. Width b	Slope $Sx10^{-4}$	Discharge Q	Velocity V	Head Loss or Utitilized	Elevation or Full Supply Level

WORKSHEET #4

FINAL FIELD LAYOUT TABULATION

STA	BED ELEV	1/2 b	BERM ELEV	1/2 TW	1/2 TW + BW
MOGHA					

APPENDIX 14

LOW COST SIPHONS FROM USED TIRES

Norman Illsley[1]

Irrigation water losses are aggravated by two problems. The first is water leakage at the check or control structures in the watercourses, and the second is leakage at the field outlets.

At present, the most effective check structures are made of masonry and concrete, but even these "nakkas," unless carefully made and maintained, suffer leakage where the concrete lids do not seal tightly (Munir, Shafique and Trout, 1978). In many places, simple earthen or mud dams are thrown up at junctions of the watercourse each time the water is to be controlled. These temporary structures typically leak. Their construction leaves large borrow pits which cause increased leakage through the banks of the watercourse (Kemper and Akram, 1975). When these earthen dams are opened a small passage is cut in them, and much of the soil from which they were made is carried downstream to cause silting of the watercourse.

The nakkas used to deliver water to the fields from the watercourse in the Indus Valley have a similar story. When water is to be delivered to the field, the farmers usually just cut an opening in the bank of the watercourse to allow water to flow out. When they finish irrigating, these cuts are filled with mud. This technique promotes erosion, and weakens the ditch banks. Occasionally a permanent concrete nakka is constructed to deliver water to the field. These are too expensive for the average farmer to use for each of his fields, and they, too, have leakage problems because a concrete lid does not seal tightly in a concrete hole.

The metal or wood structures typically used in other countries do not provide a solution for the Indus Valley, partly because of the high cost of the material, and secondly because the metal or wood from which they are made is too valuable, and if used as a removable component of an unguarded structure, would soon be stolen.

Siphons have frequently been discussed as a solution to these problems; however, a six-inch siphon in Denver, Colorado currently costs $30. This same device delivered to Lahore would probably cost between $60 and $90, and represent hard currency exchange. On the local job market, this equals 60 to 90 days labor to earn one siphon.

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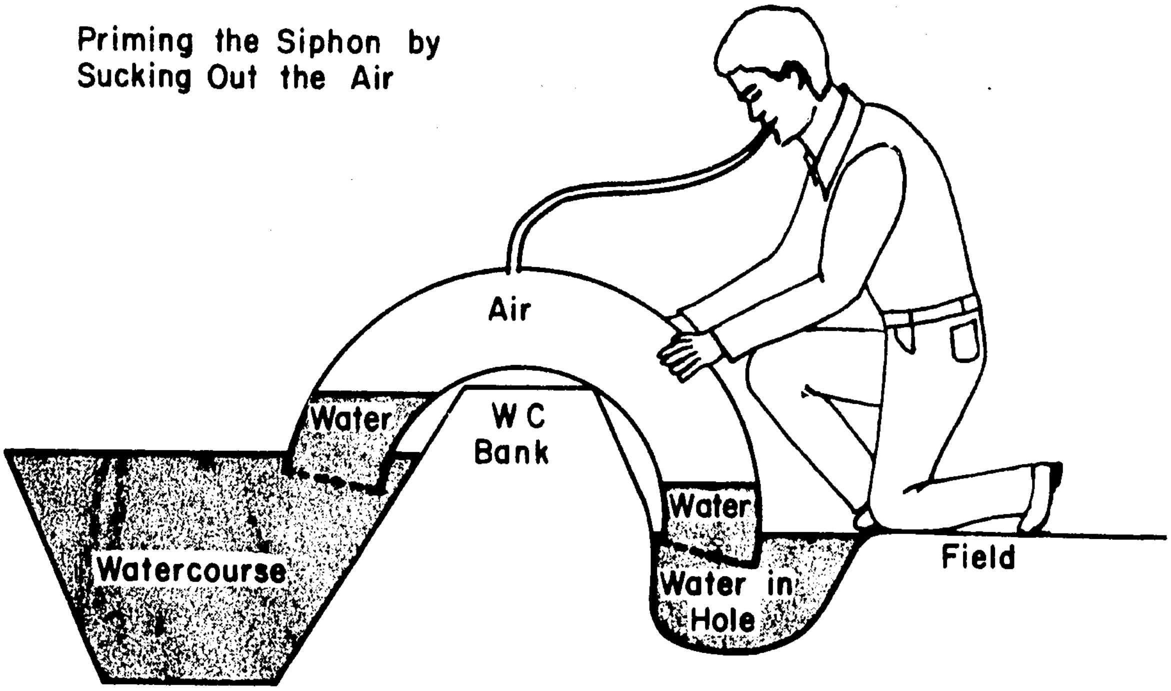
The concept of a siphon is sound; it permits the transfer of water without disturbing the banks over which the water is being conveyed. Siphons also allow the water to be taken over the bank at a number of places simultaneously or in turn. When the siphon is removed there is no leakage, and there is no piece of equipment remaining in the field unguarded.

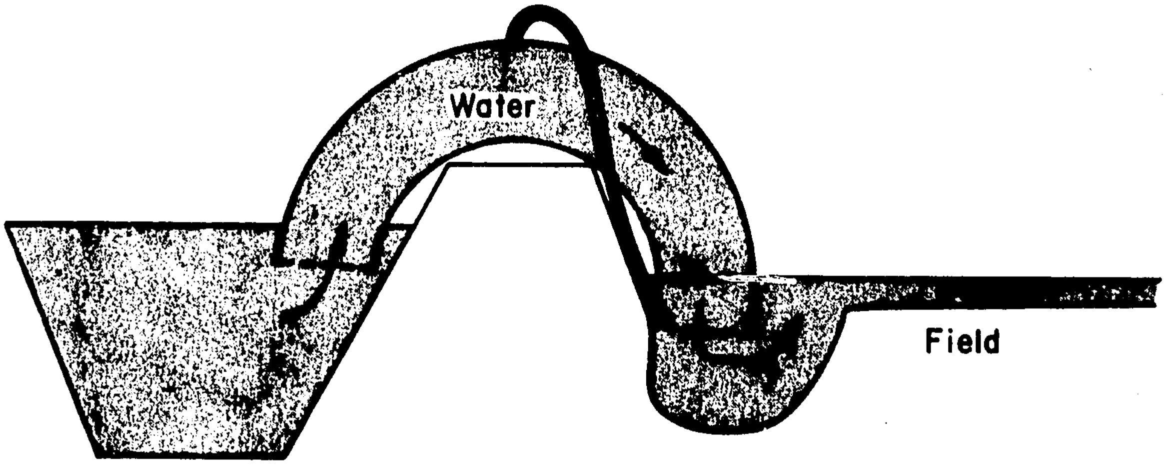
With these thoughts in mind, an attempt was made to construct a siphon of approximately six inch diameter out of material with minimum value, that would be portable and sturdy. It was reasoned that, if a worn out automobile tire could be cut in half, and the space between the beads sealed in some way, this would make an effective siphon. Three different sized tires, sized 5.50 x 15, 7.00 x 15, and 10.00 x 20 were cut and sealed. The smallest tire was cut to use approximately 190° of the tire. This allowed it to extend further down both banks, into the watercourse, and into the field. The tread from the unused portion of tire was used to seal the beads. The tread was cut into a strip approximately 5" wide. This strip was then notched along the two edges so that it gripped the beads of the tire. Silicone sealing compound was used to seal the notched portion of the tread to the beads. The tread was held in place by drilling pilot holes through the tread and into the bead wires of the tire, then sheet metal screws were twisted into these holes so that the screw entered between the wires and the threads gripped the wires of the beads. Six screws were more than adequate for holding the siphon together even under rough use. (See Figure 1A)

Small siphons are usually primed by filling them with water, keeping one end in the water and holding a hand over the other end while the siphon is laid across the ditch bank. This can not be done with a 6" siphon so a different approach was used. A 3" length of ½" brass tube was sealed in a hole in the center of the tread at the top of the siphon. This tube was held in place by two washers soldered onto the tube, one inside the tire and one outside. Silicone was used to make an airtight seal. A two foot length of plastic tubing was attached to the brass tube and was used to suck the air out of the siphon by mouth. For this method of priming to work, both ends of the siphon must be submerged. A hole dug in the soil on the discharge side can be filled with water using the siphon as a dipper to take water out of the watercourse and fill the hole. Then the siphon is laid over the bank, with the inlet end in the watercourse and the outlet end in the water filled hole, as shown in Figure 1, and the siphon is primed by sucking air out of the plastic tube. After priming, the end of the plastic tube is laid in the water at the discharge end of the siphon where it continues to flow as a small siphon as shown in the bottom half of Figure 1. In so doing, it also draws out any air that might enter the siphon through a small leak.



Priming the Siphon by Sucking Out the Air

Siphon in Operation



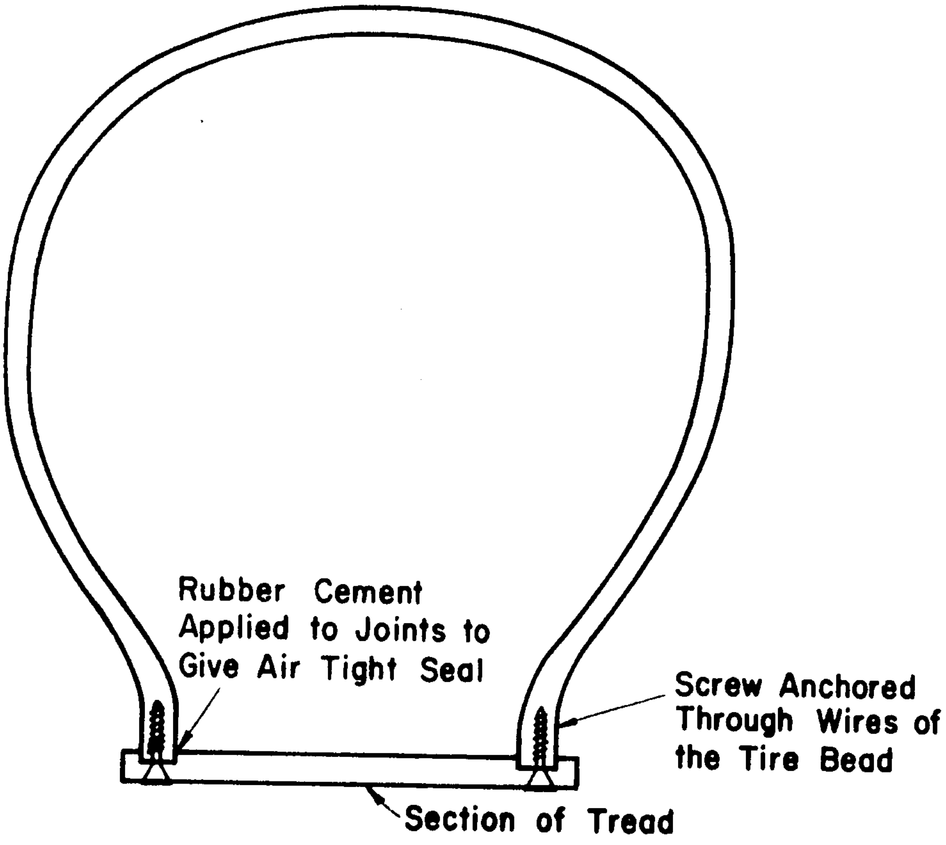


Figure 1A. Cross Section of Used Tire Siphon Showing Details of Assembly.

An alternate method of priming can be used wherein a reasonable length of inner tube (about 0.5 meters) is stretched over one end of the siphon. The siphon is submerged in the watercourse so that it fills with water. The tube is then held closed while the outlet end is pulled across the bank. The inner tube is then opened slowly until enough water has collected in the hole to cover the opening and then it can be opened completely for full flow.

Three additional siphons were made using similar principals. The first used a seven inch tire and a strip of 1/8" sheet metal instead of tire tread for sealing. The second and third used both halves of a ten inch truck tire. This meant that the tire was cut as closely as possible in half. One bead was sealed with the tread from a smaller tire and the other bead was sealed with a metal rim. The metal rim was made from a 6" wide strip of 1/8" steel with two semicircular pieces of 3/4" angle iron welded along the edges. The pieces of angle iron fitted between the beads of the tire and were again held to the beads with sheet metal screws.

All four siphons were calibrated by drawing water out of a tank with a surface area of 190 ft^2 into an oil drum. The oil drum was filled with water first so that both ends of the siphon were under water for priming as in Figure 3.

The large tank was filled with water and the siphon primed. The rate of water flow and head were determined by reading the height of water in the tank and in the barrel through manometer tubes. The head difference decreased as water level in the tank decreased (see Figure 4).

The only problem encountered was that the large 10" siphon drained the 190 ft^2 tank so rapidly, that it was difficult to record the manometer readings quickly enough.

More sophisticated testing methods could have been used in testing the performance of the siphons, such as using a recirculating hydraulic system with calibrated orifices for flow, and pressure transducers for heads. However, the purpose of this research was to see if a very simple siphon could in fact be made, and to get an estimate of what flows could be expected. The data gathered compares very closely to theoretical expectations. Siphons made after this fashion in developing countries will not have identical measurements to the siphons tested. If such siphons are made and are tested for flow at all, it will likely be with simple apparatus similar to that used in these calibrations.

An attempt was made to form a concrete siphon around a section of inflated inner tube. At this point this method cannot be considered successful, but the technique may have other useful applications, and in fact may produce a successful

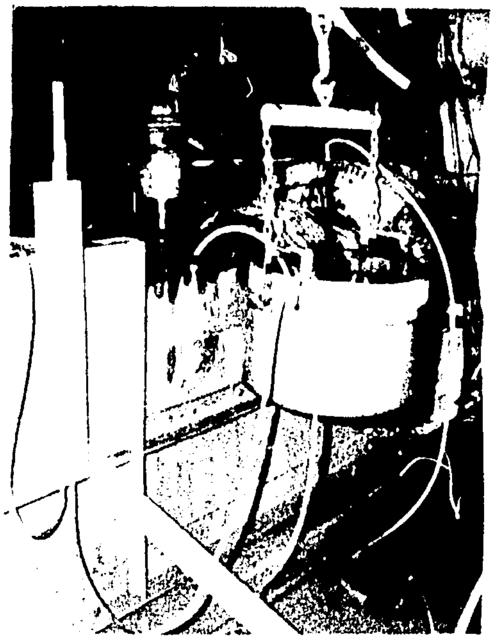


Figure 3. Calibration Set-up: Ready for Priming

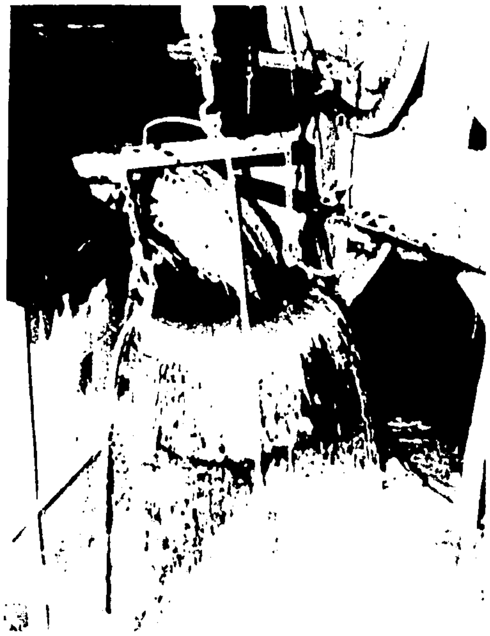


Figure 4. Water Flowing Through Siphon During Calibration

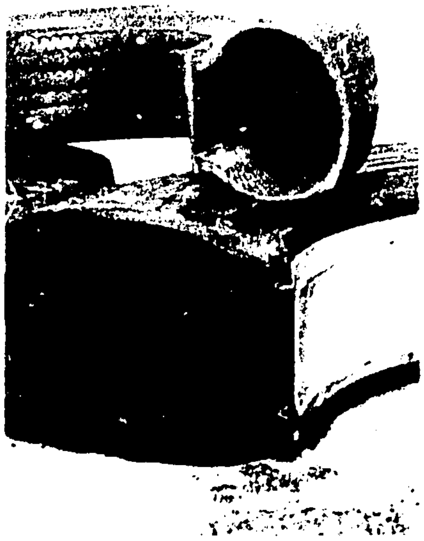


Figure 4a. Close up showing construction of tire siphon

siphon if tried in situ in a watercourse rather than on a workbench where there was no means of supporting the outside of the siphon.

A drawback of the tire siphon is its narrow span and vertical intake and discharge. Trimming the banks at points of usage allows them to fit over the banks as indicated in Figure 1, but can cause some erosion and might increase possibilities of leakage. Special concrete or masonry "cores" could be constructed about a foot high, 2' long and 4" wide (using 12 bricks and mortar and plaster). These siphons should allow farmers to draw water from the watercourse to their fields at the same location every time with less labor and without causing points of disturbance and weakness in the bank which are a primary source of water loss in watercourses. At junctions of watercourses carrying flows less than two cusecs, the large siphons might be used in place of the temporary dams currently constructed. They would reduce the labor and eliminate the downstream siltation and loss of land due to earth borrowing, bank weakening and leakage that commonly accompanies the weekly building of earth dams at junctions.

The flow tests show that these siphons are capable of delivering water at useful flow rates, and require very little head for this flow.

Figures 5 and 6 show the elevations of water in the supply tank and in the receiving barrel while water was flowing through the 10" and 7" siphons respectively. Water was allowed to overflow from the receiving barrel. As the rate of flow from the supply tank decreased, due to the smaller head difference between the water in the tank and in the barrel, the level of water in the barrel also decreased.

These data are analyzed in Tables 1 and 2, taking the slopes of the lines representing water level in the tank, multiplied by the tank area as the measure of the flow rate through the siphons and the difference in heads (elevations of the surface) as the measure of the driving force or head loss.

These data of head loss vs. flow rate are summarized along with similar data for a siphon made from a 5.5" tire in Figure 7.

The actual cross sections of these siphons are areawise equivalent to circles with 5.5, 7.0 and 10" diameters. The flow rates at given head differences are between 50 and 60% of the flow rates one would calculate using these diameters and Bernoullis equation.

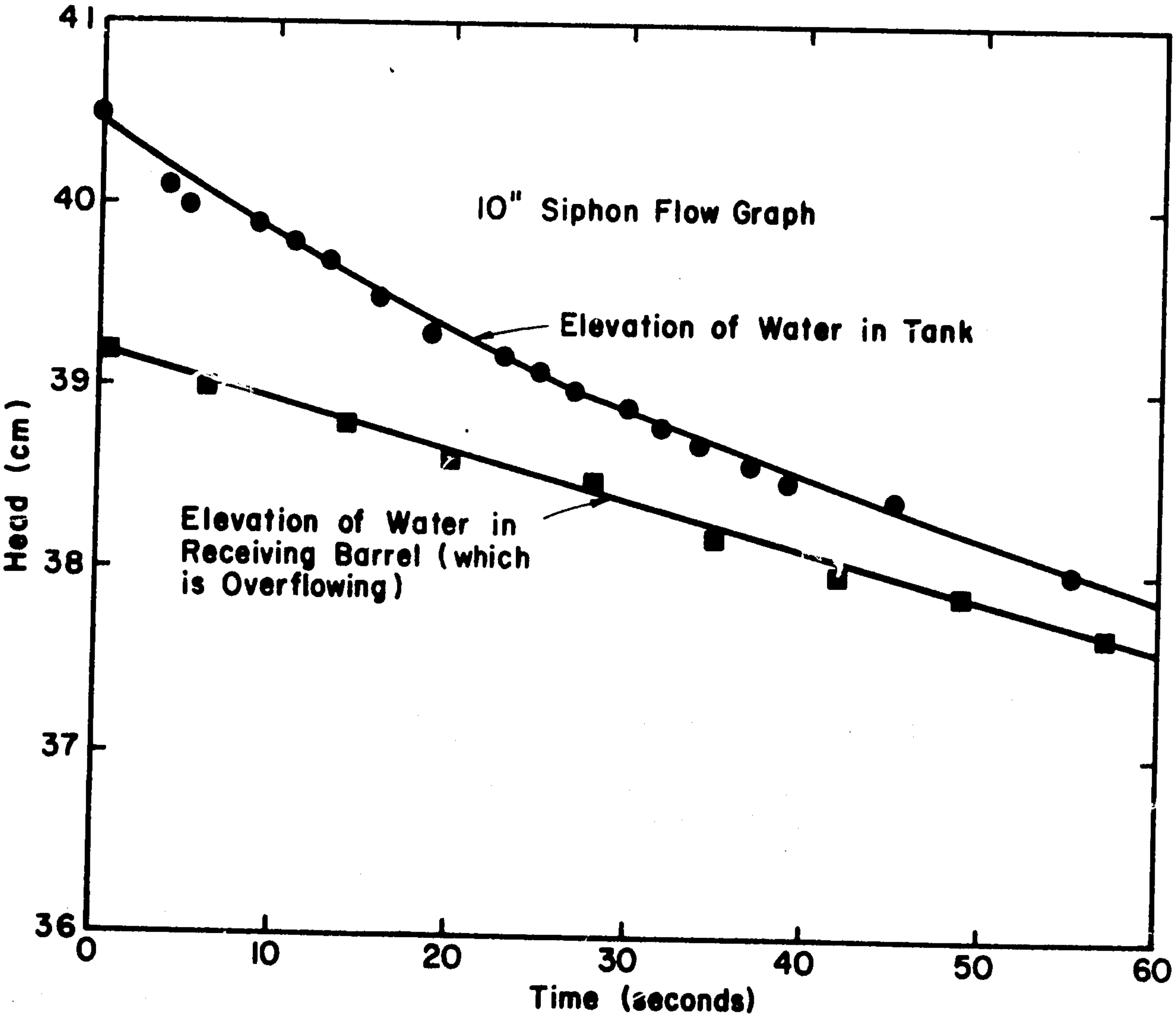


Figure 5. Flow from a Supply Tank into a Receiving Barrel Through a Siphon Made from a 10" Used Truck Tire. (Supply tank has surface area of 190 ft^2.)

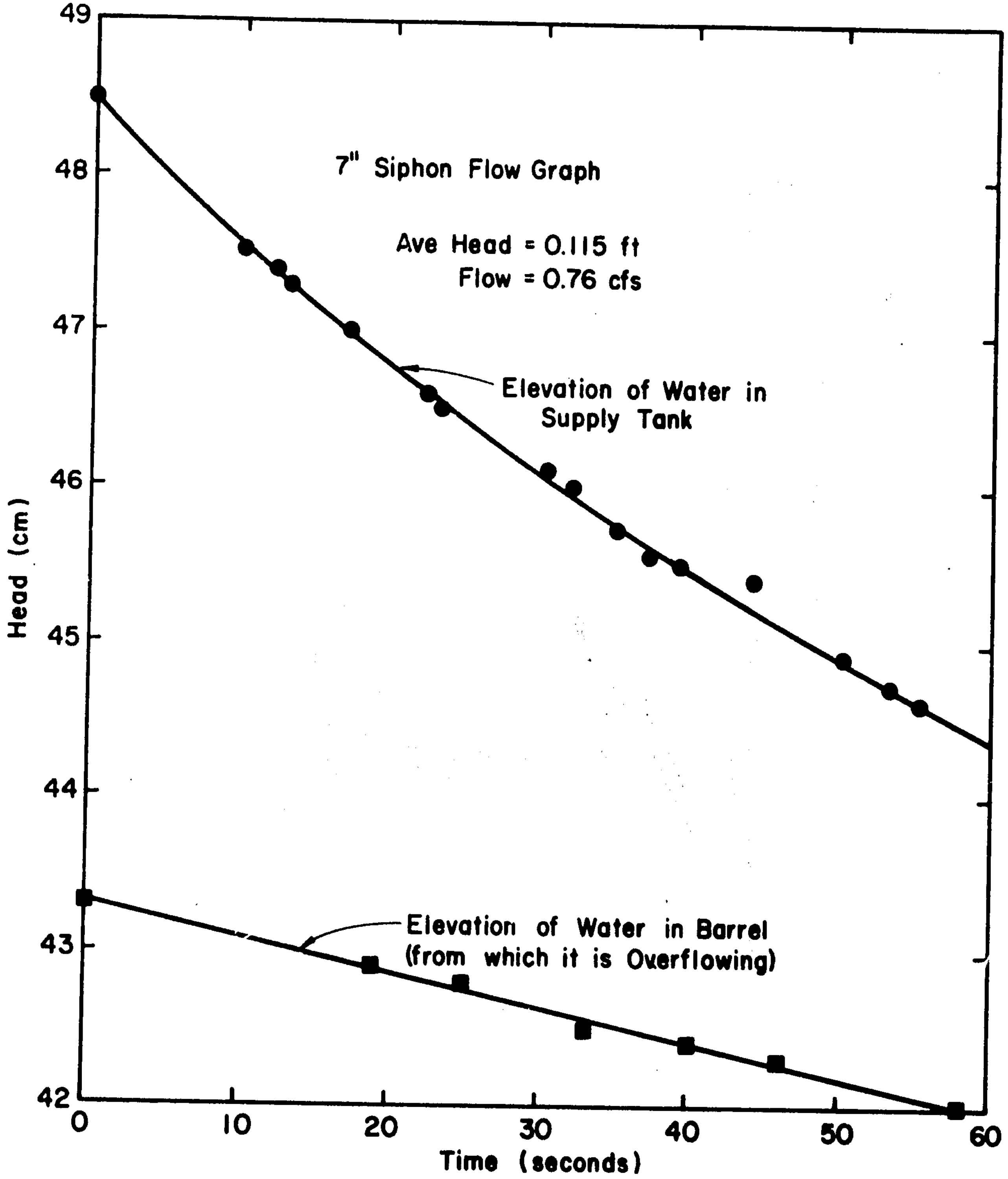


Figure 6. Flow from Supply Tank into a Receiving Barrel Through a Siphon Made of a 7" Used Auto Tire.

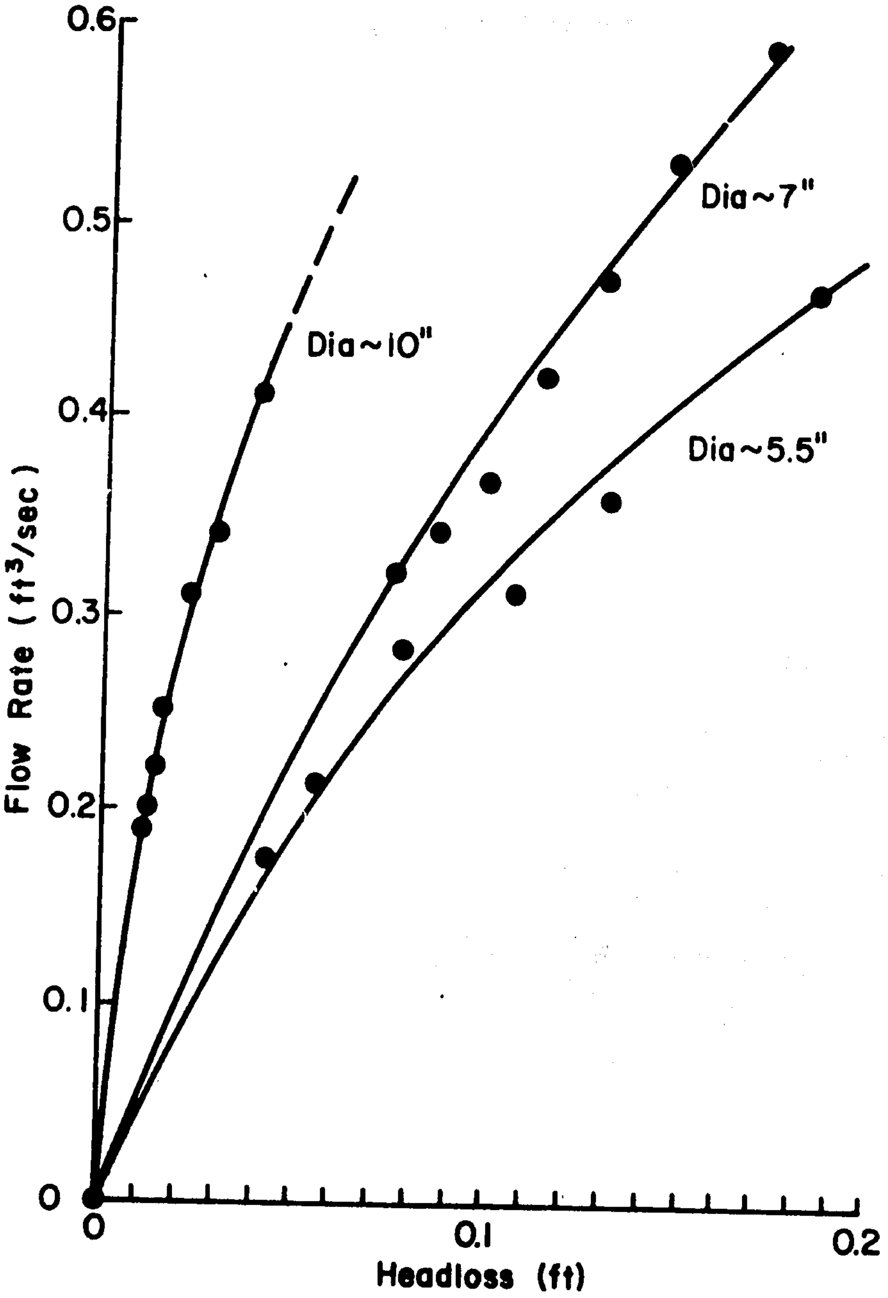


Figure 7. Head Loss Vs. Flow Rate for Siphons Made From Used Tires.

Table 1. Calibration of flow rate vs head loss for 10" siphon.

Time sec	$\Delta H_T/\Delta T$ in tank cm/sec	Head loss $H_T{*}-H_B{**}$ cm	Flow rate Liters sec	Flow rate Cubic ft sec	Head loss H_T-H_B feet
0	.065	1.22	11.5	.41	0.040
10	.055	.91	9.7	.34	0.030
20	.050	.66	8.9	.31	0.022
30	.040	.50	7.1	.25	0.016
40	.035	.40	6.2	.22	0.013
50	.032	.34	5.7	.20	0.011
60	.029	.30	5.1	.18	0.010

$\Delta H_T/\Delta T$ = rate of change of elevation of water in supply tank

H_T = elevation of water in tank

H_B = elevation of water in receiving barrel

Table 2. Calibration of flow rate vs head loss for 7" siphon.

Time sec	$\Delta H_T/\Delta T$ in tank cm/sec	Head loss H_T-H_B cm	Head loss H_T-H_B ft	Flow rate From tank to barrel Liters/sec	Flow rate From tank to barrel ft^3/sec
0	.095	5.20	.171	16.8	.59
10	.085	4.48	.147	15.0	.53
20	.075	3.92	.129	13.3	.47
30	.068	3.45	.113	12.0	.42
40	.061	3.04	.100	10.2	.36
50	.055	2.67	.087	9.7	.34
60	.050	2.37	.077	8.9	.32

The cost of worn out tires depends on their value for other uses in the country considered. In Pakistan, prices from 10 to 25 rupees per tire have been quoted. When the tread from the opposite side of the tire is used to complete the cross sectional perimeter of the tire, the additional materials required are: 12 screws (about Rs. 2), about 2 ounces of rubber or silicone cement (Rs. 3), 2" of copper tubing and 3 feet of plastic tubing (3/8" ID) (about Rs. 5) for a total material cost of about Rs. 30, if the used tire is bought for Rs. 20. Tire shop mechanics with a hack saw, a sharp knife and a hand drill should be able to build at least one of these per hour for a labor and facilities cost of less than Rs. 10/siphon. It appears feasible to construct these siphons at a total cost of about Rs.40/siphon in Pakistan.

Conclusions

Considering that concrete outlets cost from 100 to 300 rupees and that these large siphons can be moved and used at many locations, the siphons appear to offer a new low cost means of controlling water and transferring it from the watercourse to the field (or branch channel).

It also appears feasible to make reasonably good calibrations of head loss vs flow rate for these siphons, so that they could be used, along with a device to measure head loss, to estimate flow rates and amounts of water applied to fields.

References

Kemper, W. D. and M. A. Akram. 1975. Water losses in straight sections and at junctions of a watercourse. CSU Water Management Research Annual Report, Fort Collins.

Mian Munir, Siddique Shafique and Tom Trout. 1978. Low cost farm irrigation control structures for Pakistan. Presentation at the Low Cost Farm Structures Seminar at the University of Peshawar, Pakistan.

APPENDIX 15

FEASIBILITY AND DESIGN OF A LOW-HEAD JET PUMP FOR IRRIGATION IN PAKISTAN

Richard L. Aust[1]

Introduction

The constant demand for increasing food production has made farmers look for more efficient methods to make the land they have more productive. By using water more efficiently, producers who irrigate have been able to bring new lands into production that before were unproductive. These new lands are sometimes above the operating level of the water n a watercourse. Therefore, farmers are often confronted with the problem of trying to raise the level of water in their watercourse or find some other means of lifting water up to the fields. The most common method of lifting water in this country is a pump, powered by either electricity or some other fossil fuel.

Pakistan faces the problem of many underdeveloped countries; a shortage of food with an increasing population rate. However the climate and soils of Pakistan are especially suitable for agriculture. The irrigated croplands of Pakistan comprise the world's largest contiguous irrigation system of over 30 million acres (Clyma and Corey, 1974). Irrigation is the main reason there is agriculture at all in Pakistan. There are over 40,000 miles of irrigation canals in the conveyance system and the general slope downstream averages from about nine inches to one foot per mile (Corey and Clyma, 1973). Because the topography is so flat, the farmers have little hydraulic head to work with in their watercourses. The farmers and irrigators are always searching for some method to either raise the level of water in the watercourse or lift the water to the fields.

The most common method currently in use in Pakistan for lifting water is a Persian wheel or jahlar. A Persian wheel is a large wheel usually constructed of wood, with buckets fastened to the outside perimeter. As the wheel is rotated in a vertical plane the buckets fill with water when they move upward. The wheel is continually rotated and the buckets spill out the water at a higher elevation when they are tipped. Corey and Clyma (1973) estimate there are more than 200,000 Persian wheels lifting water in Pakistan today. The capacity of an eight foot diameter Persian wheel powered by two water buffalo and a small boy is calculated to be 0.186 cubic feet per second (McWhorter and Zuberi, 1972).

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A second method being used in Pakistan to raise the water from the canal to the field is an electrically driven screw pump. Since most farmers do not have access to an electrical source, this method is not frequently used.

Water is lifted in Holland and many other parts of the world by windmills that drive pumps. Although this works in many places, Pakistan's mean daily wind velocity of only 1.33 miles per hour excludes this as a feasible solution (Gill, 1977).

Because of the extensive irrigation many tubewells have been constructed in Pakistan. These tubewells are skimming wells which remove water from the groundwater and discharge it into the watercourse with the purpose of providing additional water for irrigation and also lowering the water table. These tubewells frequently discharge the water three to six feet above the ground and let it fall into the watercourse. At present it is estimated there are more than 80,000 tubewells operating in Pakistan (Corey and Clyma, 1973).

The CSU Water Management Project in Pakistan has been investigating methods of lifting water in irrigation canals, one of which led to this design project. It would be of great value if the energy from the tubewell water could be used to lift additional irrigation water in the watercourses. One possible solution which would use this energy is a low head jet pump.

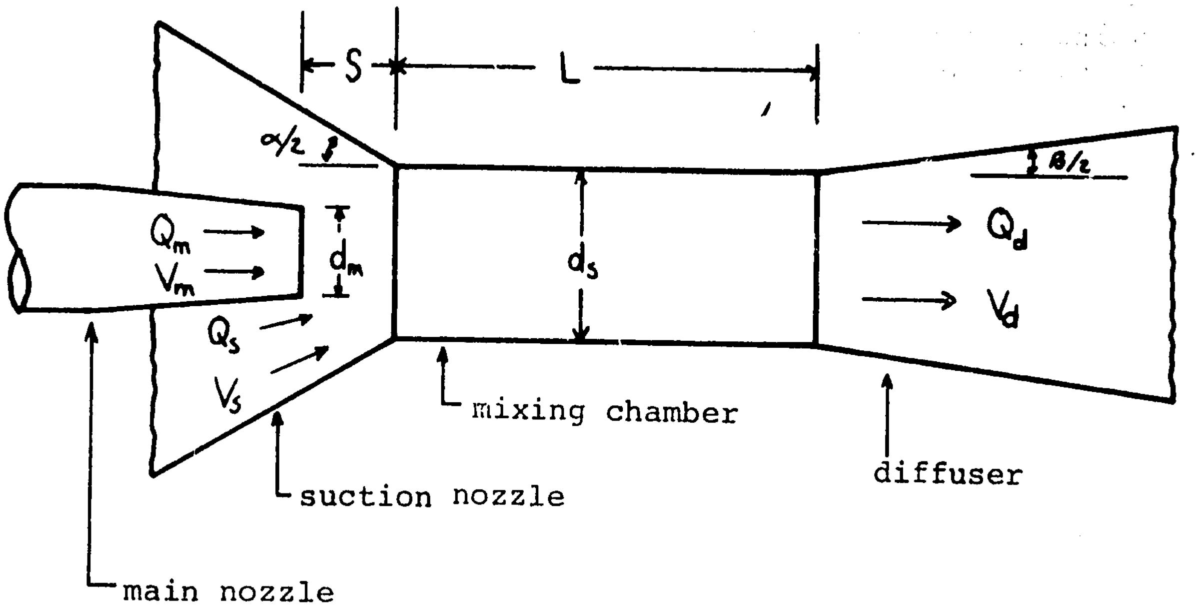
Objectives of the Design

It was necessary to determine if reasonable efficiencies could be achieved using such low hydraulic heads. This would indicate whether or not research of jet pumps should be continued.

If the jet pump was feasible at all, the parameters that effect the efficiency were to be investigated. Hopefully some relationship between the parameters and the efficiency could be determined.

Literature Review

Five papers were found which discussed water jet pumps and their efficiencies and design parameter. These parameters are illustrated in Figure 1. The parameters include the area ratio A_r, the flow ratio Q_r, and H_r, the head ratio. All of the papers said the maximum experimental efficiency obtained was less than 42%. Two different methods of describing theoretical efficiencies were discussed. Mueller (1964) defined the theoretical efficiency as:



Q_m- flow rate of main nozzle (0-2.34 cfs)*
V_m- velocity of flow in main nozzle (0-16.5 ft/sec)
d_m- diameter of main nozzle (5.0 in)
Q_s- flow rate of suction nozzle (0-3.25 cfs)
V_s- velocity of flow in suction nozzle
d_s- diameter of suction nozzle (10.0 in)
Q_d- (Q_t) Q_m+Q_s total flow or discharge (0-5.50 cfs)
V_d- velocity of discharge
s - distance between main nozzle and mixing chamber (5-7.5 in)
V_r- velocity ratio, V_s/V_m
Q_r- flow ratio, Q_s/Q_m
$\alpha/2$- angle of suction nozzle (20^o)
$\beta/2$- angle of diffuser (4.5^o)

* Items in parentheses indicate range of parameters in model.

Figure 1. Sketch of the components of a jet pump.

$$\eta = \frac{\text{work done}}{\text{work put in}} \tag{1}$$

Using this relationship the maximum theoretical efficiency is equal to 1. Reddy and Kar (1968) suggest the maximum theoretical efficiency of 0.50 by defining efficiency as:

$$\eta = \frac{2Q_s}{Qd} \frac{(V_c)^2}{(V_d)} \tag{2}$$

Where Q_s is the flow of the suction fluid, Q_d is the flow of the driving fluid, V_c is the velocity of the combined fluids, and V_d is the velocity of the driving fluid.

All of the authors tended to agree on some of the basic parameters. For example the suction nozzle should be a cone which could vary from 5.5° to 8.0°, the flow ratio Q_r should be between 0.3 and 0.8, and the area ratio A_r should be between 0.30 and 0.50. Cairns and Na (1969) achieved a maximum efficiency of 0.42 with an A_r of 0.295, S/D = 0.8, L/T = 4.1, $\alpha = 40^o$, and $\beta = 6.5^o$. The flow rates discussed by Cairns and Na (1969) varied from 20 gpm to 120 gpm and hydraulic heads from 80 ft. to 200 ft.

Reddy and Kar (1968) experimented with small jet pumps having nozzles less than 2 in. in diameter and heads of 150 ft. They acheived a maximum efficiency of 39.8%.

Sanger (1970) investigated efficiencies using nozzles less than 0.6 in. and heads of 35.0 ft. He achieved a maximum efficiency of 38.7%.

No papers could be found dealing with low hydraulic heads of less than six feet and large flow rates of up to 3 cubic feet per second, the conditions that are commonly available for irrigation use in Pakistan.

The basic hydropower equation is:

$$P = Q\delta H \tag{3}$$

Where P is the power in foot pounds per second, Q is the flow rate in cubic feet per second, δ is the specific weight of water in pounds per cubic foot, and H is the hydraulic head in feet (Morris and Wiggert, 1972). If there was 4 feet of head available at the tubewell flowing at a rate of 3 cubic feet per second, then the power available at the tubewell would be:

$$P_{tw} = (3)(62.4)(4) = 748.8 \ \frac{\text{ft. lbs.}}{\text{sec.}}$$

If water in the watercourse flowed at a rate of 3 cubic feet per second, and it was required that this water be lifted 1 foot higher, then the power required to accomplish this would equal:

$$P = (3)(62.4)(1) = 187.2 \ \frac{\text{ft. lbs.}}{\text{sec.}}$$

It appeared from this specific case that there is much more power available at the tubewell discharge than is necessary to raise the water in the watercourse. In this specific case where $P_{tw} = 748.8$ ft. lbs./sec. and $P_{req} = 187.2$ it appears the efficiency of the jet pump must be greater than 0.25 or it is not a feasible solution.

Methods for Selecting a Design

Since the literature suggested efficiencies greater than 25% were possible and there was sufficient energy available at the tubewell discharge it was decided further investigations of jet pumps would be desirable. It was decided that a full size model should be constructed in order to evaluate experimentally the different design parameters (see Figure 1) and what effect they have on overall efficiency of the jet pump. The model as it was constructed is shown in a sketch in Figure 2. The model is located outside to the west of the hydromachinery lab at the Engineering Research Center, Foothills campus, Colorado State University.

The initial model was constructed according to the optimum parameters suggested in the literature. The values of the parameters that were varied and those that remained constant are illustrated in Figure 3.

The measured variables were H_d the downstream head over the wier, H_u the upstream head and Q_p the flow rate from the centrifugal pump which was used to simulate a tubewell flow. Q_t the total flow of the tubewell water combined with the canal water was calculated from the equation:

$$Q = 3.367LH^{3/2} \tag{4}$$

(USDI, Bureau of Reclamation, 1967). The flow rate from the canal can be found by subtracting Q_p, the flow from the tubewell from Q_t the total flow rate. The tubewell flow rate could be varied by means of a valve, and the flow rate could be read from a differential mercury - manometer. The location of the staff gauges and manometer are shown in Figure 3.

The efficiency of the jet pump was calculated from the relationship:*

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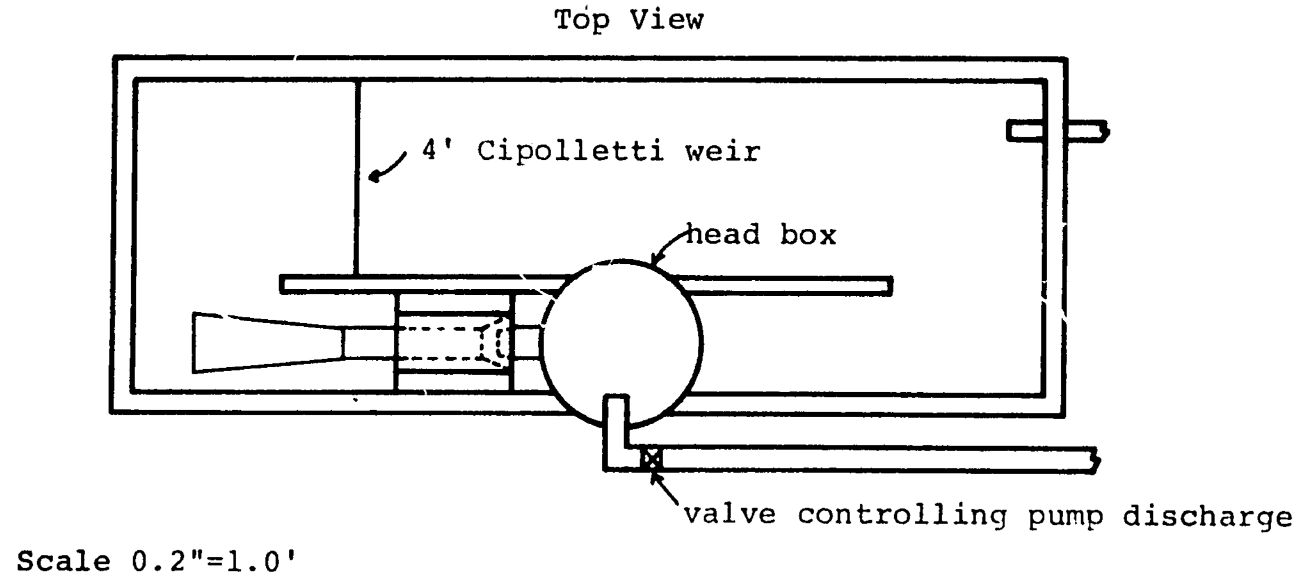
*See Appendix.



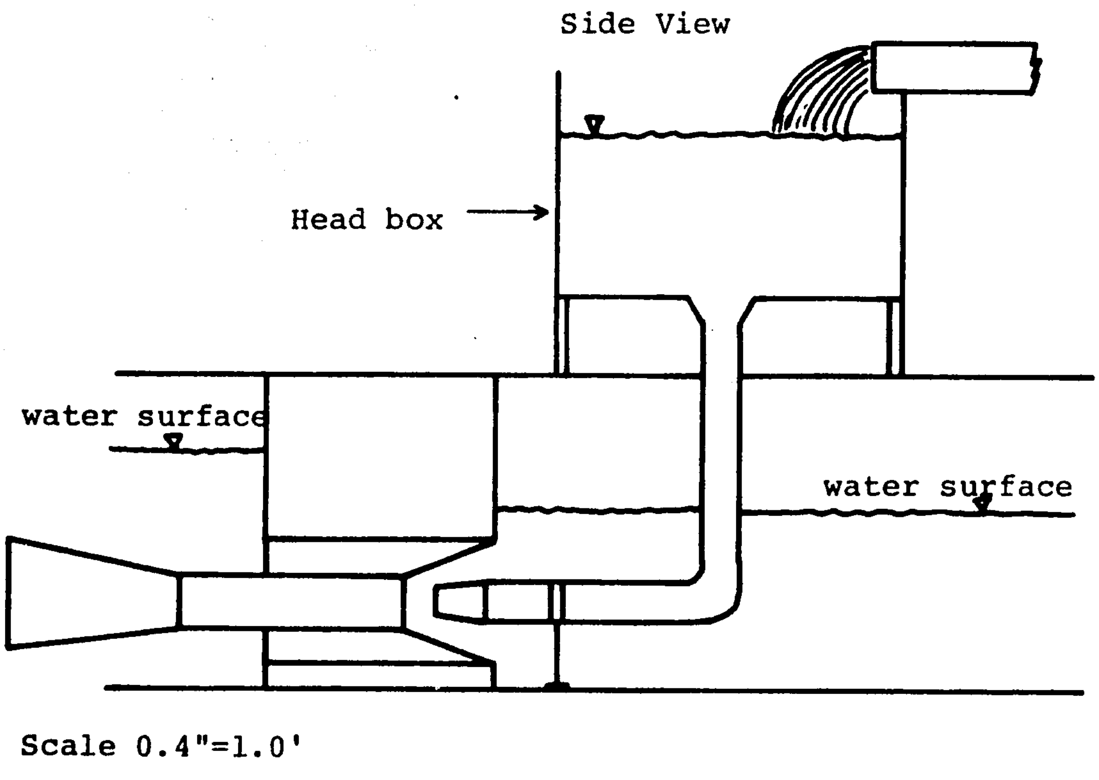


Figure 2. Sketch of how model was constructed to evaluate the jet pump.

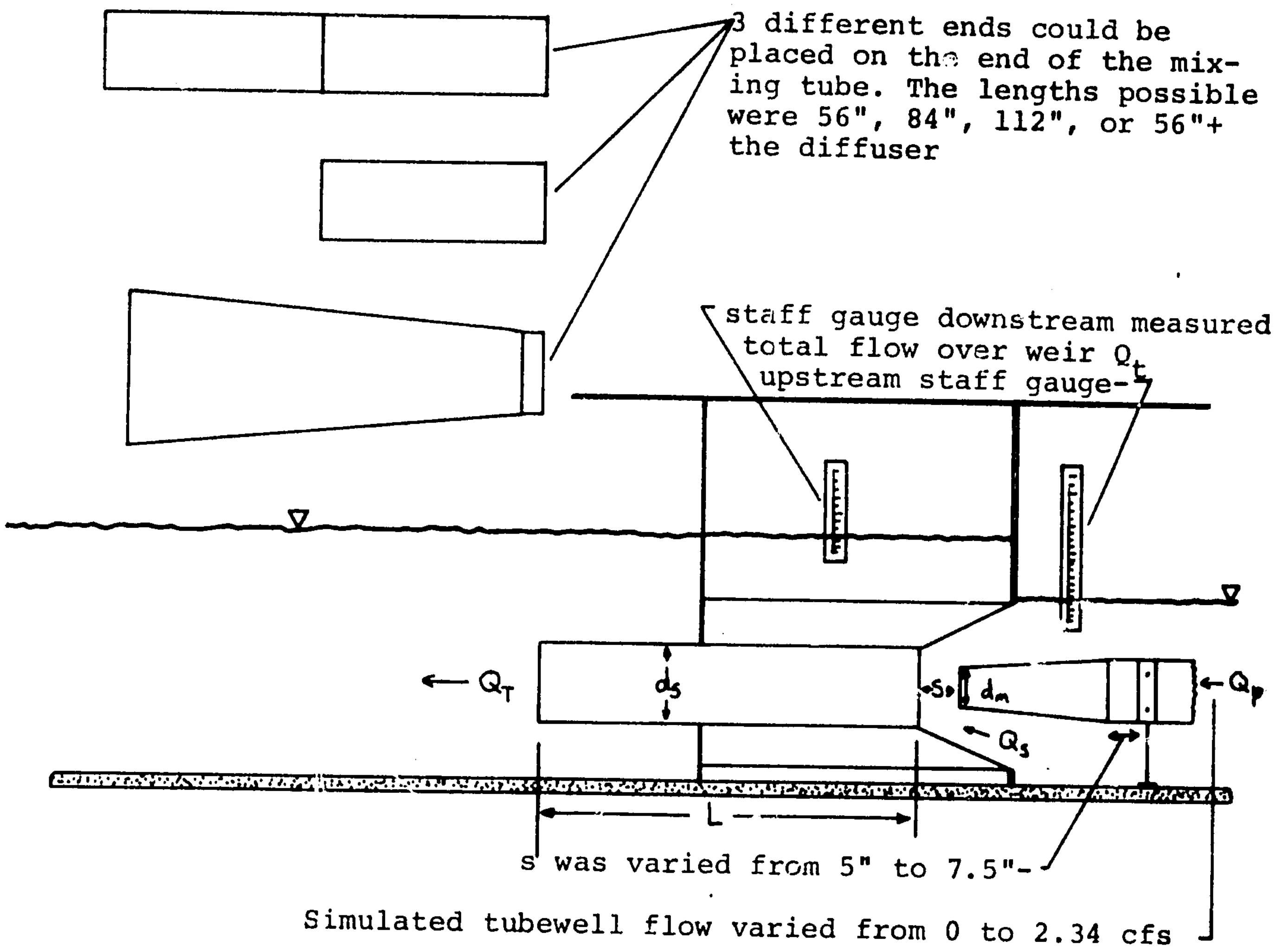


Figure 3. Sketch of model showing variable parameters.

$$\eta = \frac{\text{energy gained by canal water}}{\text{energy lost by tubewell water}} \quad (5)$$

Costing Procedures

Since the jet pump is being designed primarily for irrigation use in Pakistan, the cost estimates were determined for production in Pakistan. The cost estimates were made with the help of Dr. W. D. Kemper. The estimates were made by comparing the production of this design to other designs Dr. Kemper has had manufactured in Pakistan.

Design Constraints

There were several constraints effecting the design of a pump for lifting irrigation water in Pakistan. It should be simple enough to be manufactured in a rural setting. It should be relatively durable and maintenance free. It should be able to be constructed of low cost materials which do not need to be imported into the country.

Results

The maximum efficiency obtained with the jet pump model was 42.0%. This seems to be consistent with Cairns and Na (1969) who also achieved a maximum efficiency of 42.0%, but it is this author's opinion that efficiencies greater than 42.0% are realistically possible. The 42.0% efficiency was achieved using the diffuser attached to the mixing chamber with L = 56", S = 5.0", $Q_r = 1.05$ and $A_r = 0.25$

The characteristic head-capacity (HQ) curve appeared to be linear as illustrated in Figure 4. It was not readily apparent if this curve is linear for all jet pumps or whether the curve is just linear over the range of hydraulic heads and flow rates experimented with.

The characteristic efficiency vs. Q_s seemed to be fairly flat as shown in Figure 4, at least over the range of Q_r from 0.69 to 1.24. This seems to be highly desirable that Q_s could vary from 1.55 cubic feet per second up to 2.80 cubic feet per second and the efficiency would only change between 25.4% and 26.5%.

The relationships between changing the parameters and their respective efficiencies are shown in Figure 5. There was a steady increase in efficiency when the length of the mixing chamber was increased. The addition of the diffuser increased the efficiencies even more. The difference in efficiencies between the diffuser plus the 56" mixing chamber (which had a combined length of 56" + 60" = 116") and the mixing chamber with a length of 112" was only 4.0%. The location of the nozzle, S, had a definite effect on efficiencies. The most efficient placement seemed to be when S = 6.0". The

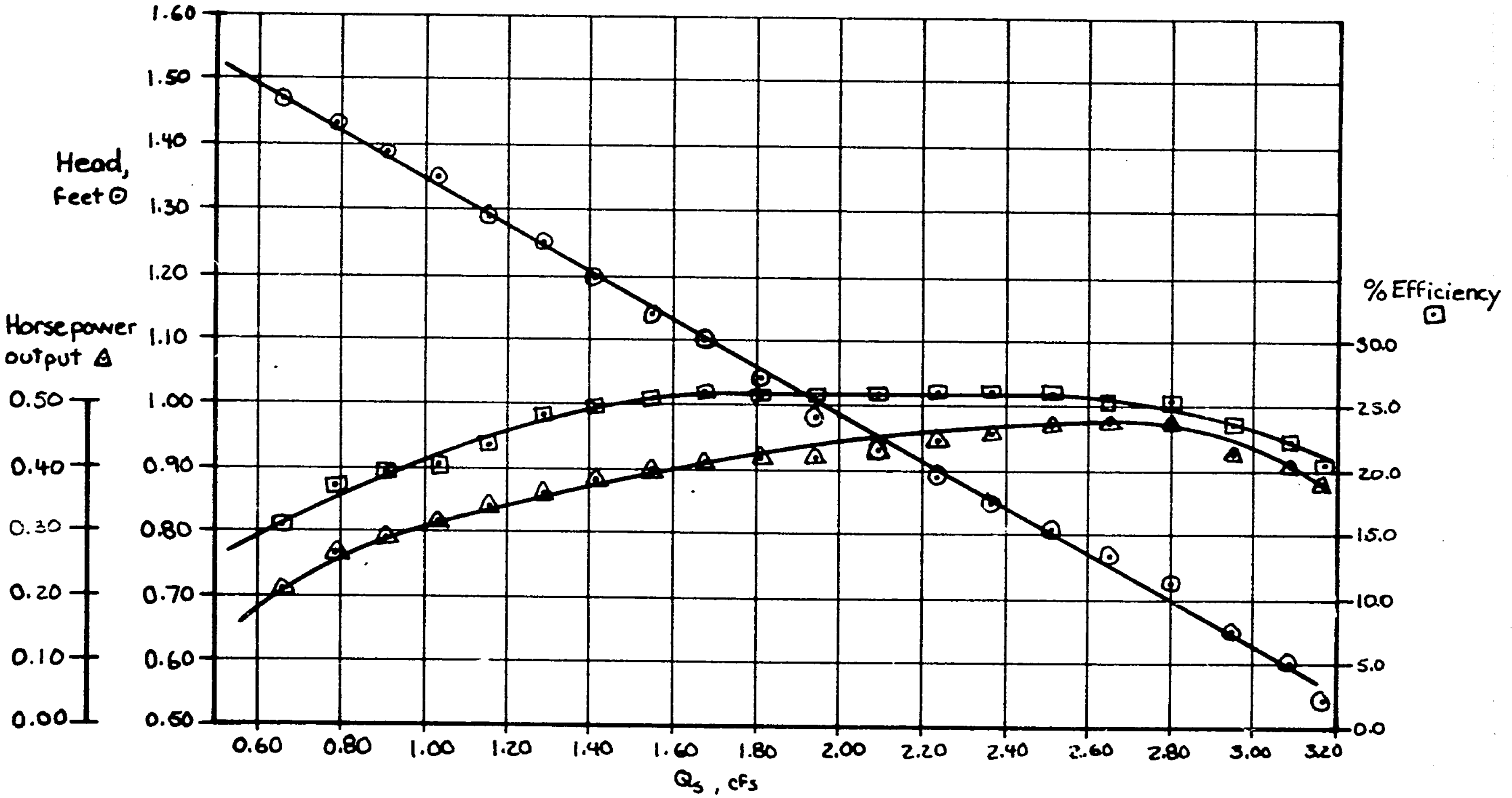


Figure 4. Characteristic performance curves for jet pump when L=56"+ diffuser, s=5.0", and Q_p (Q_m) = 2.25 cfs.

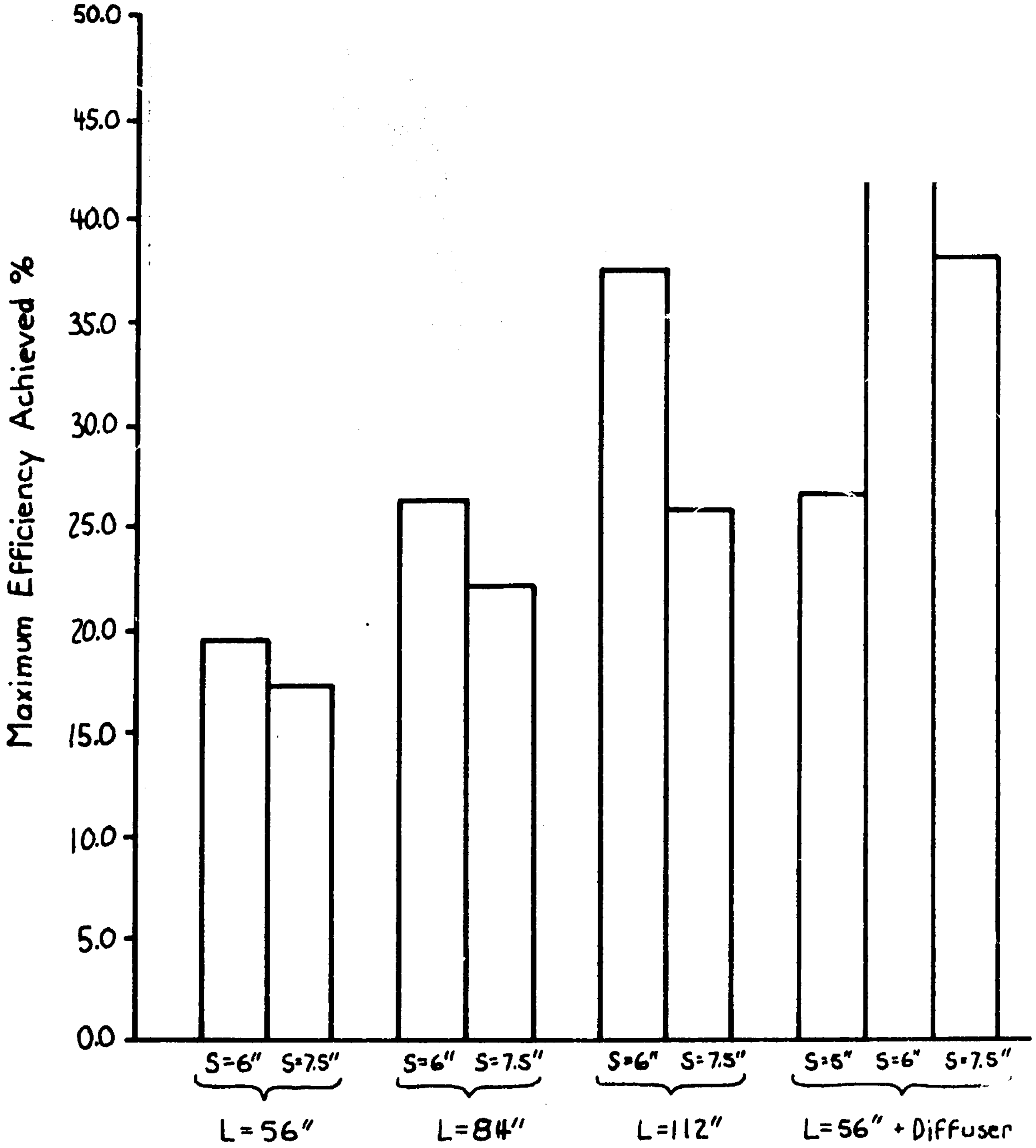


Figure 5. Maximum efficiency achieved vs. configuration of jet pump.

longer mixing chamber seemed to be more dependent on the location of the nozzle than the shorter mixing chamber.

Cost Estimates

The cost estimates were made assuming the jet pump would be manufactured in Pakistan. The pump could be manufactured almost entirely out of concrete with the exception of the main driving nozzle which would be constructed of steel. The suction nozzle mixing chamber, and the diffuser could be manufactured at any company which is capable of mixing concrete pipe. The jet pump could be manufactured in 4 components; the diffuser, the mixing tube, the suction nozzle, and the driving nozzle. The diffuser and suction nozzle are just steel reinforced concrete cones, similar to bell-mouth culverts that are currently being manufactured. The cost of these two components is estimated to be $8.10 for the diffuser and $5.55 for the suction nozzle. The mixing tube is just standard 10" concrete pipe at a total cost of $5.00. The driving nozzle would be manufactured from 1/8" steel at a cost of $6.22. The total cost for the jet pump not including installation would be $24.87.

Permanent installation in a watercourse would require an additional $133.30 which makes the total cost = $158.19. This cost estimate was arrived at using the current costs of materials and labor shown in Table 1. McWhorter and Zuberi (1972) estimated the cost of a Persian lift powered by two bullocks and a small boy to be $768.90 in 1972. Because of inflation, this amount is probably closer to $1153.35

Conclusions

The jet pump appears to meet all the requirements of a design for raising water. It is economical, much more economical than the current alternative which is a Persian lift. Because of the simplicity, a jet pump is extremely reliable; there are no moving parts to wear out. The jet pump can be practically manufactured in Pakistan in existing facilities.

The low-head jet pump seems to be a feasible solution for lifting water in Pakistan. Even though the efficiency of 42% sounds low, the energy in the form of hydraulic head at the tubewell is available and currently being wasted.

The low-head jet pump seems to have a fairly flat efficiency curve so a change in the flow rate of ±30% does not seem to affect the efficiency more than 5%.

The optimum parameters seem to be the 56" mixing chamber + the diffuser and the nozzle distance S equal to 6.0".

Table 1. Current costs of materials and labor in Pakistan.

Materials	
Concrete	Rs 7.58/ft^3*
Steel	Rs 2.73/lb
Concrete pipe, 10" I.D.	Rs 12.5/ft
Labor	
Engineer	Rs 100/day
Mason	Rs 30.00/day
Laborer	Rs 15.00/day

*Rs 10.00 = $1.00

It is thought that the low-head jet pump might have similar applications in this country where there is a supply of water available at a low hydraulic head.

Recommendations

The limited time available prevented complete investigations of all the parameters of the jet pump which might affect efficiencies. It would be desirable if a more complete study could be completed since the design has such an immediate important application. Since the production model will be constructed of concrete, it would be desirable to run some experiments with a concrete model. More investigations should be made as to other practical applications made in this country as well as other countries since the pump uses a source of energy that is often not utilized.

Appendix

Efficiencies

It should be noted that the efficiency of jet pump is calculated by two different methods so when reading literature it can be confusing. The first method, used in this report, can be calculated by either a momentum or energy balance where:

$$\eta_1 = \text{efficiency} = \frac{\text{power or momentum gained by suction fluid}}{\text{power or momentum lost by driving fluid}} \quad (6)$$

The second method used by Mueller (1964) is calculated from:

$$\eta_2 = \text{efficiency} = \frac{\Sigma \text{ power or energy downstream of pump}}{\Sigma \text{ power or energy upstream of pump}} \quad (7)$$

Two completely different values can be obtained from these different expressions. It must be realized that the efficiencies are the same in either case and these are just two different notations for expressing the efficiency. This also applies to power output.

Calculations

Following is a sample calculation of efficiencies and power output.

given $Q_p = 2.25$ cfs
$H_p = 4.23$ ft
$Q_t = 4.50$ cfs
$H_t = 0.90$ ft
$H_s = 0$ (datum)

$$\eta_1 = \frac{(Q_t - Q_p)H_t}{(Q_p(H_p - H_t)} = \frac{(2.25)(0.90)}{(2.25)(3.33)} = 27.0\%$$

$$\eta_2 = \frac{Q_t H_t}{Q_p H_p + Q_s H_s} = \frac{(4.50(0.90)}{(2.25)(4.23) + (2.25)(0)} = 42.6\%$$

$$\text{power output} = \frac{Q_t H_t \delta}{550} = \frac{(4.50)(0.90)(62.4)}{550} = 0.459 \text{ hp.}$$

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APPENDIX 16

ESSENTIAL IMPROVEMENT BY FARMERS OF THE WATERCOURSE SERVING TUBEWELL #MN60[1]

by

Moh'd Mohsin Wahla, W. D. Kemper and M. Munir Chowdhry[2]

> Bacha khuf say,
> Bara shuk say,
>
> "A child can be forced to learn,
> but an elder learns when he is interested."
> --Punjabi Proverb

Understanding farm and village life, its perceived pleasures, problems, pressures and the demands made on individuals is important in interesting the farmer in any improvement project. It is particularly helpful on improvement programs such as the watercourse improvement program in Pakistan, where cooperative action by all the farmers is needed to achieve the desired benefits.

Experiences on several Pakistani watercourses had indicated that illiteracy was not a major barrier to the farmers accepting the challenge to improve their watercourses. Increased water supply to their fields and concrete control structures were the results of farmers efforts at watercourses serving Tubewells No. 56, 57, 51, 81R and 81L (e.g. Mona-CSU team 1977).

This series of watercourses has been improved as consecutive research studies to help develop a watercourse improvement program that is beneficial and acceptable to the farmers. This watercourse improvement program has become a major component of the "On Farm Water Management Program," a development program currently underway in the Punjab, Sind and North West Frontier Provinces. That program includes provision of concrete control structures to the farmers. Current reports indicate that the rate at which these structures can be installed is limiting the rate at which the program is being implemented. Consequently, the question has arisen as to whether the increased water supply was sufficient incentive to motivate the farmers

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[1] This study was supported by USAID Contract, AID/ta-C-1411 and USAID/Pakistan Research Grant No. 204-75.

[2] Senior Research Officer, Extension and Training, Mona Reclamation Experimental Project, Water and Power Development Authority, Pakistan; Co-director of the Colorado State University, Water Management Research Project and Director of the Mona Reclamation Experimental Project and Water and Power Development Authority respectively.

to improve their watercourses, or whether the concrete structures were essential incentives. Consequently, the following effort was made to motivate the farmers served by Tubewell No. 60 to improve their watercourse, with the only initial incentive being assurances by the government personnel that the water deliveries to their fields would substantially increase.

PROGRAM INCENTIVES

A recent visitor from the USAID Mission in Afghanistan to one of the USAID funded watercourse improvement projects at the Mona Reclamation Experimental Project observed the farmers hard at work improving their watercourse. The visitor asked, "What bribe or threat have you given these farmers to make them work so hard?" The advisers replied that the farmers were given promises of materials to build their control structures, estimates about how much water they could save, and estimates of how much work they would have to do.

The visitor replied, "I do not believe that you are telling the whole truth. I have worked with farmers in developing countries for many years and have never before seen a large group like this working so hard to help themselves. I believe that the Mona Project Director must have threatened these farmers and told them that their water would be stopped unless they did what you told them to do!"

Other visitors to the watercourse improvement projects have expressed similar thoughts. The pertinent question in all pilot development programs with farmers is "What components of these projects are essential to motivate the farmers to help themselves?" The purpose of this study was to determine whether a basic promise of increased water supply was sufficient motivation or whether the concrete structures were an essential incentive. The approach to the farmers is documented as a case history, realizing that the reactions are a function of the personalities involved as well as the approach used. However, this single case does provide an indication of the reaction which may be expected from the farmers.

PROGRAM PRINCIPLES

From the beginning of the USAID-funded Mona watercourse improvement projects the following principles were adopted.

1. The function of the Mona-CSU team is to act as advisers to the farmers, and to bring them information which will allow them to make better decisions on how to manage their resources themselves.

2. The farmers are in charge of these programs. Their elected executive committee is responsible for the improvement program.

3. Farmers are best helped by doing for them only those things they cannot do for themselves. Doing for them what they could do for themselves causes them to consider the government wasteful and easy to take advantage of and causes them to lose pride and confidence in their own ability to help themselves.

Adherence to these principles has not always been easy. In some cases project delays have been caused by letting farmers make their own decisions, but usually the wisdom of the decisions has eventually become apparent.

CRITICAL QUESTIONS

In implementing the program principles some of the critical questions that team members have faced in the role of motivating farmers have been the following:

1. Do we respect their individuality?

2. Do we encourage these individuals to find some of their own solutions while communicating the process of problem identification and solution?

3. Do we encourage them to take lead roles as decision makers in developing and implementing programs designed to meet their needs?

4. Are we willing to change some of our own objectives and adopt objectives drawn up by our clients?

5. Are we willing to learn from these farmers and realize that they can teach us much which will enrich our program and our lives?

6. Are we willing to diagnose the needs of different farmers instead of handing out standardized recommendations which may not fit their needs?

The progress and success of the watercourse program has been proportional to the degree that the advisers have responded positively to these questions.

GAINING CREDIBILITY WITH AND MOTIVATING FARMERS

An extension field assistant who lived in the village and knew many of the farmers invited them to meet under a large tree to discuss improvement of their watercourse with the project coordinator. The project coordinator began by introducing himself as "a farmer of District Lyallpur" with some knowledge which he had gained in a government program that might interest them. Each of the farmers introduced himself. A philosophical discussion then followed on the responsibilities of man to his fellow men, their potential for helping each other through cooperative efforts and the responsibility, that Allah has given each of us, to help ourselves before asking help from the government.

Attention to, and consideration, of the thoughts of each speaker developed an atmosphere of faith and confidence which bridged the differences between members of the group under the tree. Sensing that these bridges had been built, the coordinator directed the discussion to a more pragmatic path and asked "Why do you not use your water in April to irrigate your wheat?" A farmer answered that "when wheat has reached this stage of maturity, irrigation will not cause it to become green and grow again or increase yield and the water would be wasted." The coordinator complimented them on the wisdom of this decision, but added, "As I came to sit with you I walked along your watercourse and saw leakage through rat holes in the banks, through improperly closed outlets and through the thin banks where you have borrowed soil to build dams as junctions. Your watercourse appears to be losing as much water as was being lost on other watercourses where we have made measurements. How much water do you believe is being wasted by leakage from your watercourse?"

A couple of opinions were offered and then the question was reflected back to the coordinator. "Your team has been making such measurements, your estimate will be better than ours, tell us how much you think we are wasting."

At this invitation the coordinator came on strongly and stated, "You are wasting about half of your water through leakage from your watercourse. This is the water for which you pay, the life blood for your crops, animals and yourselves; the water over which you fight and even kill each other. This is the water which is God's best blessing (AL QUARAN); the water for which you will be called to account (AL`HADITH). Our American advisers have told us that loss of this water is a primary factor which limits our crop production and keeps our country poor. My elders and friends, how long will you bear this loss? For whose arrival are you waiting?"

"We are here to help you if you wish to help yourselves. Your field assistant, Muhammad Ali, and I can give you advice which will allow you to improve your watercourse so that your losses will be reduced to less than half of what they are now Insha-Ullah.[3] By showing this proper appreciation and stewardship

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[3] With the approbation of God.

of God's blessing you will increase the amount of water delivered to your fields. Improving your watercourse to take better care of your water is to obey an Islamic law, and you will find it gives you a feeling that you have done your duty."

The farmers were interested. Some wished to start the improvement program immediately, others wished to wait for about two months until the wheat harvest would be over. The coordinator informed them, "It is your program and your decision. However, we can be available to work with you only for the next three weeks."

The farmers decided to start the improvement program on the following Monday.

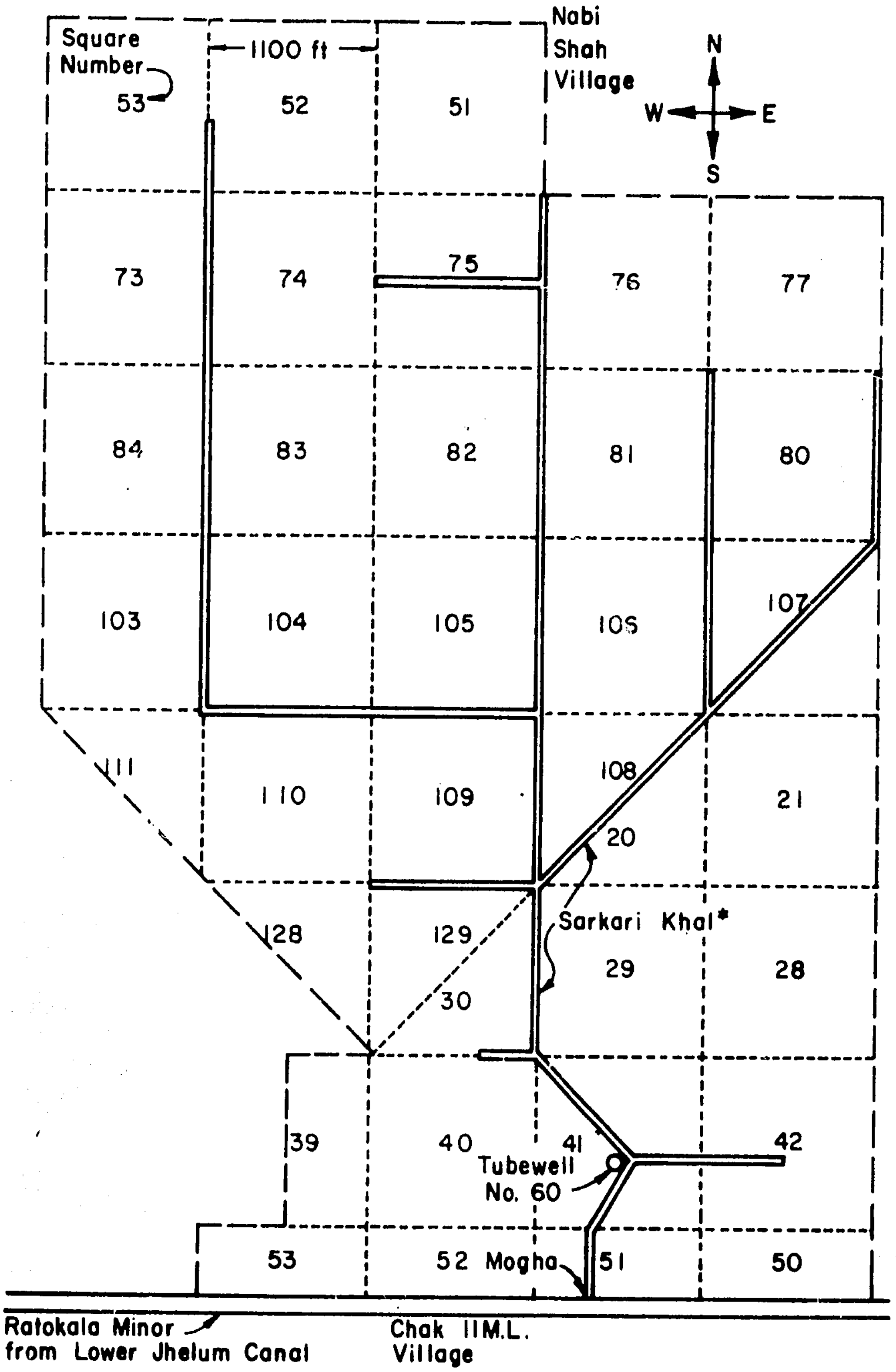
ORGANIZATION OF THE FARMERS EXECUTIVE COMMITTEE

The watercourse drawing from Tubewell 60 serves two villages as shown in Figure 1. Village No. 11M.L. is populated primarily by a Balauch biradari.[4/] Village Nabi Shah is primarily populated by the Syyed biradari. Election of an executive committee to provide organization for their efforts was suggested to the farmers. The responsibilities and authority recommended for this executive committee were outlined. Two members from each biradari were elected unanimously. Discussion resulted in the following decisions:

1. Improvement will start next Monday.
2. Labor will be assessed at the rate of three men per square.[5/]
3. Improvement will start from the head of the main branch and proceed according to water turns on all side branches.
4. The mogha and tubewell will be closed during improvement of the main branch.
5. Farmers will uproot their trees and remove them from the watercourse banks before improvement of their particular branch.
6. Working hours will be from 6:00 A.M. until 12:00 noon or until each work assignment is complete.
7. No farmer can leave until his improved section is approved by the Field Assistant on duty.

[4/] Brotherhood

[5/] A square is 25 acres of land.



* Government Authorized Watercourse with a Legal Right of Way to Permit Water Delivery to each Farmers Land. This is Cleaned and Maintained Cooperatively by the Farmers.

Figure 1. Map of the area legally served by water from Tubewell 60 and its associated mogha from the Ratokala Minor.

8. None of the executive committee members will take casual leave.

9. Following improvement no one will be allowed to graze animals on the watercourse.

10. Soil for junctions and banks can be borrowed from adjacent fields.

11. The Executive Committee made a pakka[6] promise to develop a program for cleaning and maintenance of the watercourse which will keep its delivery efficiency high.

NATURE OF IMPROVEMENT

The improvements suggested to the farmers were:

1. Removal of trees, shrubs and coarse grasses on the watercourse banks which were increasing transpirational loss, causing partial blockages in the channels and making access difficult for detecting leaks, closing leaks and cleaning and maintaining the channels.

2. Closing all observable leakages where water was running into adjacent fields from the watercourse.

3. Cleaning all the silt, grass and weeds from the channel, and generally increasing its depth by 3 or 4 inches so the normal operational level of water in the watercourse can be lowered 4 to 6 inches.

4. Widening and compacting the banks (18" wide at top with about 1:1 slope), particularly at junctions.

5. Filling sections of the watercourse which are so deep that water will not drain out of them, or excavating the channel between these deep sections so that practically all the water drains out of the watercourse into the fields.

6. Filling all borrow pits near the junctions by hauling in soil from high areas in adjacent fields.

The farmers adopted these suggestions as their plan for improvement. Sections prior to, during, and following improvement are indicated in Figure 2.

The government-authorized sarkari khal included 25,000 feet of watercourse. The executive committee selected the

[6] Firm

Figure 2. Sections Before and After Essential Improvement

A. Grassy section before improvement.

B. A degraded junction with borrow pits full of water and leaking banks before improvement.

C. Improvement in progress.

D. Farmers watching smooth unhindered flow of their water following watercourse improvement.

sarkari khal as the portion of the watercourse to be improved. The sarkari khal has a designated legal right of way from which soil can be borrowed for the maintenance and improvement of the banks.

Beyond the sarkari khal, the sections of watercourse are generally owned by a single farmer and while it is important that these sections be cleaned, the benefits all accrue to the farmer who makes the improvement. Consequently, the timing and degree of improvement becomes an individual matter to be decided on and implemented by the individual farmer involved.

AMOUNT OF TIME AND LABOR INVESTED BY THE FARMERS

The 25,000 feet of watercourse were improved by the farmers who spent a total of 6,240 man hours. The length of watercourse improved per man hour was 3.7 feet. This is almost twice as much watercourse improved/hour as compared to the regular watercourse improvement program where the banks are pulled down and the watercourse is made precisely straight.

The Watercourse Improvement Project Coordinator spent about 10 hours with the farmers and his Field Assistant spent 130 hours working with the farmers as indicated in Table 1.

Assuming the cost of farmers' labor to be Rs. 1/hour, of the Field Assistant to be Rs. 3/hour and the Project Coordinator to be Rs. 10/hour, the costs of the improvement are calculated in Table 1.

Table 1. Summary of Improvement Costs

Source of Work	Hours	Rs./Hour	Cost of Work
Farmers	6240	1	Rs. 6240
Field Assistant	130	3	390
Project Coordinator	10	10	100
Total cost			Rs. 6730

The total cost to the government of Rs. 490 was minimal. The farmers were not promised concrete control structures or incentives other than the fact that the amount of water delivered to their fields would be increased. In fact, they had the disincentive that they knew that farmers within three miles of their watercourse had been given concrete control structures as part of the regular watercourse improvement program. Consequently, the point was proven that at least some farmers will participate in cooperative watercourse improvement programs with the anticipated increased water supply as their only incentive.

BENEFITS RECEIVED FROM IMPROVEMENT

The areas owned, the length of the watercourses from the canal outlet (mogha) to the fields and the time allocated to each farmer for irrigation were information which could be collected from the farmer and verified from public records. These are recorded in Table 2. The area irrigated per hour, before and after the improvements, were obtained through interviews with farmers.

The increase in acres irrigated per turn as reported by the farmers averaged about 64%. This is higher than has been measured on the watercourse improvement programs at Tubewells 56, 51, 57, 81 and 81L. At these other watercourses, there has been a tendency by the farmers to exaggerate the benefits derived from the improvements. This tendency is a natural result of their feeling that this was their program and their achievement. It is common for most men to exaggerate their achievement. It is probable that the long term increases in delivery efficiency will be only about half of those indicated in Table 2.

However, an increase of even 32% in water supply to their fields will mean about 360 additional acre feet delivered to their fields each year. Since the improvement cost was only Rs. 6730, the cost of the additional water would only be Rs. 20 per acre foot if the same improvement were done each year. The cleaning and maintenance program necessary to keep these watercourses in condition so that they can maintain these delivery rates would require less labor per year than the initial reconstruction. Farmers at Tubewell 56 have indicated that once the watercourse has been properly improved, maintaining it requires fewer hours than were spent before the major improvement. However, these cases are not directly comparable since the farmers at Tubewell 56 received concrete control structures, buffalo baths and culverts, all of which retard the deterioration of the watercourse.

An estimate of the cost of cleaning and maintaining the watercourse at Tubewell 60 (serving about 750 acres) to keep the delivery efficiencies high would be about Rs. 4500 per year, or Rs. 12/acre foot of water.

FARMERS' ATTITUDE TOWARD IMPROVEMENT

Most of the farmers working at the watercourse were not literate. However, their response was enthusiastic. Their wives and children (i.e., Figure 3) brought their breakfast to them on the watercourse, indicating their desire to get the job done and a strong component of family participation in the project. Following the improvement program, a number of the farmers walked several miles in the severe heat of June to

Table 2. Descriptions of holdings, length of water turn, areas irrigated before and after improvement and distance of farm from the mogha.

	Farmer's name	Area owned (acres)	Water turn hours-minutes	Area irrigated/ hour before improvement	Area irrigated/ hour after improvement	% increase	Distance from outlet** (feet)
	CHAK-11						
1.	M. Yar s/o* Ahmad Khan Blauch	4.5	1 - 7	4 kanals***	6 kanals	50	220
2.	Yara s/o Ghulam Blauch	4	1 - 0	4 "	6 "	50	660
3.	Waryam Azam, etc.	15	3 - 34	5 "	8 "	60	220
4.	Ramzam s/o Ghlam Blauch	2	0 - 34	4 "	8 "	100	440
5.	Sultan s/o Dadu Blauch	30	7 - 3	4 "	6 "	50	1100
6.	Tahari s/o Raja Blauch	2	0 - 34	4 "	6 "	50	1320
7.	Khudo Yar, Nowaz, Yara & Riaz	9.5	2 - 18	6 "	9 "	50	1320
8.	Omar Hayat s/o Ghulam Blauch	12	3 - 0	6 "	10 "	65	1320
9.	Nawaz s/o Nozar Mohammad	8	2 - 0	6 "	10 "	65	1320
10.	Dosa, Dao, Dari, etc.	10	2 - 35	4 "	6 "	50	1760
11.	Raja M. Ashraf s/o Ghus	20	5 - 0	6 "	10 "	65	1100
12.	Waris, Hayat, Fazal, Allah Bux	15	3 - 30	3 "	6 "	100	2200
13.	Murad, Riaz, Manzoor Blauch	20	5 - 0	2 "	4 "	100	2200
14.	Muhammad Yagoob Blauch	6	1 - 30	5 "	8 "	60	2200
	VILLAGE NABI SHAH						
15.	Nawab Shah s/o Zaman Shah	10	2 - 20	6 "	9 "	50	3300
16.	Haider Shah s/o Najeeb Shah	25	6 - 0	4 "	6 "	50	7700
17.	Raja Shah s/o Najeeb Shah	25	6 - 0	3 "	4½"	50	8800
18.	Mirza Bashir Dewana	20	5 - 0	4 "	7 "	75	3500
19.	Zabir, Rahman	15	3 - 0	4 "	6 "	50	6600
20.	Ibin Hasan, M. Hasan, Bag Shah, etc.	20	4 - 0	3-5"	6 "	60	7040
21.	Anwar Shah s/o Najat Shah	25	6 - 0	5 "	9 "	80	5500
22.	Ghulam Shabbir s/o Haider Shah	14	3 - 5	6 "	10 "	65	3300
23.	Lal Shah s/o Alam Shah	8	2 - 10	6 "	11 "	80	5500
24.	Hussain Shah s/o Chanan Shah	15	3 - 30	7 "	11 "	60	5500
25.	Ashiq s/o Dara	8	2 - 10	7 "	12 "	70	3740

* s/o means "son of"

** Length of the watercourse between the outlet from the canal and the farmers fields.

*** A Kanal is 1/8 of an acre.

Table 2. Descriptions of holdings, length of water turn, areas irrigated before and after improvement and distance of farm from the mogha.

	Area owned (acres)	Water turn hours-minutes	Area irrigated/ hour before improvement	Area irrigated/ hour after improvement	% increase	Distance from outlet** (feet)
26. Sakandar s/o Shah Nawaz	8	2 - 0	5 kanals	9 kanals	80	6600
27. Zaman s/o Moh'd Shah	8	2 - 10	7 "	12 "	70	4400
28. Dewan Shah s/o M. Shaw	22	5 - 0	7 "	10 "	60	8800
29. Mehdi Shah s/o Anwar Shah, etc.	33	7 - 0	5 "	9 "	80	8800
30. Lol Shah s/o Behadar Shah	15	3 - 15	8 "	12 "	50	7700
31. Ahid, Khadim, Shohobol s/o Nadir Shah	18	3 - 45	7 "	10 "	60	4400
32. Toor Shah s/o Najab Shah	30	6 - 0	7 "	10 "	60	5500
33. Chanan Shah s/o Aror Shah, etc.	80	16 - 0	6 "	10 "	65	7700
34. Najab Shah s/o Sardar Shah	40	8 - 0	6 "	7 "	50	7920
35. Azman Shah s/o M. Shah, etc.	40	8 - 0	6 "	9 "	50	8140
36. Ibin Hasan, M. Hazan, Baj Shah, etc.	20	4 - 0	4 "	6 "	50	8800
37. Raja Anwar, Mulazim, etc.	45	10 - 0	3 "	5 "	70	9900
38. M. Hussain s/o Qasim	18	4 - 0	2½"	4½"	80	10340
39. Mulazam s/o Najeeb Shah Numberdar	30	7 - 0	2 "	4 "	100	11000

Figure 3. Children taking breakfast to their fathers.

express their appreciation to the extension workers who helped them. Recent reports indicate that the farmers have developed a good maintenance program as they had agreed to do when they planned their improvement program. The farmers are willing to work on the maintenance because they have seen the extra water that they have gained and because they understand the value of the extra water to their crops.

To get out of command (no longer required to pay for irrigation water) a farmer, whose land was at the tail end of the watercourse, had registered a suit in court to be relieved of water taxes. He pleaded that he had not been irrigating his fields since November, 1965 because water was not reaching his fields through the watercourse. Following improvement he withdrew his plea on the basis that he felt he was now "not only receiving water, but receiving my share."

GENERAL PHILOSOPHY OF THE APPROACH

"Man's greatest enslaver has always been ignorance. His greatest emancipator has always been truth, understood and wisely acted upon. The transformation of man's behavior, based on ignorance, to behavior based on truth is a dramatic process." (Leagans, 1963). The government policy of allowing farmers to do as they desire, as practiced in the past on the watercourses is probably a good policy for countries in which farmers understand all the facts which allow them to make the best decisions. However, it is becoming apparent that most of the farmers of Pakistan need information and guidance which will allow them to use their own initiative and resources to improve their water management. Given this information and guidance in this project they were willing and effective in bringing about the improvement.

The interactions with the farmers in this study appear closely in tune with the ideas of Leagans (1963) whom we paraphrase as follows.

Hence, the process is one of working with people, not for them; of helping people become self-reliant, and decreasing their dependency on others; of making people the central actors in the show, not stage hands or spectators. In short, the key to farmer's development is the human element. Permanent change comes only from within. Permanent change is not successfully imposed from without.

TECHNICAL QUESTION: SHOULD CONCRETE CONTROL STRUCTURES BE INCLUDED IN AN ESSENTIAL IMPROVEMENT PROGRAM

Costs and Benefits of Control Structures

Concrete control structures were installed on the previously improved watercourses at costs ranging from about Rs. 600 down to about Rs. 100/structure. The purpose of these structures is to facilitate direction of the water to the point in the watercourse system where it is needed and to stop the flow of water into other branches. Satisfactory structures (of the type shown in Figures 4 and 5) to handle about 4 or 5 cusecs of water, as are allocated to this watercourse, would cost about Rs. 220 each. Maintenance costs on these structures will probably range around Rs. 20/year, for a total annual cost of Rs. 50 assuming capital can be borrowed for 10%.

Farmers spend an average of about 10 minutes constructing the average earth dam on a watercourse carrying 4 or 5 cusecs of water, moving about 6 cubic feet of soil and compacting it into the watercourse. He then spends about 3 minutes removing the dam, generally opening a small hole and allowing the rushing water to wash about half of the soil downstream in the watercourse from which it must later be removed with about 5 minutes worth of labor. The three cubic feet of soil borrowed from a farmer's field next to the watercourse and washed downstream must eventually be replaced by bringing it from adjacent fields at a cost of about Rs. 0.3 per 3 cubic feet. This amount of time and expense, incurred about 50 times/year results in a labor cost/year of about 15 hours plus about Rs. 15 to pay for bringing soil from adjacent fields to these junctions to fill the borrow pits. Assuming labor worth Rs. 1/hr, labor and earth moving cost that could be saved by having the structures is about Rs. 30/year.

An additional benefit of the structure is the reduction of the water loss which takes place in the vicinity of these junctions. Kemper and Akram (1975) found that almost 50% of the water loss on one branch occurred within 30 feet of the junctions where borrowing of soil had narrowed the banks, taken away much of their external support and generally made them more prone to leaks and breakouts.

If annual maintenance replaces the soil borrowed at these junctions, this junction degradation could be kept within reasonable limits and it is likely that it would not increase the loss (compared to having structures) by more than 2% of the total flow. However, even 2% of the flow in a watercourse drawing 5 cusecs from the canal and the tubewell amounts to .1 cusec, or .2 acre feet per day, or about 60 acre ft/year. The value of water is at least equal to its pumping cost (Hussain et al., 1976) which for water delivered to the fields

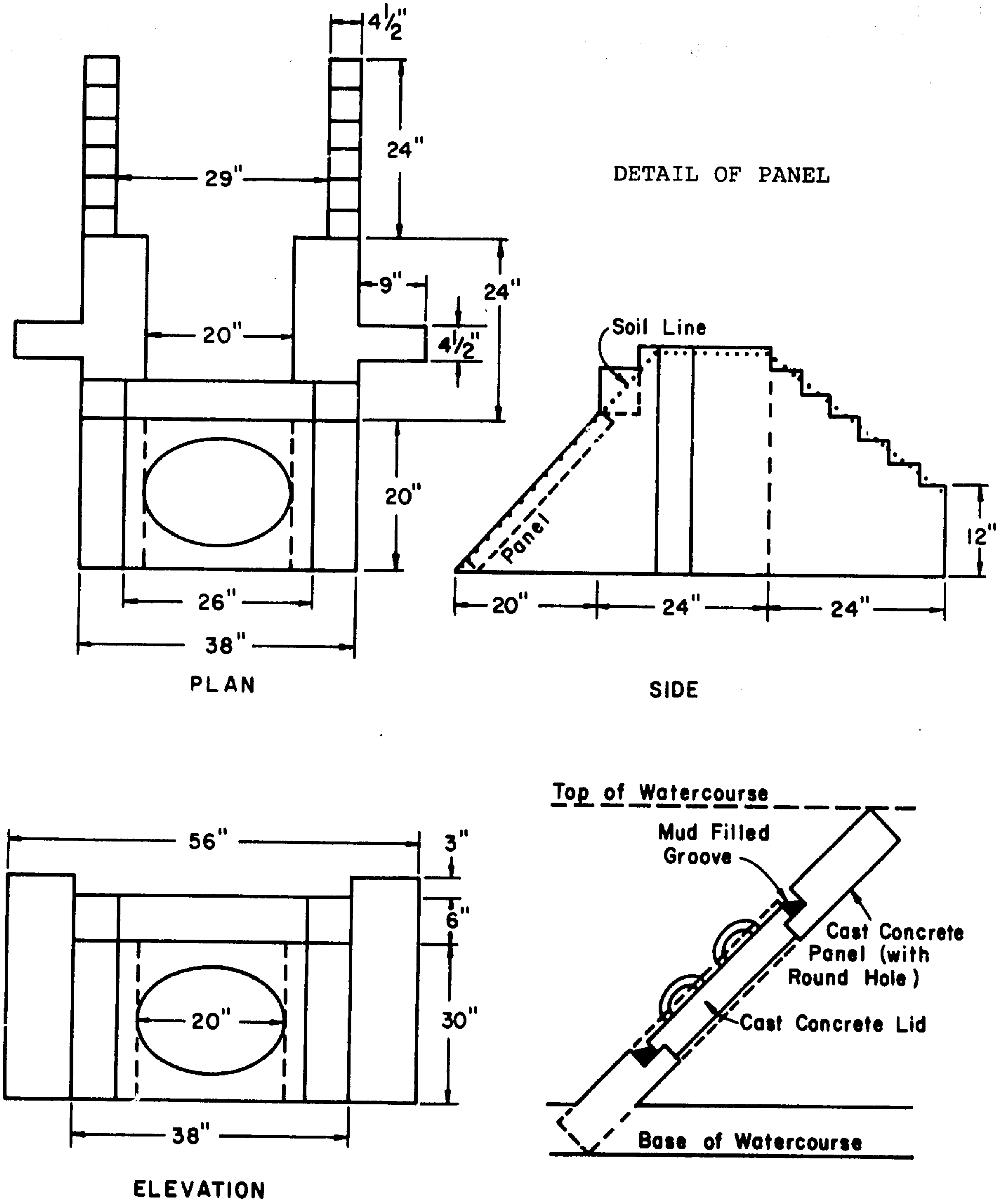


Figure 4. Concrete Control Structures.

Figure 5. Farmer Inspecting Concrete Control Structure at the Watercourse Serving Tubewell 81.

is about Rs. 100/acre; consequently, the value of the water saved could be as much as Rs. 6000/year. About 70 control structures would be needed on this watercourse, and, consequently, the indirect cost of not having a structure is about 6000/70 = Rs. 80/year (assuming that structures would result in 2% more of the canal and tubewell water getting to the farmers' fields). This figure is obviously a rough estimate, but even if the water saved by installing structures were 1% rather than 2%, the savings would be sufficient, when combined with labor savings, to justify installation of control structures.

Farmers' Ability to Pay for Concrete Control Structures

Since the farmers on this particular watercourse had displayed such enthusiasm in using their labor to improve their watercourse, and the above analysis indicates that concrete control structures are a good investment for the farmers, the question arose as to whether they should, or could, make such capital investments. The average income of rural families in Pakistan in 1964 is shown in Figure 6. Since that time inflation and increased productivity have raised rupee incomes to about 250% of their 1964 figures. A major portion of those families earning less than Rs. 100/month in 1964 were landless labourers. Considering these factors, the average income of small (less than 25 acres) farmers would now (1977) be about Rs. 400/month. Consequently, the purchase of 70 control structures by the 39 farmers served by the watercourse would require about one month's income from the average farmer.

However, the question of whether an investment can be afforded by a group of individuals must often be answered in terms of whether the poorest people involved can afford the investment. Consequently, an informal survey of economic conditions was made in several of the homes of farmers with the smallest holdings.

In the first home visited by the interviewer the mother and her son were suffering from malaria and the family had no means of buying the medication to cure them. The interviewer brought the needed medication the next day, but the mother and son were not able to take it because it was supposed to be taken with milk and they had no milk, nor money to buy milk.

In another household there were three daughters and three sons. One son was very small and the other two sons were herding the family's goats. None of these sons go to school, even though the cost of school and books at the elementary level is only Rs. 30 or 40 ($3 or 4) per year. When asked why his sons were not in school the father said, "I cannot educate them as yet because I must first arrange marriages and dowry for my daughters."

Another farmer said "My hookah[7] is my best friend. I start smoking at 4 A.M. to dissolve my grief. My family is large and my holding is small. After payment of land taxes and other expenses, our wheat grains are consumed by November, and I must borrow seed from others."

At one home, the farmer was very direct when asked about his finances. He said to his wife "Holima, let Sahib check our paytey.[8]" The box contained a turban, a big sun hemp rope, some cloth and a purse containing two ten rupee notes.

The mother and daughters of one family were found in a wheat field plucking heads of barley. The following conversation ensued. "Sisters, these barley heads are not yet filled. Why are you plucking them? Are you purifying your wheat stand?" They answered, "No brother, we will eat these as we have nothing else to eat."

Another pertinent observation occurred while the watercourse improvement was in progress. Food was brought to the laborers for breakfast, commonly by their daughters (i.e. Figure 3) who carried a set of food boxes on their heads, usually with chapatees[9] in the bottom box, occasionally vegetables or pickles in the next and generally topped by a small crock of milk or buttermilk. The extension agent urged the farmer to go ahead and eat while he was being instructed. The farmer slowly drank the buttermilk and the extension agent casually opened the other food box, but it was empty. The farmer quickly covered it again and said, "Please do not tell my neighbors. Our food is gone and we have only a little milk from our buffalo, but my neighbors must not know or they will laugh at me because I am so poor.[10]"

This is not the whole picture. There are farmers with larger holdings who have reasonable incomes. Well managed citrus gardens can bring incomes up to Rs. 10,000/acre in some years! Most of the land and the water are good. Much of the poverty is due to mismanagement of resources. However, their constraints are often very real in the form of lack of power and equipment to properly cultivate and shape their land for irrigation, lack of credit (for fertilizer, insect spray, etc.) and particularly lack of information concerning how to bring more water to their fields, increase their crop yields and understand the market opportunities available to them. Many of these constraints could be removed by an intensive

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[7] Water cooled tobacco pipe.

[8] The paytey is a locked box in which the family generally keeps all its valuables. The wife generally keeps the key.

[9] A flat unleavened bread.

[10] Wheat harvest was only about three weeks away and it is likely that several of the poorer farmers' families were out of wheat, their basic food.

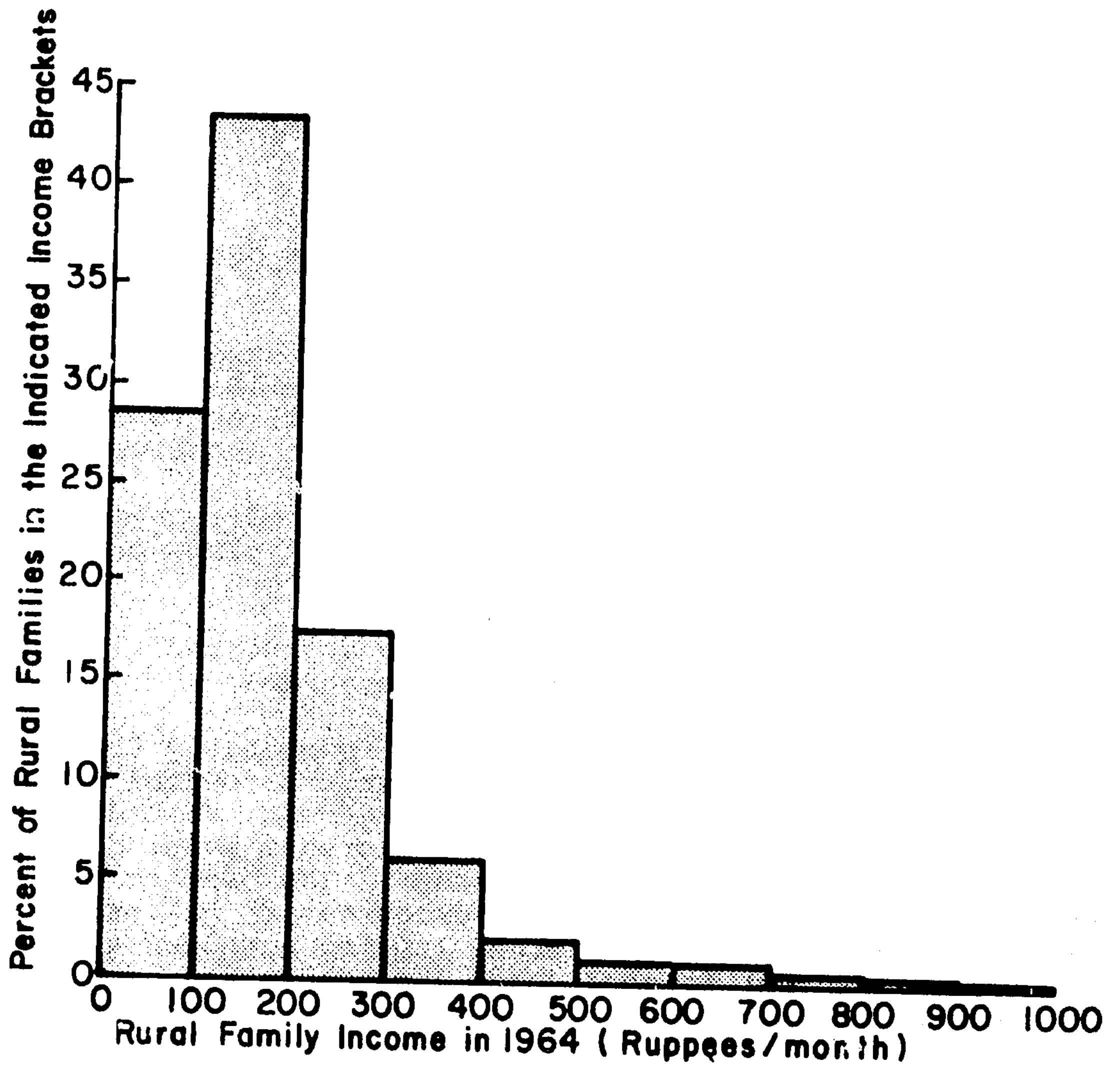

Figure 6. Income Distribution in Rural Pakistan (Bergman 1967).

extension approach, such as this essential watercourse improvement program which will allow them to irrigate about 30% more land than they have been irrigating in the past.

However, the primary question that this brief and qualitative survey was to answer was whether the farmers could presently afford to pay for concrete control structures on their watercourses. Paying for these structures would obviously be a real hardship for several farmers on this watercourse which is probably reasonably representative of a large portion of the watercourses in Pakistan. Social pressure and pride of poor farmers would in many cases cause them to enter into such programs, even though this would cause serious food deficiencies in their homes.

Effect of Including Control Structures on a National Program for Essential Improvement of Watercourses

These water control structures are a reasonable good investment and developed countries (e.g. USAID) and international agencies (e.g. World Bank) are willing to loan the capital for such investment. The remaining questions are:

1. Will this borrowing, development and repayment be good for the country if this takes place on a national scale?
2. Will the installation of such structures slow down the watercourse improvement program?

The answer to the first question is probably the affirmative. The structures will help the farmers control their water. They facilitate a higher level of management, retard degradation of the watercourses and should increase water deliveries to the fields by at least one percent. The cost to install such structures in the 88,000 watercourses in Pakistan would be about $100,000,000. External leading agencies are willing to loan this amount if good sound implementation programs are developed. The necessary bricks and cement can be produced within the country. The cement required would be about 0.8 bags/structure, or about 3,500,000 bags of cement (196,000 tons) which would be less than 3% of the national cement production over a period of 5 years. About 5 pounds of reinforcing steel would be required in each of these structures, or 8,800 tons for a countrywide program. Approximately 850 million bricks would be required, which would generally be produced locally providing about 4,250,000 days of rural employment opportunities, but using about 850,000 tons of wood and coal to fire the bricks.

The installation of concrete check structures would probably slow down the rate at which trained extension personnel could help farmers improve their watercourses in this "essential improvements" type of program. The construction period of the watercourse at Tubewell 60 was 13 days using this program where no structures were installed. When structures have been installed in a watercourse improvement program the construction period has been at least twice this long. The trained extension field assistant would probably be needed on the watercourse for a longer period of time. However, it is possible that the field assistant could select a good local mason from the masons who work on the first watercourse improvement program and encourage him to follow the development program to other watercourses, giving this private entrepreneur a book of drawings of the different types of structures needed. This mason would then compete with other masons in bidding to help farmers on other watercourses to install their structures.

Simplified instruction booklets showing dimensions, materials needed, etc., could be written for the field assistants and the masons. The field assistants could read the instructions in Urdu, but the masons would commonly be illiterate and would have to depend largely on the pictorial content of the book.

Conclusions and Recommendations

If farmers can be convinced that the government officer has come to them to help them solve their problems and that he has successful experience, they will engage in watercourse improvement projects with no incentives other than the probability of an increased water supply. They will invest their time and energy in such a project when their group decides to go ahead with it--even though their individual caloric intakes may be low.

Farmers perceived that the water supply to their field following this essential improvement program averaged about 160% of the water supply prior to improvement. This was a larger increase than has been measured on other watercourses where more intensive improvements have been made. The perception of more increase than has actually occurred is common to other improvement projects where the perceiver has been personally involved as the change agent.

The general tendency of man to overrate his own accomplishments must be considered in developing methods for evaluation of projects. The tendency also emphasizes the importance of letting farmers take leadership in the project as far as possible. The tendency can also be used to good advantage in advertising the program, by bringing the farmers from other watercourses to hear these farmers tell the enthusiastic story of their improved program.

The cost of concrete control structures appears to be a reasonably good capital investment (benefits/cost about 1.5), whereas the investment of farmers' labor to improve the watercourse is an excellent investment. (Benefits/cost ratio greater than 4). Moreover labor is a resource available to most of these farmers, whereas capital is practically nonexistent with a substantial portion of them.

Some of the larger farmers have [illegible] capital to invest in structures, but a general program [illegible] required farmers to pay for their own structures would be a hardship on the poorer farmers. A program of this type would tend to exclude watercourses serving large numbers of poor farmers. Consequently, it is recommended that government programs for essential watercourse improvement either have no provisions for control structures or, if such structures are included, that they be provided to all farmers at government expense.

Methods of involving masons as private specialists in control structure installation should be investigated in terms of how structure installation can be facilitated so that it does not slow down the improvement program.

The low cost to the government of this "essential improvement" of the watercourse at Tubewell 60, benefits perceived by the farmers, their enthusiastic participation and the rapidity with which the improvement was accomplished all argue for further consideration of this type of an improvement program to assist the country to quickly bring about the first major improvement of water supply to the farmers fields.

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APPENDIX 17

WATERCOURSE CLEANING AND MAINTENANCE PROGRAM: ITS ORGANIZATION AND INFLUENCE ON CONVEYANCE LOSS[1/]

by

Mumtaz Ahmad Awan, Ch. Bashir Ahmad, M. Mohsin Wahla,
M. Rafique Gill, Javaid Iqbal, and S. A. Bowers[2/]

INTRODUCTION

Studies conducted in Pakistan during the past 4 years show that the water conveyance efficiency on most watercourses is approximately 50 percent. Several techniques for reducing conveyance loss have been tested. The most successful were both lining and earthen improvement of watercourse channels. The use of the former has generally been discouraged because of its high cost. The latter proved most successful both because of its loss reducing capacity and because of farmer participation and subsequent low cost. However, since this earthen improvement alternative involves complete reconstruction according to new design criteria, engineering assistance is required. There is not now nor will there be in the near future sufficient engineer assistance to improve Pakistan's 80,000 watercourses.

Yet, a third alternative for reduction of water conveyance losses exists! Cleaning and maintenance of watercourses! Pakistani farmers have cleaned watercourses for decades; they are aware that excessive vegetation and sediments retard flow, increases the water level, causes overtopping, etc. However, their cleaning practices appeared irregular in timing, poorly organized, and with little maintenance.

Actual data on water loss reduction due to cleaning and maintenance are rare. Yet intuitively, coupled with some observation, it was anticipated that timely cleaning and maintenance could significantly reduce water loss with negligible cost and, with no requirements for professional engineering input.

For cleaning and maintenance to be truly effective it must be done frequently and on time. This requires a degree of cooperation and organization rarely found on Pakistani watercourses. Formal organization of water users are practically unknown.

[1/] Cooperative contract between Colorado State University working under a United States Agency for International Development Contract AID/ta-c-1411 and the Mona Reclamation Experimental Project, WAPDA.

[2/] Agricultural Officer Punjab Agri. Dept. (deputed to MREP), Technical Officer MREP, Senior Research Extension Officer MREP (on leave), Junior Research Extension Officer MREP, former Jr. Agri. Eng. CSU, and CSU Advisor, respectively.

There are perhaps two primary unknowns in this program: 1) how effective is cleaning and maintenance in reducing loss, and 2) what are the most effective techniques for organizing a viable cleaning and maintenance program on the watercourses. It is to both these points this report is addressed.

PROCEDURE

Watercourse Selection. Twenty watercourses were selected from the Mona Project Area for this study. Fifteen unimproved watercourses were randomly selected; an additional five earthen improved watercourses were assigned to the study. These improved watercourses were not randomly selected since five were the total which had, as of that date, been improved in the Project area. All twenty watercourses had tubewells; only one did not have, in addition, a supply of canal water.

The inclusion of improved watercourses in this study reflected the concern that the full benefits and life expectancy of an earthen improved watercourse could be drastically reduced without benefit of an organized cleaning and maintenance. This seems to be borne out by the observations of TW 81-R where, six months after improvement, many channel cross-sections had degraded which allowed considerable spillage and overtopping.

After selection, the 15 unimproved watercourses were closely inspected. Six had special problems which made cleaning and maintenance by conventional methods difficult to impossible. Some of the problems were physical such as long sandy sections or high silt banks bordering the channels. Others were social problems among the watercourse farmers. These six watercourses are referred to herein as "abnormal" improved.

Extension Treatments. What are the most successful techniques for organizing a watercourse cleaning and maintenance program and how much extension effort is required? If a national program were initiated, such information would be useful in its planning and implementation. To answer these questions, five extension treatments were selected such that each treatment contained all of the preceding treatments plus one additional item or technique. The five treatments were as follows:

Treatment 1.

Control; no extension contact with farmers concerning cleaning and maintenance.

Treatment 2.

1. Hold one group meeting with farmers from each watercourse to explain the program objectives and benefits.

Treatment 3.

1. Same as above.
2. Hold additional group and individual meetings to further motivate participation in cleaning and maintenance. Contacts are limited to 5 per individual farmer and 5 additional group meetings.

Treatment 4.

1. Same as 2 and 3 above.
2. Contacts with individuals and groups will be supplemented with extension literature to further explain the benefits of a cleaning and maintenance program.

Treatment 5.

1. Same as 2-4 above.
2. A tour will be arranged of a watercourse which has benefited from a cleaning and maintenance program. Personal contacts will be possible with farmers who have experience with a cleaning and maintenance program.

The intent of the extension treatments was to make farmers aware of the magnitude of their water losses, the causes of such loss, and the means of reducing such loss. They were further intended to motivate them to organize in such a way that their watercourses would be cleaned and maintained when required and according to the standard specified by the extension staff. Thus, it was emphasized that farmers should clean and maintain the watercourses under the supervision of trained extension field assistants and that the work was not complete until it was approved by the field assistants. Although emphasis is placed on the physical aspects of cleaning and maintenance the most important aspect is a watercourse committee and users organization which are viable and dynamic. It was hoped that organized cleaning would contribute to cooperation among the water users on other watercourse problems.

With any of the above treatments, extension assistance was provided in organizing and implementing a cleaning and maintenance program on those watercourses that elect to participate.

As originally conceived there was to be greater difference between treatments 3, 4 and 5. Additional extension literature and movies were planned. However, unexpected difficulties prevented their development in time for inclusion in the study.

Table 1 shows the assignment of treatments to the various selected watercourses.

Table 1. Extension Treatments Assigned to Various Watercourses

	WATERCOURSES		
Treatment	Improved	Unimproved	
		Normal	Abnormal
1	81-L	79-L, 126	47
2	56-L	132, 40	65
3	81-R	117,7	32
4	51	28	144, 46
5	56-R	15, 68	140

Conveyance Loss Measurements. Conveyance loss both before and after cleaning and maintenance were measured on all watercourses. Loss was equal to the difference in discharge between two consecutively placed flumes. Losses are reported as percent loss/1000 ft. In addition farmers from four watercourses were asked to estimate the acres irrigated per turn both before and after cleaning and maintenance and thus a loss estimate could be calculated.

Equipment. On each of the 20 watercourses concrete Cutthroat flumes were installed at the head and tail of the main branch for measurement of flow rate and conveyance losses. Since frequently these concrete flumes were damaged, flow rates were often determined with portable steel flumes. In addition, the three level cleaning indicator plates were installed at strategic locations along several watercourses. Since these plates are subject to theft, they were not placed on all watercourses.

A special bulletin was developed for the extension material. This related, in cartoon form, the reasons for conveyance loss and how such loss can be reduced through a cleaning and maintenance program. Although the cartoon pamphlet contained Urdu descriptions, it was intended for the illiterate farmers. This bulletin is shown in Figures 1-A to 1-O.

Data Collection and Analysis. Data collection on motivating farmers was limited to a six month period. This data does not easily lend itself to normal statistical procedures. In most cases comparisons and results are reported in terms of "apparent trends" rather than statistical significant differences. Data was collected in the following categories:

1) Effectiveness of the extension treatements:

   Counts were made of the number of watercourses on which an executive committee was organized and cleaning and maintenance conducted at least once. Thus, comparisons were possible between treatments as well as types (improved, unimproved, etc.) of watercourses. Perhaps a more effective evaluation of the treatments will be how long organized cleaning and maintenance continues.

2) Effect of cleaning and maintenance on water loss:

   Conveyance efficiencies and water losses were measured on all watercourses both before and after cleaning by the use of Cutthroat flumes.

3) Social and economic information diaries:

   Records were maintained on all meetings held with farmers pertaining to cleaning and maintenance. The following information was recorded:

   a. Meetings with watercourse members. Information recorded includes data of gathering, problems discussed, and decisions made.

   b. Meetings with the watercourse executive meeting where dates of gathering, problems discussed, and decisions made are recorded.

   c. Comments and discussions made by farmers among themselves concerning the program. Such information was collected through the help of friends of the farmers.

   d. Working days diary which recorded information on the number of workers, time, nature of work, amount completed, etc.

   e. The extension agents diary which recorded the discussions of agent-individual farmer meetings.

Cleaning and Maintenance Specifications. The major cleaning and maintenance criteria was to eliminate all observable loss and causes of loss. For improved watercourses it was required that sediments and grasses be cleaned from the channel and that bank heights, bank widths, nakkas, channel cross sections all be maintained according to new design specifications.

Requirements for unimproved watercourses were as follows:

1. Clean sediment and weeds from channels.
2. Plugging of all visible rodent holes and seepage points.
3. Rebuild all degraded cross-sections particularly at major junctions.
4. Rebuild all degraded and narrow banks to prevent overtopping and leakage.

In addition the following were strongly recommended:

1. Remove trees, shrubs, etc. from channels and channel banks.
2. Build path along tops of banks so farmers can easily walk the length of watercourse and easily check for leakage.
3. Provide a few common animal drinking and bathing points with well compacted banks and having proper slope for easy entrance and exit.
4. Alignment of channels where extreme meandering exists.
5. Pile soil at major junctions for bunding.

RESULTS AND DISCUSSIONS

I. EFFECT OF VARIOUS EXTENSION TREATMENTS

Improved watercourse. It was anticipated that improved watercourses would be easier to enlist in a cleaning and maintenance program because of their experience with and investment in the improvement program. Since it was also believed, based on observations only, that the life expectancy of earthen watercourses would be limited without an accompanying cleaning and maintenance program they were included in this study.

On watercourse MN 81-L, the control treatment, cleaning, as in the past emphasized the removal of sediments and aquatic grasses only with no attention given to maintenance.

On MN 56-L, where only one group meeting was held and no individuals contacted (treatment 2), the farmers promised to participate in the cleaning and maintenance program but they were late in initiating the work. While the physical condition of the watercourse had not deteriorated, there was considerable grass growth and silt deposition. During the cleaning process some attention was paid to maintenance, but their tendency was to finish the work with the least possible time and effort.

On watercourse MN 81-R (treatment 3) although the cleaning was started late it was accompanied with watercourse maintenance. Moreover, only two to three individual contacts were required with a few important members of the watercourse "biradari". The cleaning program was late in starting because the farmers were busy making soil cement blocks for use in lining that section of their watercourse which passes through the village. The watercourse members cooperated satisfactorily with the field assistants during cleaning and maintenance and acted upon at least 75 percent of their recommendations.

On watercourse MN 51-R (treatment 4) the farmers initiated cleaning on time and completed about 75 percent of the suggested watercourse maintenance. Here also, only two-three visits were required with certain influential watercourse members to assure the water users participation in the program. According to the survey, the printed material (cartoon booklet) did convince some literate farmers of the need to organize cleaning and maintenance but its effect on this watercourse must be considered of minor importance.

On TW 56-R, the watercourse which received the maximum extension effort (treatment 5), the best results were obtained with respect to timely and proper cleaning and maintenance. All of the suggested maintenance was completed. These farmers were not interested in field days or demonstration; they were already aware of the benefits in proper cleaning and maintenance through the improvement of their own watercourse and the considerable watercourse research activity in their area during the preceding year.

The credit for 100 percent maintenance is largely due to the watercourse executive committee and its chairman who takes considerable interest in such matters. Their program was so well organized that it required only one contact with the chairman to bring the farmers to the watercourse prepared to clean and maintain. They had previously hired a khal chowkidar to patrol the watercourse and take care of minor maintenance and report to the committee on the status of the watercourse.

Unimproved Watercourses. With normal unimproved watercourses the first two extension treatments failed to organize the farmers in a cleaning and maintenance program despite a detailed discussion with the farmers of MN-132 and MN-40 regarding their water losses. One meeting is insufficient to convince farmers of the benefits in organizing a cleaning and maintenance program.

On watercourses MN-117 and MN-7 (treatment 3) a maximum of five individual contacts was required, in addition to the first group meeting, to organize the farmers for cleaning and maintenance. One of the farmers on MN-7, who by virtue of his holding was assigned a large amount of work, would not participate even after the fifth contact. The influential committee chairman could not secure his participation until he threatened him with social boycott.

A similar situation occurred on MN-117 (treatment 3). Twenty percent of the farmers, mostly from the watercourse head, refused to participate in the program even after the fifth individual contact. This particular watercourse could not be organized under the treatment limits. On relaxing the treatment limits, the farmers agreed to participate in the program after 2-3 additional individual contacts. Once work was initiated, the farmers cooperated satisfactorily with the extension staff. In addition to cleaning they removed 80 percent of the trees, strengthened and compacted the banks, and allowed soil to be borrowed from the adjacent fields in order to make the banks two feet wide at the top, etc.

Due to certain social problems among the farmers, watercourse MN-28 (treatment 4) could neither be cleaned nor maintained with the program 6 month limit. By the third and fourth visit most of the members were willing to participate in cleaning and maintenance and the starting date was set. Three days before this date a serious personal dispute occurred between certain watercourse factions and work could not begin. After two weeks they were contacted again and on showing their willingness to work another date was set. This time one day prior to the date a murder was committed and some of the important watercourse members were arrested; again work was postponed. A few days later, most of the arrested farmers were released. When they were again approached about cleaning and maintenance one of them replied, "We are involved in a murder case and you are talking of the watercourse!" The time limits set on this study did not allow further contact. But for this murder, watercourse MN-28 would have successfully organized a cleaning and maintenance program within the study constraints. (After the six month limit had expired the field assistant again attempted to organize cleaning and maintenance on MN-28 and was successful.)

From farmer interviews it appears the cartoon pamphlet had little effect in convincing them to clean and maintain. Its primary original intent was to influence the illiterate farmer. Apparently, it did not achieve this goal.

The watercourses MN-15 and MN-68 (treatment 5) were cleaned and maintained on completion of the planned extension emphasis. Most of the farmers on MN-15 were willing to cooperate by the third and fourth visit. Here also, the pamphlet was not an important factor.

When the farmers were requested to visit a watercourse that had benefited from cleaning and maintenance, they replied that they had previously seen a watercourse whose banks were built well to prevent loss and they were already impressed. They added that their previous visit to that watercourse was one of the reasons for their willingness to participate in the program and thus there was no need to visit another well built watercourse. Obviously, the watercourse earthen improvement program in the Mona project had influenced these farmers.

One land owner of this group refused to participate even after five contacts, reading the pamphlet, and a personal visit to a maintained watercourse. However, social pressures from his fellow farmers forced him to complete his assigned work. Social pressures are apparently one of the very strong forces for convincing reluctant farmers to participate.

Another example of social interactions which force cooperation among farmers was seen on watercourse MN-68. All watercourse farmers agreed to participate in the cleaning and maintenance program at the first group meeting. However, on the starting date, no farmers showed up. When the field assistant visited one committee member and asked why he did not attend, the member replied that he had no objection to the program but would not come unless certain other farmers came first. The field assistant visited another member and received a similar answer. A third farmer replied that there are bad feelings between his family and one at the head of the watercourse and that he would not contribute his labor share unless this rival group also participated. Most farmers gave similar answers. Even when convinced of the program's benefits for the third and fourth time no one participated. The distributed literature seemed not to help. When asked to visit a demonstration watercourse, the committee chairman replied, "The reason for our reluctance is not that we are not convinced, rather it is the lack of confirmation that our rival groups will participate." When further pressed to see a demonstration watercourse, the chairman declined again; he said he could not go out of his territory without servants, guns, and ammunition because of the danger of attack by his enemies.

Work was finally initiated by the extension agent telling a small falsehood; he went to each individual group and assured them of the other groups participation. This method proved successful and more than sixty farmers arrived on the watercourse ready to work on the fixed date. The watercourse was cleaned and maintained in two weeks.

The program could not be implemented on the so-called abnormal watercourses within the limits and resources of the study. Watercourses MN-47, MN-46 and MN-140 contained large sandy areas which were not suitable for maintenance by the previous established method. MN-140, an uncommanded area, consisted mostly of sandy soils including the channel banks. The grass growth on the banks appeared essential for stabilization. It was thought that removing grass from the banks would promote erosion and increase loss. An interesting observation on this watercourse was the almost complete lack of rat or other rodent holes in the banks. Presumably such banks collapse making burrowing virtually impossible.

Watercourse 46 also had another serious problem beyond the help of this program. Large silt banks from previous cleanings had built up on both sides of the main channel for a distance of 3000 ft. These banks were so high that it was almost impossible to throw out the sediments cleaned from the channel. Farmers from this watercourse as well as those from the other sandy watercourses were willing to participate in the program and donate all the required labor but thought that the government should offer some assistance with the watercourse problem which the program could not solve.

On MN-65, program implementation failed because one landlord was more interested in the improvement program rather than cleaning and maintenance. In fact, this was a preference commonly heard while trying to establish these programs. Many of the farmers contacted were aware of the improvement program and the subsidies offered there. Probably, implementation would be more successful in areas where farmers are unaware of the earthen improvement program.

On termination of the six month time limit contact was still maintained with the watercourses listed above and additional efforts were made to promote cleaning and maintenance. It became obvious that all watercourses could have been eventually organized. It is not known if extension agents could afford the additional time and emphasis required to organize these more difficult watercourses.

Tables 2 A-C summarize the results on cleaning and maintenance for the three types of watercourses during the 6 month study period.

II. WATERCOURSE CONVEYANCE LOSSES AND FARMER ESTIMATES OF LOSSES

Table 3 shows the losses both before and after cleaning and maintenance on 7 unimproved and 3 improved watercourses. Two of the unimproved watercourses were not included in the original study. For the unimproved watercourses, the average "before" loss rate was 11.84%/1000 ft.; the average "after" loss rate was 3.32%/1000 ft.

The average loss rate on the improved watercourses was much lower "before" cleaning and maintenance; 3.86%/1000 ft. This

TABLE 2. EFFECT OF EXTENSION TREATMENT ON WATERCOURSE CLEANING AND MAINTENANCE

A. Improved Watercourses

Extension Treatment	Watercourses	Achievement
1	81 L	Cleaning done as in the past with no devotion towards maintenance.
2	56 L	Cleaning done late with minor attention towards maintenance.
3	81-R	Cleaning done late with 75% devotion towards maintenance.
4	51	Watercourse cleaned in time with 75% devotion towards maintenance.
5	56-R	Watercourse cleaned very well in time with 100% devotion towards maintenance.

B. Unimproved Normal Watercourses

Extension Treatment	Watercourses	Achievement
1	79 L	Watercourse neither cleaned nor maintained under the supervision of extension staff
	126	-do-
2	32	-do-
	40	-do-
3	117	Watercourse cleaned and maintained under the supervision of extension staff to a satisfactory level
	7	-do-
4	28	Watercourse neither cleaned nor maintained under the supervision of extension staff
5	15	Watercourse cleaned as well as maintained under the supervision of extension staff to an appreciable level
	68	-do-

C. Unimproved Abnormal Watercourses

Extension Treatment	Watercourse	Abnormality	Achievement
1	47	Big sandy portions	Cleaning and Maintenance Program not adopted
2	65	Social. The program dependent on only one influential landlord who was interested in improvement and not maintenance	-do-
3	32	Social: Farmers very much dependent on trees. Tree removal difficult just for the maintenance without Pakka check structures	-do-
4	144, 46	Watercourse 144 had big sandy portions and W/c 46 had silt dunes in about 3000 ft. length	-do-
5	140	Big sandy portions	-do-

TABLE 3. WATERCOURSE CONVEYANCE LOSSES BEFORE & AFTER CLEANING & MAINTENANCE

Tubewell No.	Flume to flume distance	Before Cleaning & Maintenance Discharge in cusecs				After Cleaning & Maintenance Discharge in cusecs				
		Head	Tail	Difference	% loss per 100	Head	Tail	Difference	% loss per 1000	Percentage reduction per 1000
UN-IMPROVED WATERCOURSES										
68	9900 ft	2.88	2.36	.52	1.82	3.21	2.80	0.41	1.29	0.63
7	6600 ft	2.10	1.13	.97	7.00	1.16	0.90	0.26	3.40	3.60
15	6600 ft	2.25	1.34	.91	6.13	1.53	1.30	0.23	2.27	3.85
117	1400 ft	1.75	1.50	.25	10.20	1.70	1.66	0.04	1.68	8.52
32	5550 ft	3.31	1.79	1.52	8.27	3.47	2.90	0.57	2.96	5.31
54**	1320 ft	1.20	.70	.50	31.56	1.20	1.10	0.10	6.31	25.25
126**	2750 ft	3.06	1.55	1.51	17.94	3.05	2.60	0.45	5.36	12.58
				Average:	11.84				3.31	8.53
IMPROVED WATERCOURSES										
31-R		2.45	1.95	0.50	3.58	2.70	2.45	0.25	1.62	1.96
Branch-A*	5700 ft	2.60	2.30	0.30	2.02	2.75	2.55	0.20	1.28	0.74
Branch-B*		2.20	1.50	0.70	6.00	2.75	2.40	0.35	2.40	3.60
	5300 ft	2.30	1.80	0.50	4.10	2.90	2.55	0.35	2.28	1.82
81-L*	6100 ft	1.65	1.43	0.22	2.19	1.78	1.65	0.13	1.20	0.99
		1.60	1.45	0.15	1.54	1.81	1.70	0.11	1.00	0.54
56-R Branch-C	8800 ft	5.20	2.62	2.58	5.64	5.29	3.64	1.65	3.54	2.10
Branch-C*	9900 ft	4.83	2.27	2.56	5.35	5.00	3.49	1.51	3.05	2.30
	9900 ft	4.72	2.72	2.00	4.28	5.01	3.70	1.31	2.64	1.64
				Average:	3.86				2.11	1.75

*Losses were recorded before and after completion of cleaning and maintenance at two different times.
**Not part of the original 20 watercourses included in this study.

lower rate is obviously a function of the previous work during improvement. The average loss rate "after" cleaning and maintenance was 2.11%/1000 ft. Thus, the percent reduction in loss rate due to cleaning and maintenance was 72% $\{(1 - \frac{3.31}{11.84})\ 100\}$.

For the improved watercourses the loss rate was reduced 45% $\{(1 - \frac{2.11}{3.86})\ 100\}$.

While all watercourses had concrete flumes permanently installed at various points, many of these flumes could not be used due to damage, subsidence, etc. Farmers resented them feeling that they impeded the flow. Frequently there were intentionally damaged and often channels were dug around the flumes. In addition the village women always used these flume installations for washing clothes. The result was that flow measurements were most frequently made with the portable steel flumes.

Farmer estimates of the time required to irrigate one acre of land both before and after cleaning and maintenance are given in Table 4. From the average of the four surveyed watercourses, there was a time reduction of 33 percent due to cleaning and maintenance. Since the time required to irrigate an acre is inversely proportional to the flow rate, their estimates imply an approximate 50 percent increase in water delivery to the fields. While this exaggerates the true increase, it does indicate the farmer satisfaction with the program.

Table 5 shows the man hours required to clean and maintain portions of 8 watercourses. Three of these watercourses were not part of the original 20 selected. On the average, 6 feet of watercourse channel were cleaned and maintained per man hour. Assuming a beldar's labor is worth Rs. 1/hr. (Rs. 8/day) then the cost of cleaning and maintenance runs Rs. 0.17/ft. ($0.02 US). This value is considerably less than the Rs. 3.0/ft. required for earthen improvement and should not prove a financial burden on the watercourse farmers.

CONCLUSIONS

Based on a limited selection of extension techniques, a successful approach to organizing farmers on a watercourse is to identify the watercourse leader in a general group meeting and then try to organize through these identified individuals.

Group social pressure proves very effective in convincing reluctant farmers to participate in cooperative programs.

Extension hand-out materials and field demonstrations did not appear effective as extension tools.

Various social problems and rivalries on a watercourse may prevent cooperation among the various farmers on a watercourse.

TABLE 4.

FARMER ESTIMATES OF TIME TO IRRIGATE ONE ACRE BEFORE AND AFTER CLEANING AND MAINTENANCE (IN MINUTES)

Tubewell No.	Head		Middle		Tail		Percentage reduction in time
	Before	After	Before	After	Before	After	
68	130	85	180	131	280	170	34.6
15	240	160	300	220	300	210	29.8
117	180	115	200	135	323	238	30.6
32	125	80	165	90	150	90	40.9
Average:	168.8	110	211.2	144	263.2	177	34.0

TABLE 5. MAN HOURS UTILIZED FOR CLEANING AND MAINTENANCE OF WATERCOURSES

Tubewell No.	Date started	Date completed	Total length cleaned and maintained	Total man hours spent	Progress per hour (ft/hr)
68	8-08-77	8-23-77	10780 ft	930	11.6
7	7-03-77	3-31-78	6600 ft	1135	5.8
15	6-21-77	8-30-77	6820 ft	1884	3.6
117	6-25-77	7-12-77	1650 ft	361	4.6
32*	12-27-78	1-11-78	7949 ft	661	12.3
54**	2-02-78	2-14-78	1320 ft	400	3.3
26**	1-09-78	1-29-78	2780 ft	958	2.9
126**	2-21-78	3-14-78	2750 ft	750	3.7
			Average:		6.0

*Not completed within the specified 6 month study period.

**Not part of the original 20 selected watercourses.

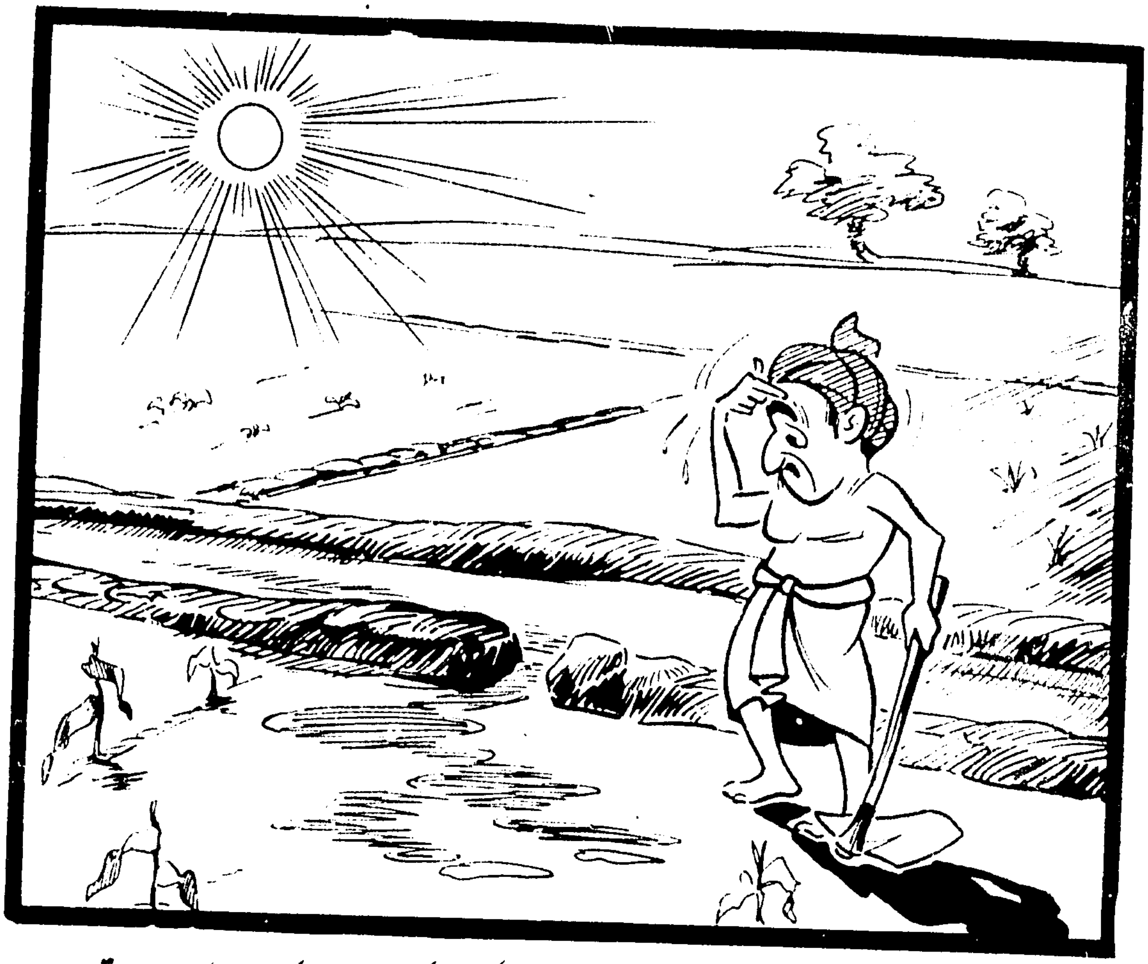
Certain physical constraints, such as excessively high silt banks and sandy soils, may disallow the participation of certain watercourses, in the present cleaning and maintenance program.

The previous watercourse improvement program hinders the establishment of a cleaning and maintenance program on unimproved watercourses in the Mona project area.

The water loss rate decreased on the average 8.53%/1000 ft. and 1.75%/1000 ft. respectively for unimproved and improved watercourses.

Farmers perceived a 50 percent increase in water delivery due to cleaning and maintenance.

On the average farmers cleaned and maintained 6 ft./hr. of channel at an approximate cost of Rs. 0.17/ft.



۱۔ میرے کھیت میں پانی کیوں نہیں آ رہا ہے ...... ؟ اتنے کم پانی سے یہ کھیت کیسے سیراب ہو سکتا ہے ۔ اس طرح تو میری
ساری فصل تباہ ہو جائے گی

Fig. 1-A. Why isn't water coming to my field? How can I irrigate with this little water? My whole crop will be lost!

۲۔ مجھے پیچھے جا کر دیکھنا چاہیئے کہ میرے کھیت کو پورا پانی کیوں نہیں پہنچ رہا ہے۔ شاید کسی اور جگہ سے پانی بہہ رہا ہو یا کوئی اور
آدمی تو میرا پانی نہیں لے رہا......؟

Fig. 1-B. I must go back and see why the water isn't reaching my field. Maybe water is going somewhere else or maybe someone is stealing my water.

۳- لو دیکھو! پانی تو کھال کے اس کنارے سے اُچھل کر بہہ رہا ہے۔ میں تو حیران ہوں کہ ایسا پچھلے ہفتے تو نہیں تھا۔ اب اس جگہ
سے پانی کیوں بہہ رہا ہے......؟

Fig. 1-C. Look! The water is flowing over this bank. Last week it wasn't doing that. Why is it flowing over now?

۴۔ یہ بھینس یہاں کیا کر رہی ہے......؟ یہ بھینس اپنے نہانے یا پینے کے لئے میرے کھال کا سارا پانی تو استعمال نہیں
کر سکتی........؟

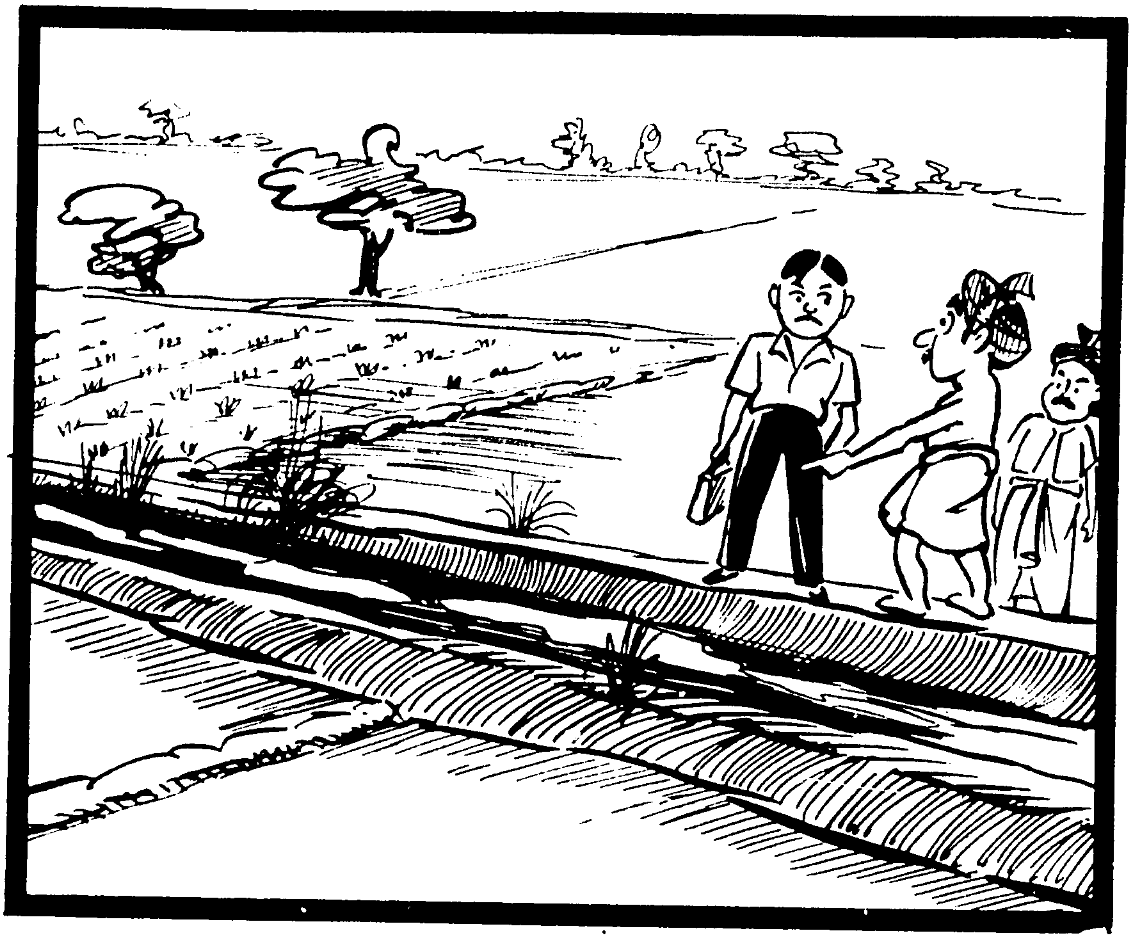
Fig. 1-D. What is this water buffalo doing here? He could not possibly use all my water for bathing and drinking!

۵- میری سمجھ میں نہیں آتا کہ ... پانی کہاں چلا جاتا ہے ..... ؟ نہ تو کوئی دوسرا آدمی استعمال کرتا ہے اور نہ ہی میرے کھیت
سیراب ہوتے ہیں۔ آخر یہ پانی کہاں چلا جاتا ہے .....!

Fig. 1-E. I can't understand where all my water goes! No one is using my water. It isn't irrigating my field. Where is it going?

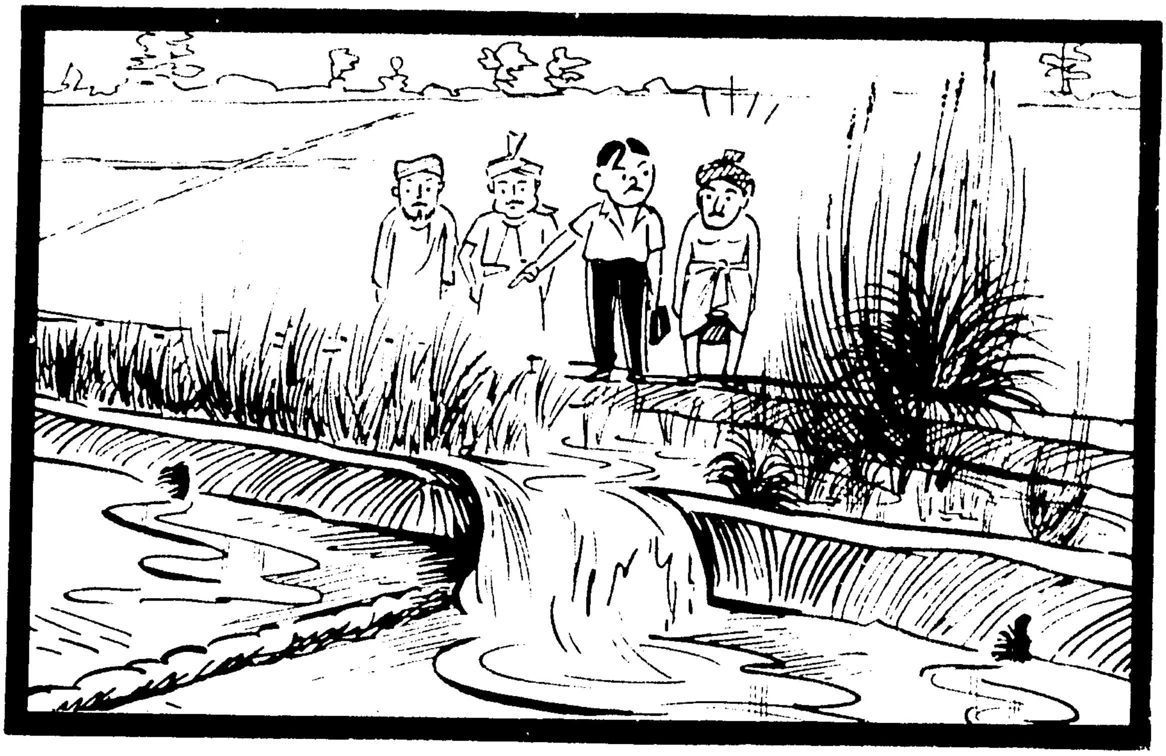
۶۔ اسلام علیکم! مجھے اطہر احمد کہتے ہیں۔ میں آپ کے علاقے میں زمیندار بھائیوں کے مسائل حل کرنے آیا ہوں۔ اگر آپ کو کوئی مشکل
ہو تو مجھے بتائیں تاکہ میں آپ کی مدد کر سکوں ۔

Fig. 1-F. Hello. My name is Athar Ahmed. I am here to help you farmers with your problems.



،۔ جناب ۔ مجھے تو سب سے بڑا یہی مسئلہ ہے کہ میں پانی کی اس مقدار سے اپنے کھیتوں کو سیراب نہیں کر سکتا ۔ مجھے تو کچھ سمجھ نہیں آتا
کہ میں کیا کروں ..... ؟ کیا آپ اس مسئلے کو حل کرنے میں میری مدد کر سکتے ہیں ..... ؟

Fig. 1-G. My biggest problem is that I cannot irrigate my fields with this quantity of water. Can you help me?



۸۔ کیوں نہیں ——— آئیے میں آپ کو بتاؤں کہ آپ کے پانی کے کھیتوں تک نہ پہنچنے کی کیا وجوہات ہیں۔ یہ کھال میں جو جڑی بوٹیاں
آپ دیکھ رہے ہیں ان کی وجہ سے پانی کی سطح اتنی بڑھ جاتی ہے کہ وہ کھال کے کناروں سے باہر بہنے لگتا ہے اور پانی کی رفتار میں
کمی آ جاتی ہے۔ انہی جڑی بوٹیوں کی وجہ سے کھال کے کناروں میں مختلف سوراخ ہو جاتے ہیں جن میں کیڑے مکوڑے اور چوہے وغیرہ
اپنا گھر بنا لیتے ہیں۔ اور اس طرح کناروں کے کمزور ہونے کی وجہ سے سوراخوں میں سے پانی رستا رہتا ہے اور بعض دفعہ ان سوراخوں کی وجہ
سے پانی کھال سے باہر نکلنے لگ جاتا ہے ——

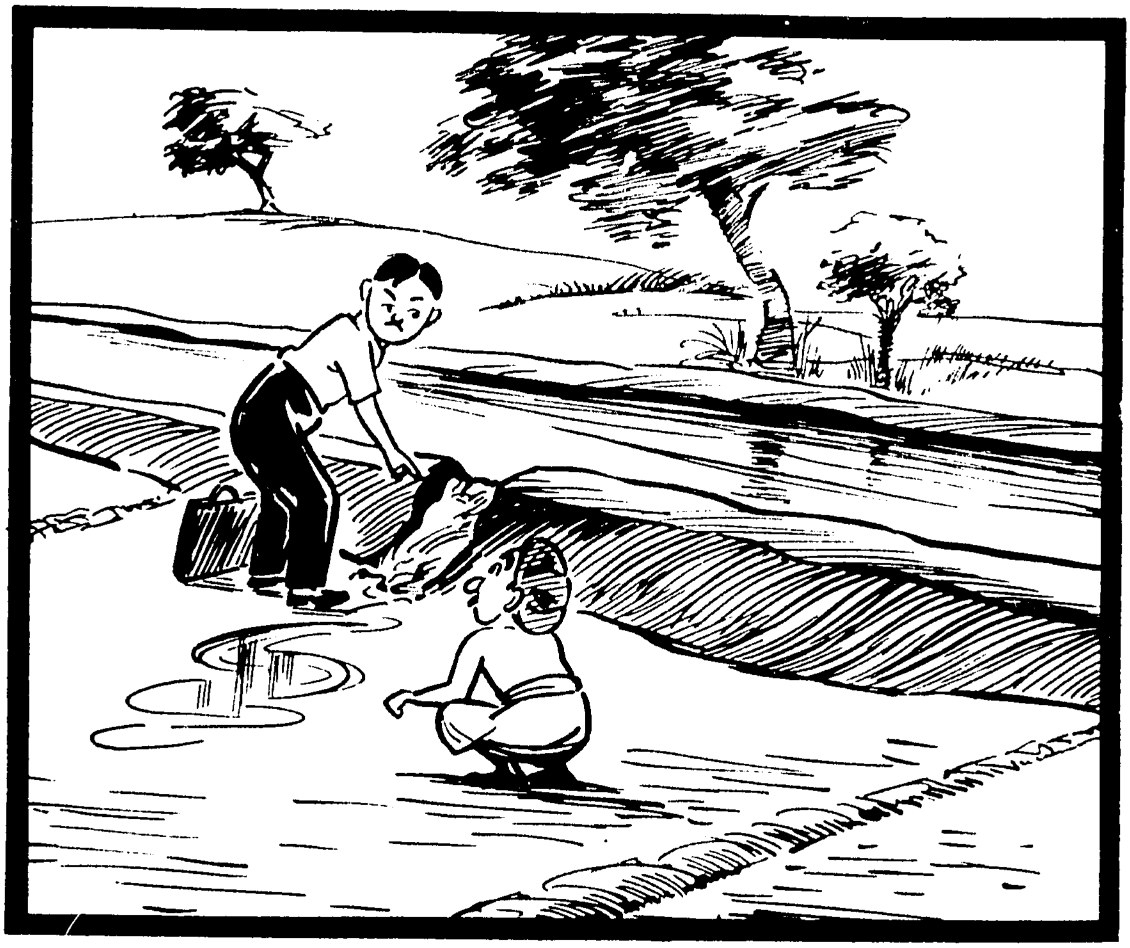
Fig. 1-H. Why Not! Come with me and I'll tell you why water isn't reaching your field. The weeds you see are raising the water level and causing it to overflow the banks and so water flow is reduced. Because of weeds, insects and rats build their nests in these banks and make them more porous. These porous banks cause seepage and sometimes large leaks.

۹- ان بھینسوں کی وجہ سے کھال کے کنارے ٹوٹ جاتے ہیں اور پانی ان سے باہر بہنے لگ جاتا ہے اور کھال میں ان کے بیٹھنے
سے پانی کے بہاؤ میں کافی کمی آجاتی ہے۔ اس طرح یہ بھینسیں کھال کے ٹوٹنے کا سبب بنتی ہیں۔

Fig. 1-I. These water buffalo break the watercourse banks which allows water to flow out. When buffalo bathe in the watercourse flow is retarded.

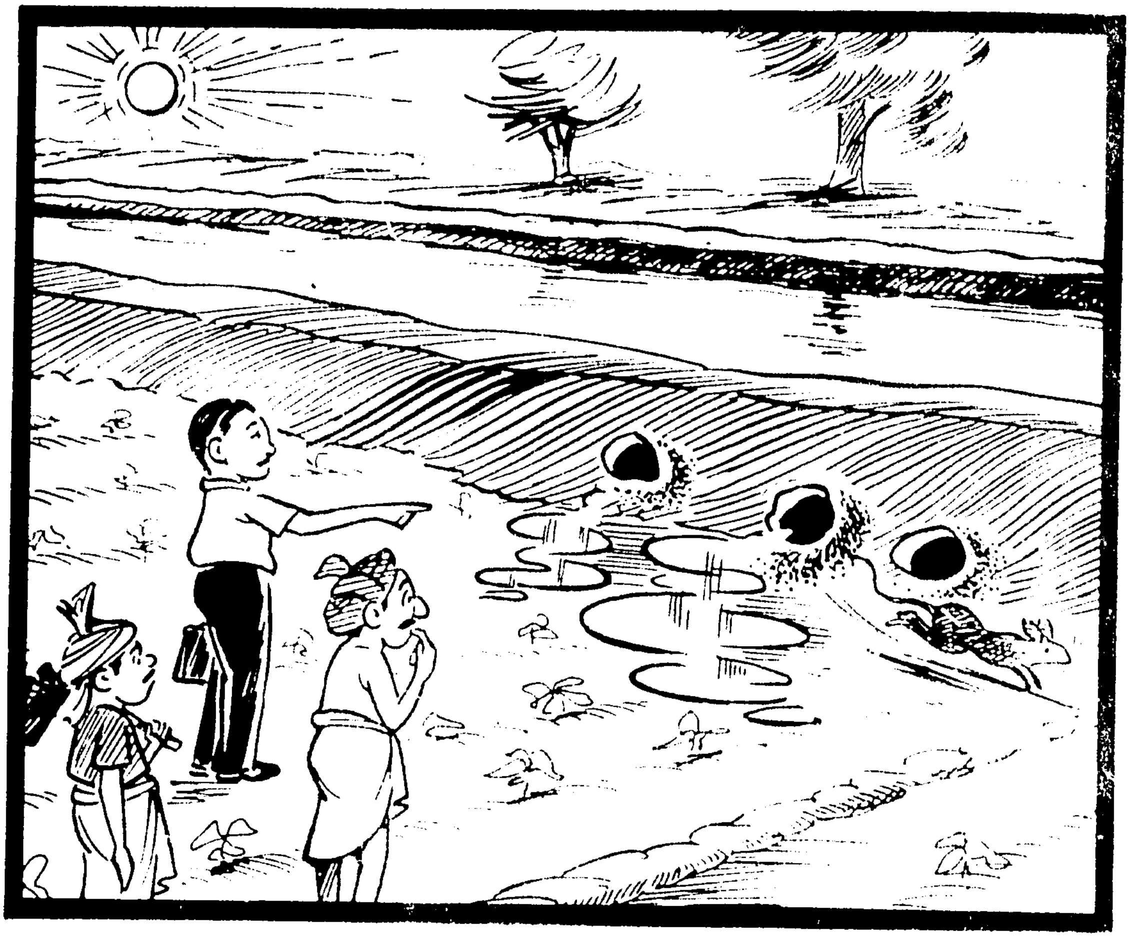
۱۰۔ اب دیکھو...... یہاں سے پانی رِس رِس کے اس کھیت کے کافی حصّے کو نقصان پہنچا رہا ہے کیونکہ یہاں سے کھال کے کنارے کی موٹائی بہت کم ہے۔ یہ صرف اس وجہ سے ہے کہ ہل چلانے والے نے کھال کے کنارے پر بھی ہل چلا دیا ہے۔ جس سے کنارا کمزور ہو گیا ہے۔

Fig. 1-J. Now look! Water is seeping and damaging a large part of the field because bank width is too thin. This happened when the farmer shaved the bank too closely while plowing.



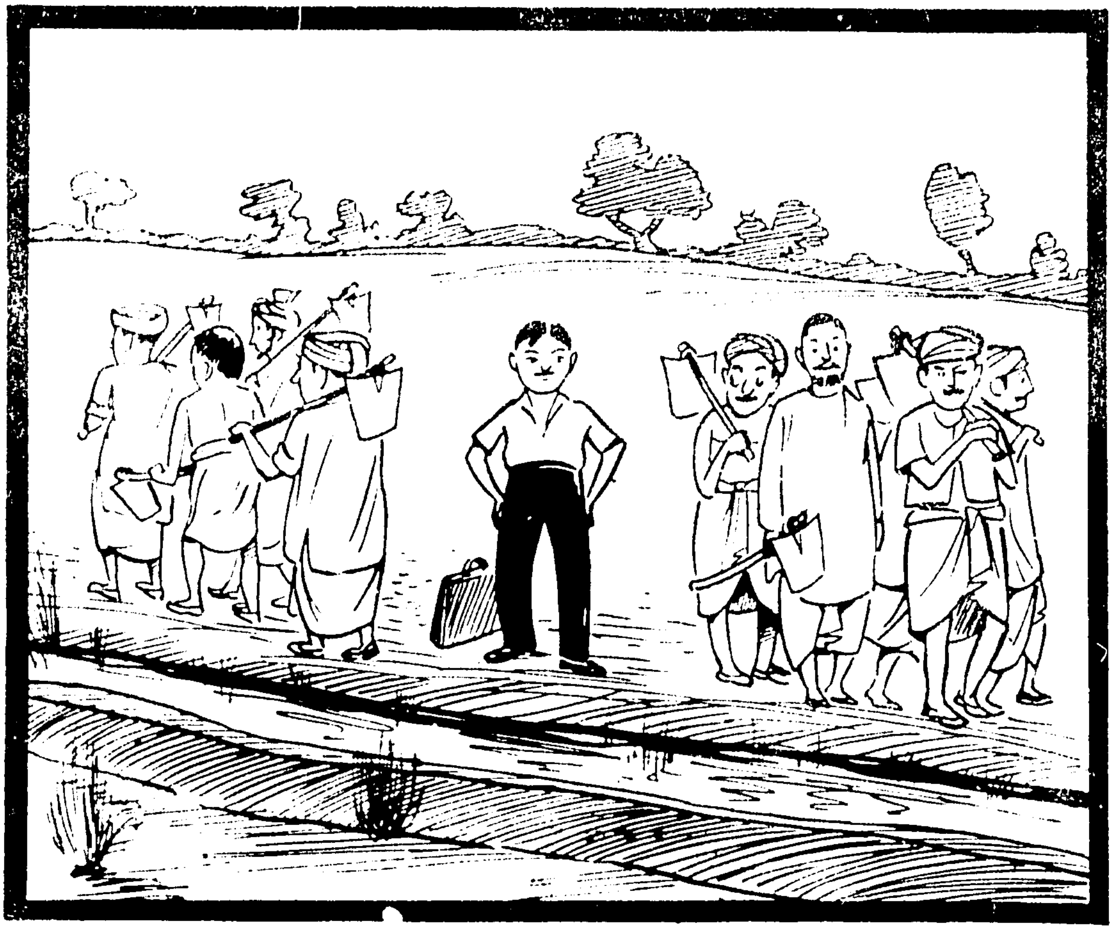
۱۱۔ اب اِسی ٹوک کو ہی دیکھو۔ اِس کو صحیح طریقے سے بند نہیں کیا گیا ہے۔ اور اِسی طرح کی بہت سی مثالیں آپ کو پیچھے ملیں گی۔

Fig. 1-K. Look at this turn out. It was not properly closed. There are many more like this further on.



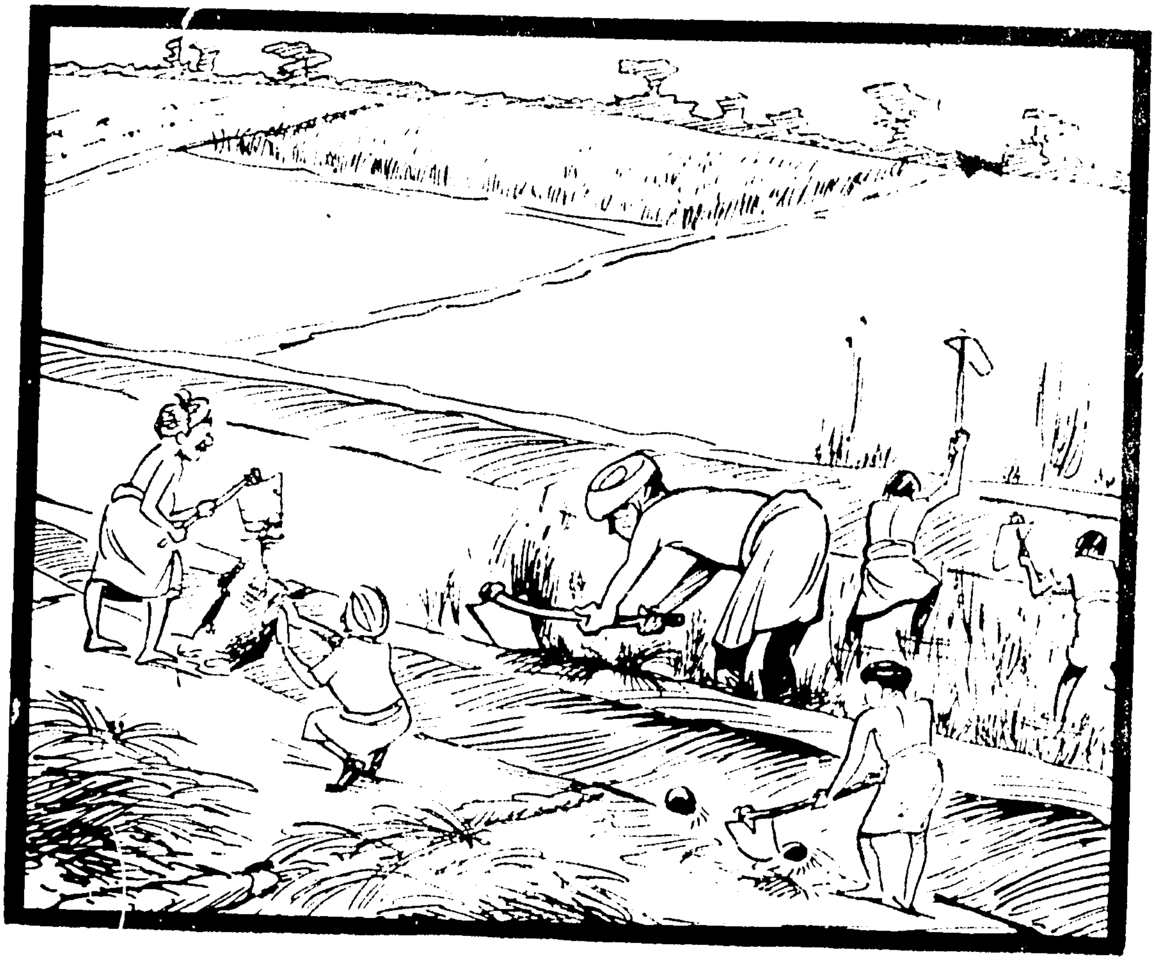
۱۲۔ ایسی ہی مثال ان چوہوں کے سوراخوں کی ہے جن سے پانی باہر بہتا رہتا ہے اور بہت سا پانی ضائع ہو جاتا ہے۔ ان سوراخوں کو مکمل طور
پر بند کرنا چاہیئے۔

Fig. 1-L. The same is true from these rat holes from which water is flowing; this wastes a lot of water. These holes should be completely closed.



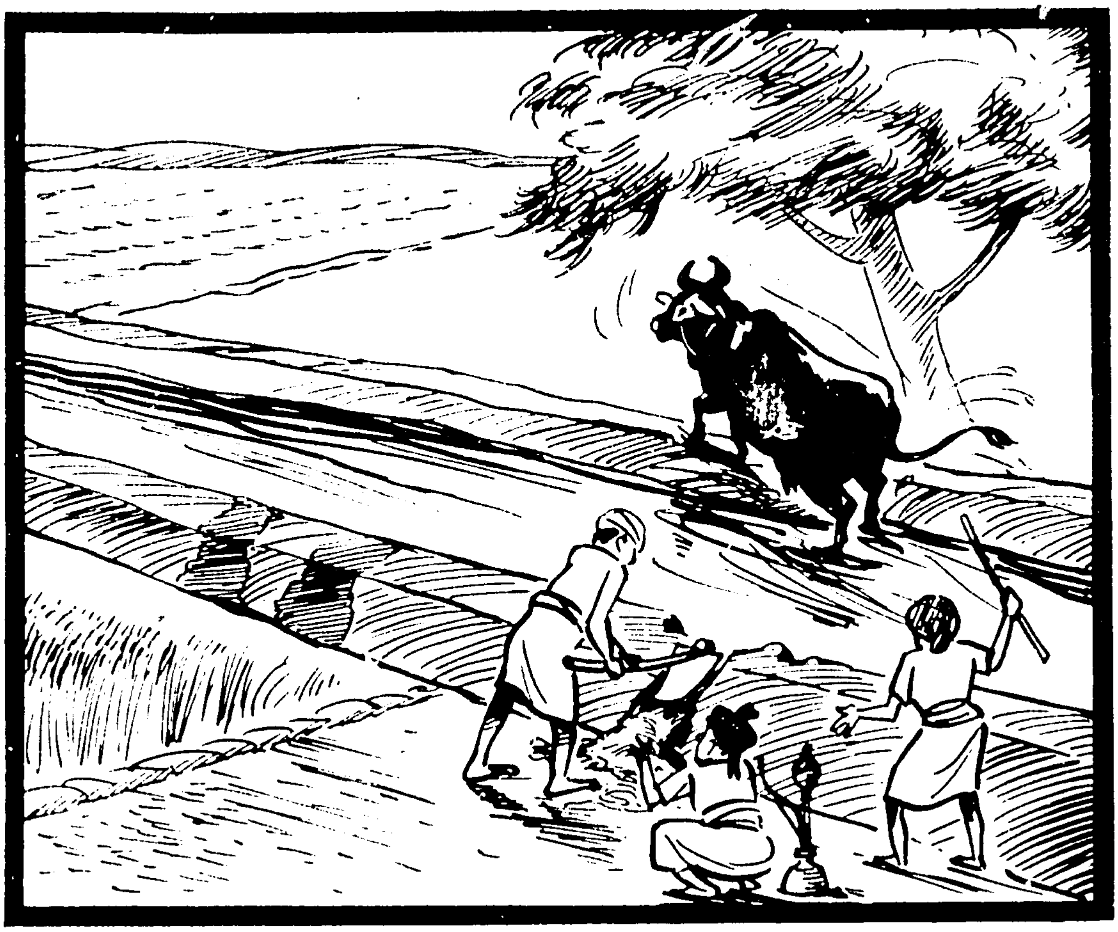
۱۳- آیئے ہم سب مل کر اس کھال کی مرمت اور صفائی کا کام شروع کریں۔

Fig. 1-M. Let us all begin to clean and maintain this watercourse.



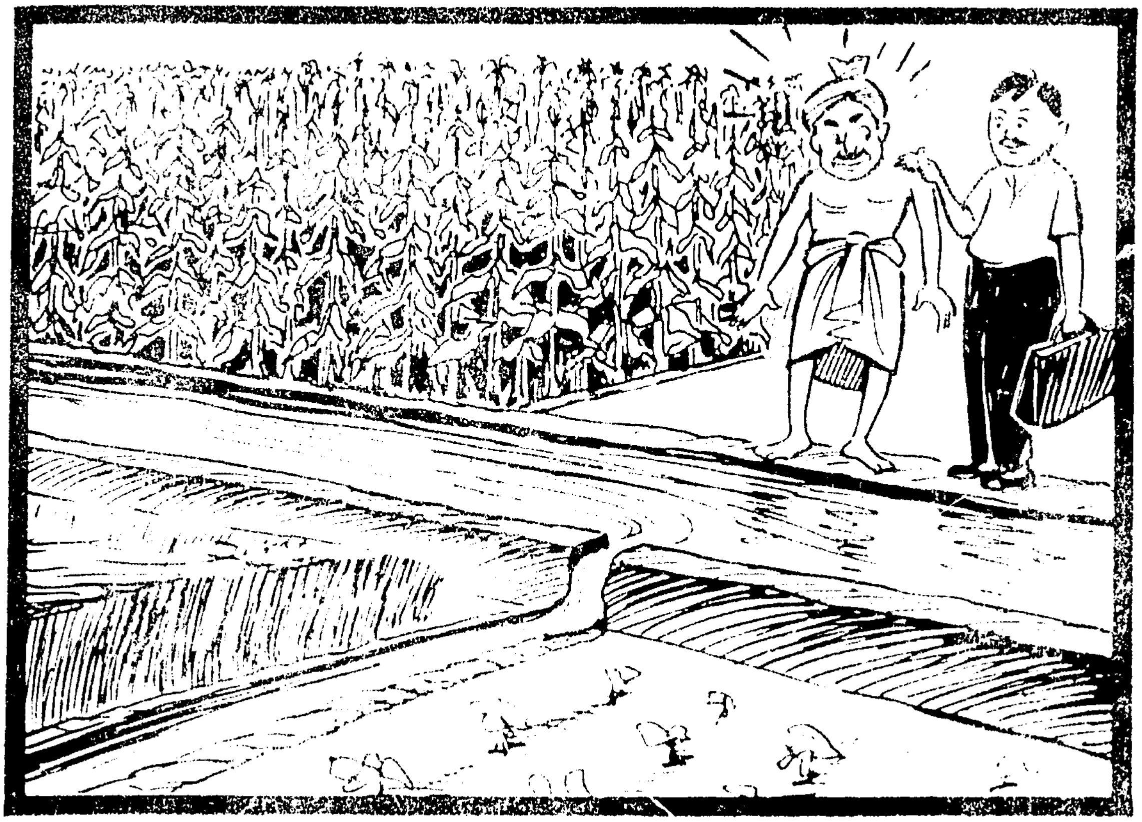
۱۴۔ ان بوٹیوں کو جڑ سے اکھاڑ دیں۔ سوراخوں کو مٹی سے اچھی طرح سے بھر دیں۔ کھال کی تہہ پر جو زائد مٹی ہے اس کو نکال دیں اور
نکوں کو اچھی طرح سے بند کریں۔

Fig. 1-N. Remove all these weeds! Fill the holes properly. Remove the sediments and close the turnouts correctly.



۱۵- اپنے مویشیوں کو کھال سے دُور رکھیں۔ اور جو کھال کے کنارے ان کی وجہ سے ٹوٹ پھوٹ گئے ہیں انہیں اچھی طرح سے مرمّت کریں۔ آپ کے کھال کا کنارا چوڑا اور مضبوط ہونا چاہیئے ۔

Fig. 1-O. Your animals should be kept out of the watercourse. The banks broken by them should also be repaired. The watercourse bank should be wider and stronger.



اگر آپ باقاعدگی سے اپنے کھال کی صفائی اور دیکھ بھال اسی طرح کرتے رہیں تو آپ کو پانی کی زیادہ مقدار ملے گی۔ جس سے
آپ اچھی فصل حاصل کر سکتے ہیں۔ اگر آپ کو اپنی کھال کی صفائی اور دیکھ بھال کی ضرورت محسوس ہو تو آپ ہر وقت میری مدد لے سکتے ہیں
آپ اپنے دوسرے بھائیوں کو بھی بتائیں کہ میں اُن کی مدد کے لئے بھی ہر وقت تیار ہوں۔ آپ اپنے دوسرے ساتھیوں کو بھی بتائیں کہ کھال کی
صفائی اور دیکھ بھال سے کتنا فائدہ پہنچتا ہے۔ تاکہ وہ بھی اپنے کھال اسی طرح سے بنا سکیں۔

Fig. 1-P. If you maintain your watercourse continually just like I have told you, you will get more water and better crops. You can call on me anytime you need advice in maintaining the watercourse. You should tell the others I'm always ready to help. You should also tell your friends of the benefits of cleaning and maintenance so they will make their watercourses like this.

APPENDIX 18

IMPROVING WATERCOURSE CONVEYANCE EFFICIENCY THROUGH CLEANING AND MAINTENANCE

by

Bashir Ahmad and S. A. Bowers[1/]

BACKGROUND

There are approximately 80,000 watercourses in Pakistan delivering irrigation water to the farms. Many of these watercourses are not properly aligned and due to poor maintenance are generally in poor condition. Degraded sections and junctions are found on most watercourses. The banks are very high where water velocities are low, and heavy sedimentation occurs; banks are very thin and weak wherever bank shaving is practiced; the junctions serve as small ponds because of borrowing of soil from the bed and banks for construction of earthen bunds. Excessive growth of grass and trees is quite common and sometimes the watercourses are fully covered. This excessive growth in the channel frequently causes overtopping.

Though the water users have developed their own system of cleaning they seldom pay attention to maintenance, the lack of which is the major cause of deterioration. In SCARP areas like Mona where tubewells have augmented canal supplies, conditions have further deteriorated. Watercourse remodeling for conveying the enhanced flows of almost 100 percent was seldom considered. The net result of all this mismanagement is apparent from the excessive losses from the watercourses.

Watercourse losses include seepage, leakage, spillage, overtopping, dead storage, etc. Seepage, leakage, and spillage losses increase because of development of pond-like conditions at junctions, rise in full supply level due to deposition of sediment and growth of vegetation, leakage through thin banks and poorly closed nakkas, etc. Studies conducted at the Mona Project showed that in earthen watercourses losses increased 2 to 3 times with a 2 inch rise in full supply level primarily because upper bank portions are more porous due to greater insect and rodent activity and decomposition of plant roots.

Most of the data collected in Pakistan during the last four years show that watercourse conveyance losses range from 30 to 50 percent. This is a great national loss both because yields are depressed by a shortage of irrigation water and because the lost water often contributes to waterlogging and salinity problems. Losses from spillage and leakage can be fully checked and seepage losses substantially reduced by earthen rehabilitation of watercourses.

[1/] Technical Officer, Mona Reclamation Experimental Project, WAPDA and CSU Advisor, respectively.

Various improvement techniques for reducing watercourse conveyance losses were developed and tested at the Mona project during these last four years. Initially pacca channel linings of brick and cement and concrete in rectangular and trapezoidal designs were tested; the cost ranged between Rs. 27 to 56 per foot. In view of its high cost, other alternatives were considered. Of the techniques so far tested, earthen improvement with pacca control structures, undertaken with water users participation, is the most economically feasible for adoption on a national scale. It covers reconstruction of existing watercourses according to new design criteria. These include proper alignment and cross section, compaction of banks, provision of adequate freeboard, pacca water control structures, proper channel gradients, etc. This type of improvement can be undertaken in medium to fine textured soils; it may not be feasible with sandy soils. Earthen improvement requires an engineering staff, surveys, designs and supervision of construction work; the cost is about Rs. 2/ft.

Presently and in the foreseeable future, it will be difficult to provide engineering assistance and construction material for water control structures for all the watercourses in Pakistan. Another alternative which could be implemented without engineering assistance and at the least possible cost has since been considered; this is simple cleaning and maintenance of watercourses. This study was initiated to test this alternative.

AIMS AND OBJECTIVES

The two main objectives in this study were as follows:

1) To define the extension emphasis required to motivate the water users for cleaning and maintenance of their watercourses.

2) To evaluate the impact of watercourse cleaning and maintenance on improving conveyance efficiency.

METHODOLOGY

Twenty watercourses in the Mona Project area, and five extension stress levels were selected for this study. The unimproved watercourses were randomly selected from those available in the Mona Project area. Five improved watercourses were also included; these were not randomly selected since at that time only five watercourses had been improved. The extension stress levels (treatments) were randomly assigned to the watercourses as shown in Table 1.

As a preliminary step, Cutthroat flumes, or pacca rectangular sections were installed or constructed at the head and tail of

Table 1. Distribution of watercourses according to extension stress emphasis.

Level of Extension Emphasis		Watercourses	
		Improved	Unimproved
I.	Control - no contact with farmers	81L	79L, 126 & 47
II.	Holding one meeting with farmers to explain the program purpose and benefits	56L	132, 40 & 65
III.	Holding 5 group meetings and up to five individual contacts to explain the program and its benefits to farmers	81R	117, 7 & 32
IV.	Same as treatment III plus distribution of a cartoon pamphlet to the farmers	51	28, 144* & 46**
V.	Same as for treatment IV plus conducted tours to improved watercourses	56R	15, 68 & 140*

* These watercourses are located in sandy areas.
** Watercourse banks are very high due to deposition of sediment.

each selected watercourse to measure and demonstrate watercourse conveyance losses. A number of loss measurements were made on each watercourse before cleaning and maintenance. No personal contact or group meeting was organized at the watercourses assigned to the control treatment. On the remaining watercourses, the program was introduced by organizing a group meeting in which the program objectives, methodology to be followed and program benefits were explained to the water users. No personal contacts or other efforts were made at watercourses selected under the second treatment. On watercourses assigned to third treatment, the first group meeting was followed by up to four additional group meetings and up to five individual contacts with most water users. The fourth treatment consisted of treatment three plus the distribution of a cartoon pamphlet explaining the causes and solution to watercourse conveyance losses. While the cartoons were provided with Urdu explanations, it was also intended to be self explanatory to the illiterate farmer. The fifth treatment contained all the stress of treatment four plus transport facilities to visit other watercourses which had benefited from cleaning and maintenance. Practically no visits were made because farmers did not feel it was necessary.

The Senior Research Officer, Junior Research Officer, Agricultural Assistants and Field Assistants from the Mona Reclamation Experimental Project extension staff participated in this program. Only common farm tools were used in program implementation.

RESULTS AND DISCUSSION

1) Effectiveness of extension levels on motivation process.

As was expected, the control (treatment 1) and the one group meeting (treatment 2) did not generate enough interest among the water users for them to organize any subsequent activity. As planned, the extension agent did not make any further efforts but simply noted their response. With treatment 2 after one group meeting, a few individuals did report their interest in the program but they could not organize water users for group action. Thus, no watercourse was cleaned and maintained under the first and second treatment.

With the third, fourth and fifth treatments, after the initial group meeting, additional group meetings were held on each watercourse. Contacts were also made with the individual water users. This effort afforded the extension agent an opportunity to identify group leaders who then were persuaded to use their personal influence to support the program. The selected leaders were then formed into watercourse committees which greatly helped in organizing the cleaning and maintenance program.

As already explained, a cartoon pamphlet was distributed to the farmers in watercourses assigned to the fourth and fifth treatments. No significant contribution resulted from its distribution. The farmers from all watercourses assigned to the third, fourth, and fifth treatments were successfully motivated to undertake cleaning and maintenance programs except tubewell MN-28. At that watercourse the farmers had agreed to initiate the cleaning and maintenance program on a fixed date but prior to that date a murder occurred which involved some of the important members of the watercourse. The tension created in the village prevented the farmers from implementing the program at that time although they were fully convinced of its benefits. In addition, cleaning and maintenance at tubewells 46, 140 and 144 proved impractical due to physical limitations such as high banks and sandy soils.

Cleaning and maintenance on a watercourse was initiated when the overwhelming majority of the water users agreed to participate. The program was implemented even if at the beginning a few farmers were reluctant to take part. Such farmers generally joined during program execution and shared the work load according to their ownership. Although the attitude of these hard-liners appeared discouraging initially, their ultimate participation ensured the success of the program.

Many of the farmers in the project area were aware that pacca nakkas and other water control structures were provided to earthen improved watercourses. Furthermore, it was difficult for them to differentiate between watercourse improvement and the watercourse cleaning and maintenance program. Quite often during the initial discussions, program implementation, and even after completion of work, they demanded pacca nakkas for watercourses included in this program. Whenever a senior project officer visited their watercourse they invariably made this demand. In the beginning they were told that pacca structures were not included in the program but their demands persisted. When the program was expanded and more watercourses were included additional extension emphasis was applied to those watercourses included in treatment I and II. The farmers at three watercourses (tubewells 15-R, 14 and 94) preferred to wait until pacca nakkas were included in the program. During later parts of the program the farmers were informed that the provision of pacca nakkas was under consideration and the project authorities would accommodate their damand provided funds could be spared. Their minimum demand was the provision of pacca nakkas at main junctions so that their deterioration could be eliminated. They even offered to provide 50% of the cost of the pacca structures. In order to popularize this program it was decided that in the future pacca nakkas will be provided at main junctions on a cost share basis. This would provide sufficient incentive to the farmers, the cost to the project would be minor, i.e. about Rs. 2,000 to Rs. 4,000 per watercourse. With this new arrangement, deterioration of junctions will be checked and labor cost on subsequent maintenance will be greatly reduced. Furthermore, the farmers will feel that the Mona Project is actively involved in the program.

All these watercourses fall in the unimproved category. Five were originally included in treatments III, IV and V and three more were completed at the end of the study period when the impact of extension emphasis had been fully evaluated and it was decided to continue watercourse cleaning and maintenance as a regular extension activity. Thus, cleaning and maintenance of three additional unimproved watercourses, 54, 26, and 126 was completed as a result of extensive extension efforts. The labor hours spent and length of the sections improved are included in Table 2.

Five earthen improved watercourses completed before the initiation of this study were also included in the cleaning and maintenance program. Although the farmers of improved watercourse were more conscious of the benefits of cleaning and maintenance, even they had to be persuaded to organize a cleaning and maintenance program. At tubewell 81-L where no contact was made with the farmers, cleaning was done as in the past without attention to maintenance. For the watercourse under treatment II, cleaning was done late with inadequate attention to maintenance. At tubewell 81-R falling under treatment III, cleaning was late but with 75% attention to maintenance; at tubewell 51, falling under treatment IV, cleaning was completed in time with sufficient attention to maintenance. The watercourse at tubewell 56-R has ideal arrangements for this program, as two members of the watercourse committee are devoted social workers and assumed full responsibility for timely and adequate cleaning and maintenance. The watercourse committee engaged a full time khal chowkidar (watercourse watchman) to take care of minor cleaning and maintenance work. For major operations he informs the watercourse committee when cleaning and maintenance is required. He is jointly paid forty maunds of wheat per year. This arrangement has ensured timely cleaning and maintenance operations at that watercourse during the last two years and such arrangements are recommended for other watercourses.

2) Labor investment

The Field Assistant in charge of a watercourse stayed at the site of work with the farmers during each day's work period. Under the seniors' directions he organized daily work and distributed the work load among the water users on the basis of ownership. He also maintained daily records of man hours spent and the length of section completed. Data on working hours for eight completed watercourses is presented in Table 2.

The last column of Table 2 indicates that feet of channel completed per hour varied from watercourse to watercourse depending upon quantity of earth work involved. Watercourse channel length completed per hour varied between 2.9 to 11.6

Table 2. Man hours utilized for cleaning and maintenance of watercourses

Tubewell No.	Date started	Date completed	Total length cleaned and maintained	Total man hours spent	Progress per hours (ft/hr)
68	8.08.77	23.8.77	10780 ft	930	11.6
7	3.07.77	31.3.78	6600 ft	1135	5.8
15	21.06.77	30.8.77	6820 ft	1884	3.6
117	25.06.77	12.7.77	1650 ft	361	4.6
32	27.12.77	11.1.78	7949 ft	661	10.7
54	2.02.78	14.2.78	1320 ft	400	3.3
26	9.01.78	29.1.78	2780 ft	958	2.9
126	21.02.78	14.3.78	2750 ft	750	3.7
			Average		5.8

ft. with overall average of about 6 ft. This is not a large labor investment and required farm labor can be mobilized without adversely affecting other farm operations. The first cleaning and maintenance requires the most labor but if done properly, subsequent cleaning and maintenance operations could be undertaken with much less effort. The first cleaning and maintenance should be done during a slack season when farmer labor can be spared for the job.

Cleaning and maintenance of improved watercourses is simple and requires far less labor investment as compared to unimproved watercourses. It can be handled as a routine work and does not require any special efforts. Cleaning and maintenance of earthen improved watercourses has, therefore, been accorded priority over unimproved watercourses in the extension program for the future. Records of labor hours for cleaning and maintenance of earthen improved watercourses were maintained. This information will be recorded in the future.

3) Reduction in loss rates

Loss rates within the selected sections of the watercourses were measured with Cutthroat flumes. A number of measurements were taken to determine the average loss rate before cleaning and maintenance was undertaken. The losses were also measured after completion of cleaning and maintenance to evaluate its impact on loss reduction. Losses recorded for seven watercourses before and after cleaning and maintenance are presented in Table 3. It is clear that losses were considerably reduced as a result of cleaning and maintenance. However, the reduction rate was directly influenced by the condition of a watercourse before cleaning and maintenance. Maximum reduction occurred in cases of badly deteriorated sections where spillage and leakage losses were abnormally high. Percentage reduction in losses ranged between 0.62% and 25.25% per 1000 ft. with an average of 7.49%/1000 ft. This proves that the farmers can improve their irrigation supplies by organizing regular cleaning and maintenance activity on these lines without waiting for governmental engineering or financial assistance.

The conveyance losses before and after cleaning and maintenance of earthen improved watercourses are also presented in Table 3. The table shows that conveyance losses were substantially reduced as a result of cleaning and maintenance. The average reduction in loss was about 40%. The reduction in losses varied between 0.74% and 3.60% per 1000 ft. with an average of 1.86% per 1000 ft. This demonstrates the importance of cleaning and maintenance of earthen improved watercourses.

The losses at the watercourse serving tubewell 81-L were less than half of the losses on the other improved watercourses. This apparent discrepancy was discussed with Trout and Kemper

TABLE 3. WATERCOURSE CONVEYANCE LOSSES BEFORE & AFTER CLEANING & MAINTENANCE

Tubewell No.	Flume to flume distance	Before Cleaning & Maintenance				After Cleaning & Maintenance				
		Discharge in cusecs				Discharge in cusecs				
		Head	Tail	Difference	% loss per 1000 ft.	Head	Tail	Difference	% loss per 1000 ft.	Percentage reduction per 1000
UNIMPROVED WATERCOURSES										
68	9900 ft	2.88	2.36	.52	1.82	3.21	2.80	0.41	1.29	0.53
7	6600 ft	2.10	1.13	.97	7.00	1.16	0.90	0.26	3.40	3.60
15	6600 ft	2.25	1.34	.91	6.13	1.53	1.30	0.23	2.27	3.85
117	1400 ft	1.75	1.50	.25	10.20	2.20	2.00	0.20	6.49	3.71
32	5550 ft	3.31	1.79	1.52	8.27	3.90	2.75	1.15	5.31	2.96
54**	1320 ft	1.20	.70	.50	31.56	1.20	1.10	0.10	6.31	25.25
126**	2750 ft	3.06	1.55	1.51	17.94	3.05	2.60	0.45	5.36	12.58
				Average:	11.85				4.35	7.49
IMPROVED WATERCOURSES										
Branch-B*	5300 ft	2.20	1.50	0.70	6.00	2.75	2.40	0.35	2.40	3.60
		2.30	1.80	0.50	4.10	2.90	2.55	0.35	2.28	1.82
81-L*	6100 ft	1.65	1.43	0.22	2.19	1.78	1.65	0.13	1.20	0.99
		1.60	1.45	0.15	1.54	1.81	1.70	0.11	1.00	0.54
56-R Branch-C	8800 ft	5.20	2.62	2.58	5.64	5.29	3.64	1.65	3.54	2.10
Branch-G*	9900 ft	4.83	2.27	2.56	5.35	5.00	3.49	1.51	3.05	2.30
	9900 ft	4.72	2.72	2.00	4.28	5.01	3.70	1.31	2.64	1.64
				Average:	4.16				2.30	1.86

*Losses were recorded before and after completion of cleaning and maintenance at two different times.
**Not part of the original 20 watercourses included in this study.

who designed the improvements on this watercourse. They had designed it so that the normal operation level is at about the ground surface, rather than several inches above the surface as was the case before improvement and is common for most watercourses in Pakistan. This design requires special check structures and extra freeboard so the water can be checked up to about 6" above normal operating levels at the point of delivery. This special "low operating level" design apparently avoids much of the leakage occurring from watercourses.

4) Farmers estimate about reduction in losses

In order to document farmer response towards cleaning and maintenance, information concerning area irrigated before and after cleaning and maintenance was collected by interviews at four watercourses. The farmers were randomly selected on each watercourse; three at the head, three in the middle and four at the tail. Their estimates about time required to irrigate an acre were recorded both before and after cleaning and maintenance. A questionnaire was developed for collection of required information. Each farmer was asked to state the area irrigated per turn in his alloted time both before and after cleaning and maintenance. From the collected information, average time to irrigate an acre at the head, middle and tail was calculated. The data so collected are presented in Table 4.

The farmers' estimates confirm the reduced losses as recorded through the flume measurements. Though their estimates may not be so accurate as compared with actual measurements they do confirm that farmers are satisfied with the program and its benefits. According to farmer estimates, about 30 to 41% water was saved on completion of the assignments. The average saving for four watercourses was estimated as 33% which certainly justifies the extension of this program to all watercourses in the country.

LESSONS LEARNED AND FUTURE RECOMMENDATIONS

* Considerable extension effort is required to motivate and organize the farmers for cleaning and maintenance. The job becomes easier when watercourse leaders are identified and persuaded to support the program.

* Watercourse cleaning and maintenance can be undertaken by the farmers themselves under the direction of Agricultural Extension staff. It does not require any professional engineering assistance hence the provincial Agriculture Extension Department may pay proper attention to this program of great importance.

Table 4. Farmer estimates of time to irrigate one acre before and after cleaning and maintenance (in minutes)

Tubewell	Head		Middle		Tail		For full section		Percentage reduction in time
	Before	After	Before	After	Before	After	Before	After	
68	130	85	180	131	280	170	197	129	35
15	240	160	300	220	300	210	280	197	30
117	180	115	200	135	323	238	234	163	35
32	125	80	165	90	150	90	147	87	41
Average	169	110	211	144	263	177	215	144	33

- The cleaning and maintenance program is feasible to normal watercourses where banks are not high or not constructed in sandy soil.

- Formation of watercourse committees is a prerequisite for organizing a cleaning and maintenance program on proper lines and to insure its continuity in the future.

- Junctions are major sources of losses and without the provision of pacca nakkas, their maintenance is difficult. Provision of pacca nakkas at junctions can reduce deterioration and cost of subsequent maintenance.

- For construction of pacca nakkas, financial incentives are required as the farmers are generally reluctant to bear full cost.

- At least one bank of the watercourse should be 1½ ft. wide to serve as a path for watercourse inspection and for natural compaction.

ACKNOWLEDGEMENTS

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APPENDIX 19

EFFECTS OF CLEANING A WATERCOURSE ON RATES OF WATER LOSS[1]

by

M. Akram[2], W. D. Kemper[3], and S. A. Bowers[4]

I. INTRODUCTION

A major portion of the farmers water is being lost from his major watercourses before it reaches his fields (Clyma, et al., 1975). The Clyma et al. data were obtained using flumes and flow meters and the resulting loss rates were higher than those obtained by the Irrigation Department in their limited, but carefully conducted studies using the ponding and recession rate method for determining losses. Consequently, it was decided that the two methods should be used on watercourses to determine whether they gave the same results. It was found (i.e., see Ashraf et al., 1977) that when the two methods were properly used that the rates of loss measured by the two methods were practically the same. However, it has also been observed (Kemper et al., 1975a) that the rate of loss was highly dependent on the elevation of the water surface in the watercourse. On the average the rate of water loss was approximately doubled for each five centimeter increase in the level of water in the watercourse. Mohammad Afzal and Muhammad Akram, of the Mona Reclamation Experimental Project, and Thomas Trout of the CSU Field Party observed (personal communications) that the operating water level in watercourses commonly dropped from 7 to 10 centimeters when farmers cleaned their watercourse. These observations lead to the tentative conclusions that the primary mechanism by which cleaning and maintenance reduced watercourse losses was by lowering the operational level of water in the watercourse. This factor and its effect on the rates of watercourse losses was discussed by Kemper et al., 1975b and estimates of the benefits of a consistent cleaning and maintenance program were made. However, a complete set of data showing the water levels before and after cleaning, the shape of the watercourse before and after cleaning, and the rates of loss before and after cleaning have not been available. The purpose of this study is to provide such a set of data. The authors hope that this data and the accompanying discussion will help clarify the role of cleaning in reducing watercourse losses and can be used by extension personnel to

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[1] Joint contribution from the Mona Reclamation Experimental Project, Water and Power Development Authority, Pakistan and Colorado State University. Portions of this work were supported by USAID/Pakistan Agreement No. 204-75 and by USAID/ Washington Research Contract No. AID/ta-c-1411.

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[3] Professor of Agricultural Engineering, CSU.

[4] Professor of Agronomy, CSU.

educate the farmers to the good investment opportunity which is available to them in the cleaning and maintenance of watercourses.

II. PROCEDURE

Two types of watercourses were selected for improvement. The first of these was Branch I at Tubewell 78 which is a part of the authorized watercourse or "sarkari khal"[5] and was the first branch watercourse in the Mona project which was improved by the farmers in the current watercourse improvement research. This improvement occurred about 16 months before the cleaning involved in this study took place. Three consecutive sections, each 30 meters long, were selected for this study on Branch I. The soil in the fields adjacent to this stretch is a sandy loam. However, immediately along the watercourse the soil has been mixed with sediment which has been cleaned out of the watercourse during the past 70 years. The authorized portion of this branch is about 760 meters long and the whole branch was cleaned at the time of this study. The sections selected for this study were within the first 180 meters from where this branch originates at the masonry lined channel. Water was flowing into the head of this section at a rate of about .11 m^3/sec.

The second watercourse selected was a private branch about 490 meters long belonging to an individual farmer. Flow rate was approximately .085 m^3/sec. The first 300 meters of this branch were cleaned and the test sections consisted of the first 90 meters. The soil in the fields adjacent to this watercourse were sandy loams. Since the section was about over 2,500 meters from the canal, water reaching this point has comparatively less sediment than was the case of Branch I at Tubewell 78. This private branch had not been improved prior to this study and as is the case with most private branches is not cleaned as frequently as those branches which are part of the sarkari khal.

The general procedure followed on these two watercourses is outlined below:

1. The operating level in the test sections of the watercourse was determined when the farmers were using this water to irrigate fields near the lower end of the watercourse. An elevation marker was then set at a height 3 centimeters higher than this full supply operating level and all further measurements of water surface elevations were made from this elevation marker or "datum".

2. The rate of flow in the watercourse was determined.

3. Just before the conclusion of the irrigation turn of the farmers using this branch, this watercourse was filled to 3 centimeters above the operating level.

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[5] The "sarkari khal" is the portion of the watercourse delivery system which is operated and maintained cooperatively by the farmers. It has authorized right of way extending a few feet beyond its banks which allows borrowing of soil for access for maintenance purposes.

Earthen dams were constructed at the bottom and top ends of each of these sections and the rate at which the water level receded in each of these sections was determined. The width of the water surface of the watercourse was also determined at these times. From these widths and rates of recession the rate of water loss was calculated as a function of the elevation of the water in the watercourse.

4. The watercourse was then cleaned, recording the approximate number of hours spent by the farmers and laborers on the watercourse. At Tubewell 78 these cleaning operations were primarily a removal of the grass from the sides of the watercourse with a small amount of sediment taken with the grass. On the unimproved watercourse at Tubewell 56 cleaning the grass from the banks and beds uncovered a substantial number of rodent holes which were generally filled by the laborers who recognized them as potential avenues for water loss. The extra effort involved in filling these obvious sources of potential leakage required about three hours per thousand feet of watercourse cleaned.

5. After cleaning, when the farmers used this watercourse again, the operating level was determined with respect to the datum markers set before cleaning. At the conclusion of their turn the water level was again brought up to 3 centimeters above the operating level which was observed before cleaning. The dams between the sections are constructed as before and the recession rates and watercourse widths were again determined as a function of time until all the water had left the watercourse.

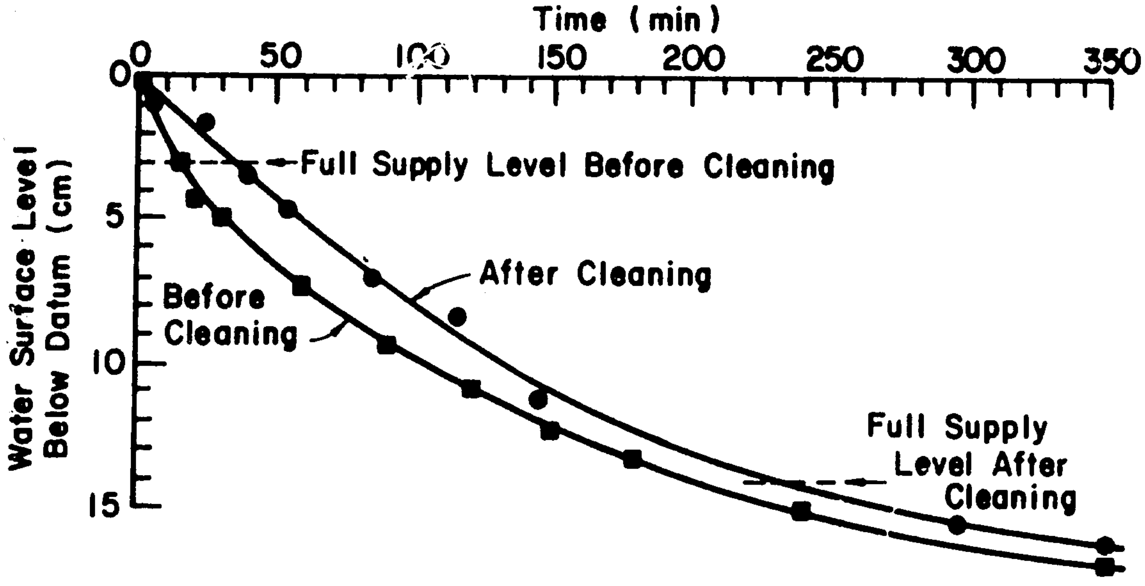
III. RESULTS AND DISCUSSION

The rate at which the surface level of the water receded in the test sections of Branch I of Tubewell 78 are shown in Figures 1, 2 & 3. The "A" portions of the figures show the recession rate in detail for the first 5 or 6 hours as was necessary to get good estimates on the rate of water loss when the water surfacewas at these levels. The "B" portions of the figuresshow the complete recession curve to the time when all of the water has seeped out of the watercourse.

The slopes of these curves in Figures 1, 2 and 3 were then used with the respective watercourse width to obtain the data indicated in Figures 4, 5 and 6, where loss rates are plotted against the level of the water surface below the datum markers.

In section 1, as indicated in Figure 4, the rate of loss following cleaning was considerably less than prior to cleaning

Figure 1A. Initial Portion of Recession Curves (Section No. 1, Branch I, T. W. 78) Prior to and After Cleaning.



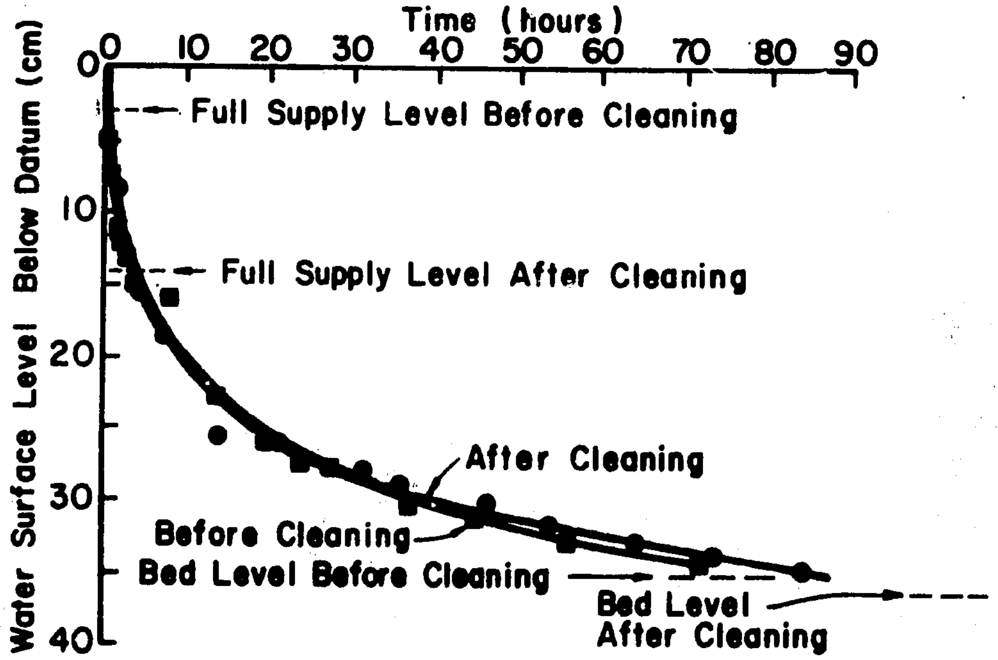
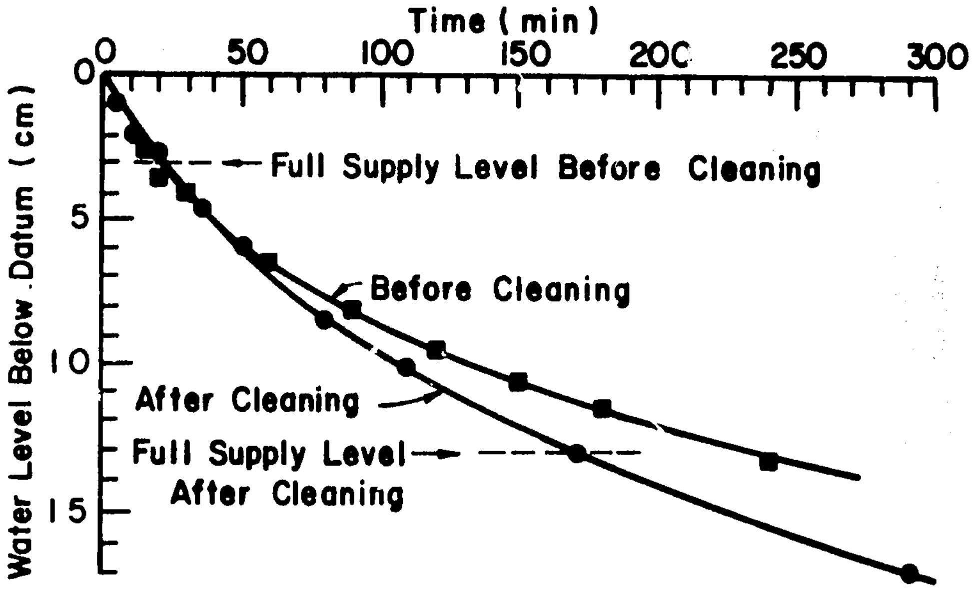


Figure 1B. Complete Recession Curves (Section No. 1, Branch I, T. W. 78) Prior to and After Cleaning.

Figure 2A. Initial Portion of Recession Curves (Section No. 2, Branch I, of the Watercourse Serving T.W. 78) Prior to and After Cleaning.



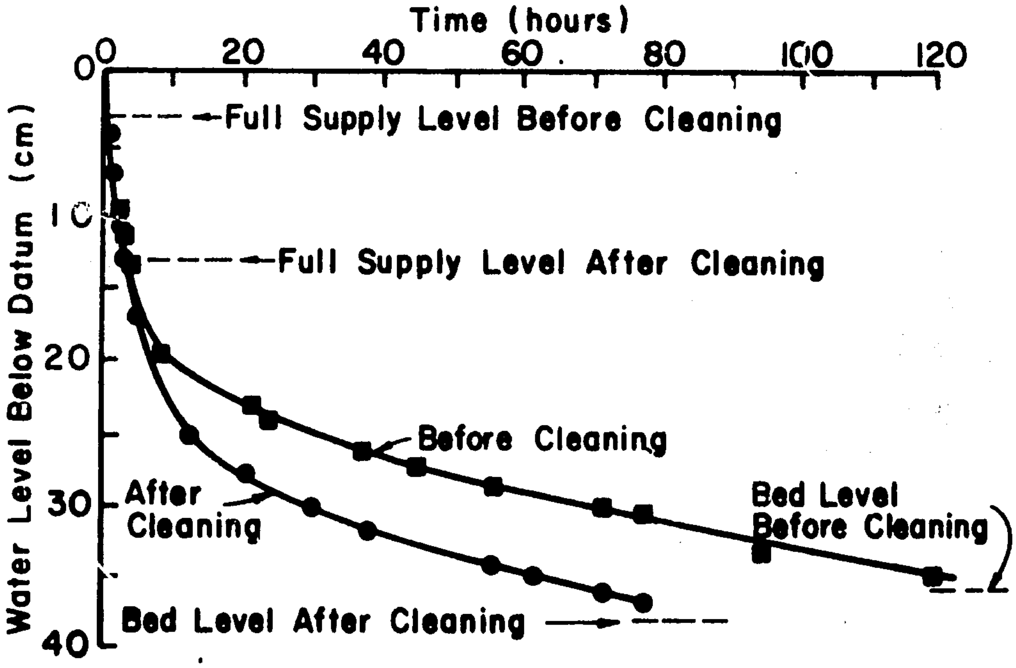
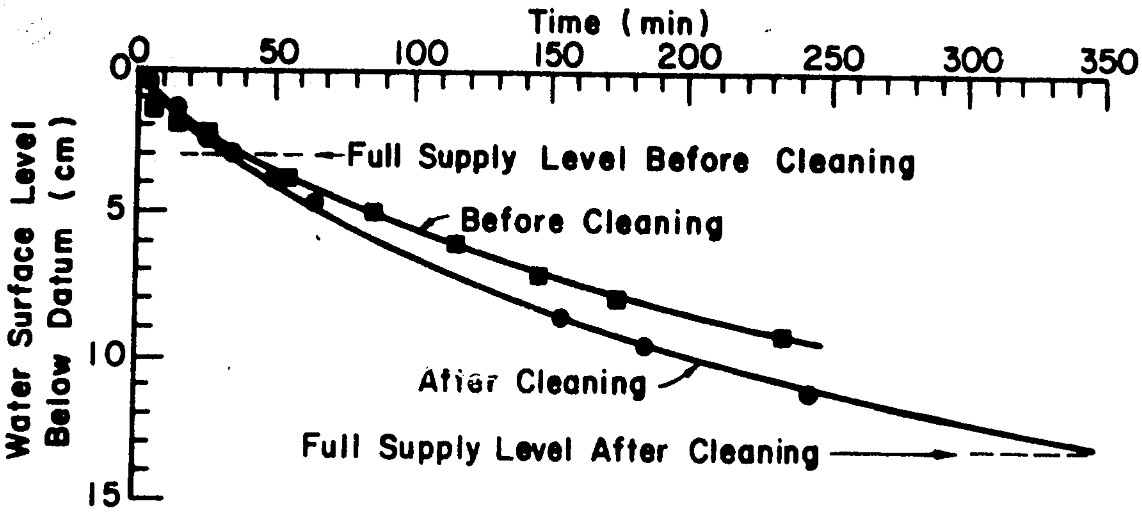


Figure 2B. Complete Recession Curves (Section No. 2, Branch I, T. W. 78) Prior to and After Cleaning.

Figure 3A. Initial Portion of Recession Curves on (Section 3, Branch I, T. W. 78) Prior to and After Cleaning.



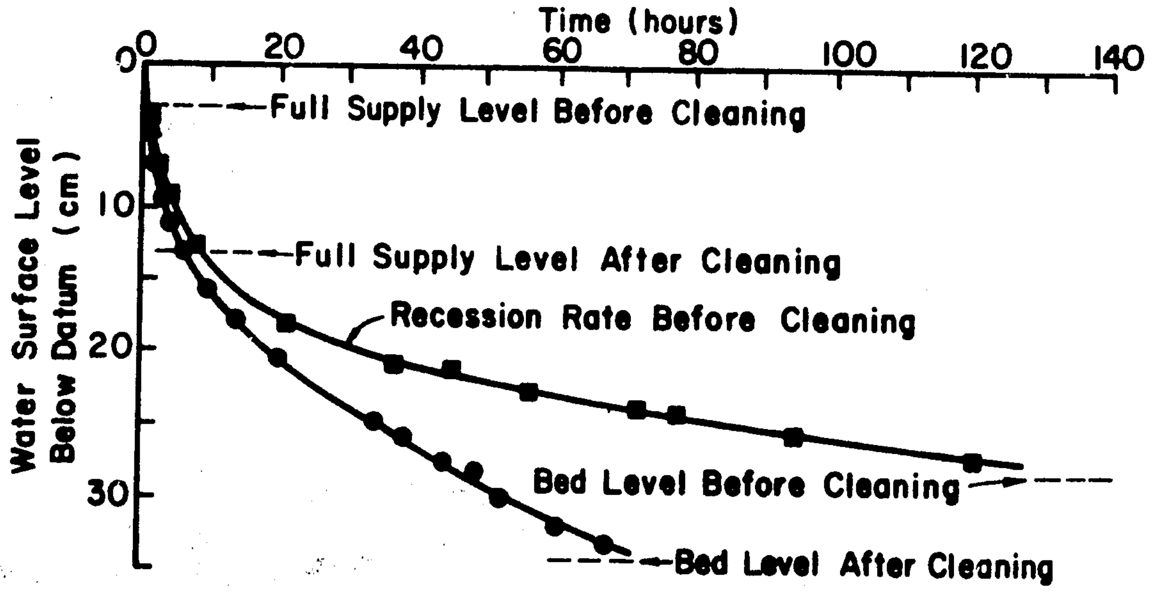


Figure 3B. Complete Recession Curves (Section 3, Branch I, Tubewell 78) Prior to and After Cleaning.

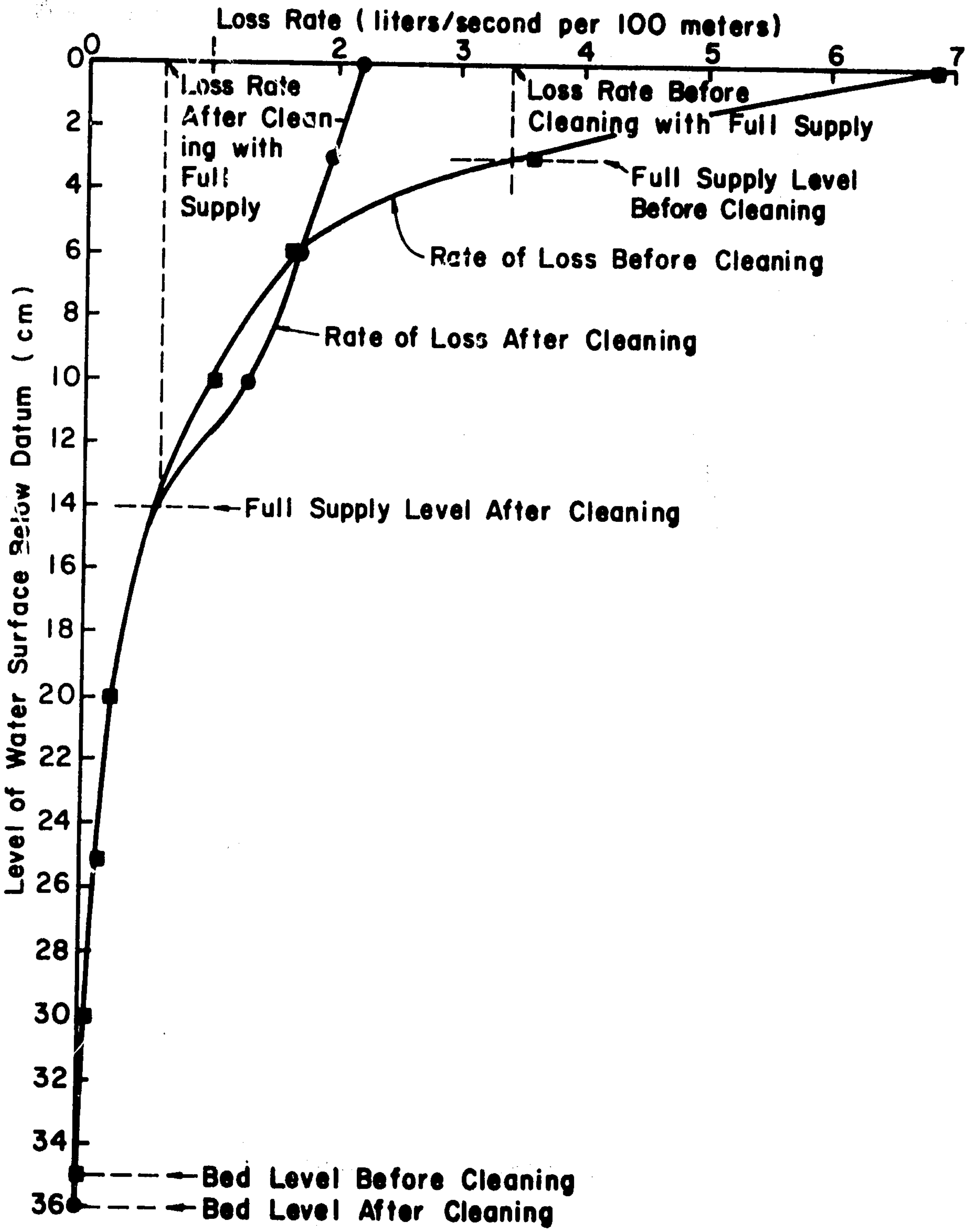


Figure 4. Effect of Water Surface Elevation on Loss Rate of Section No. 1 Before and After Cleaning.

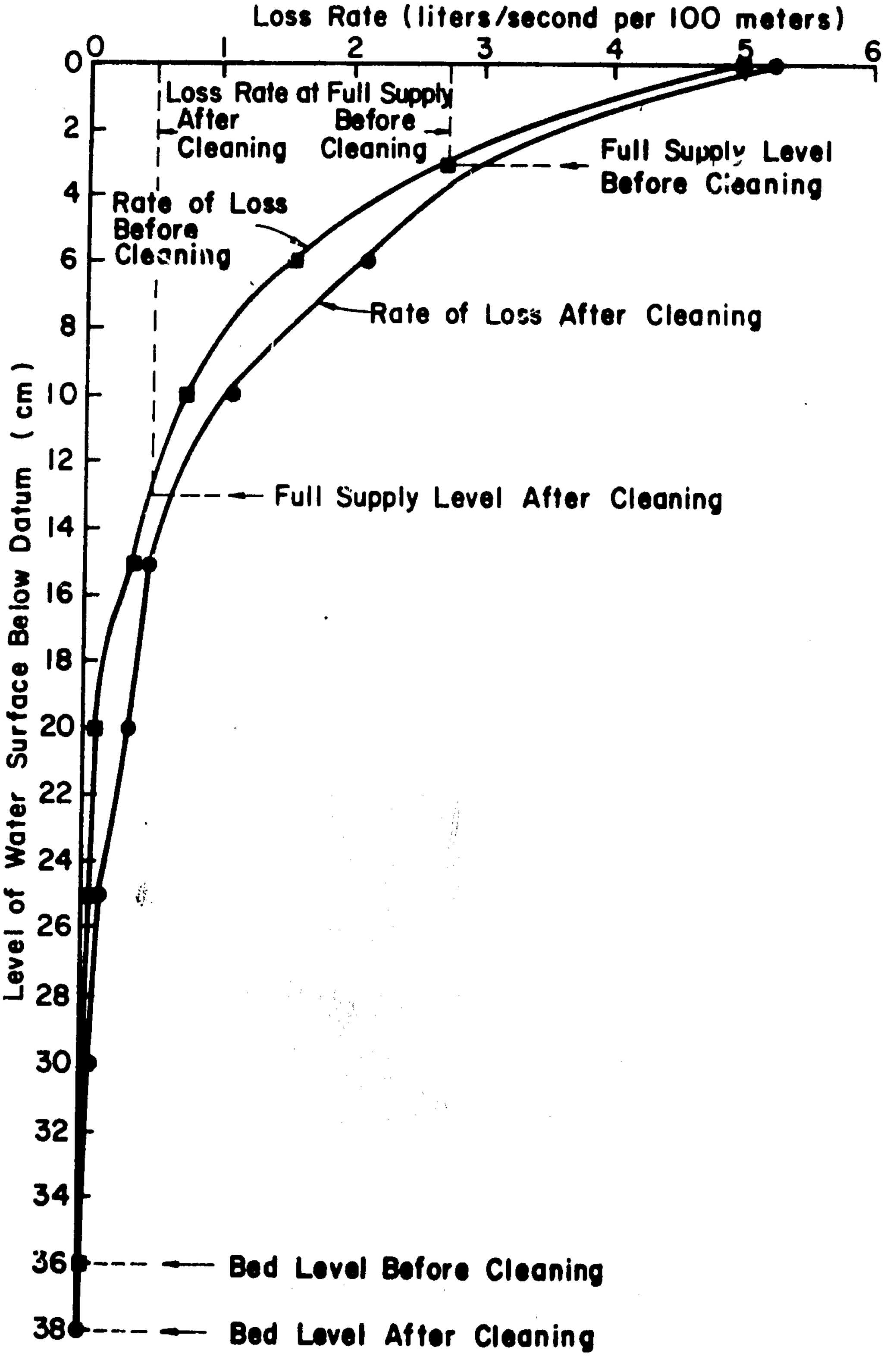


Figure 5. Water Surface Elevations and Loss Rates on Section No. 2 (Tubewell 78) Before and After Cleaning.

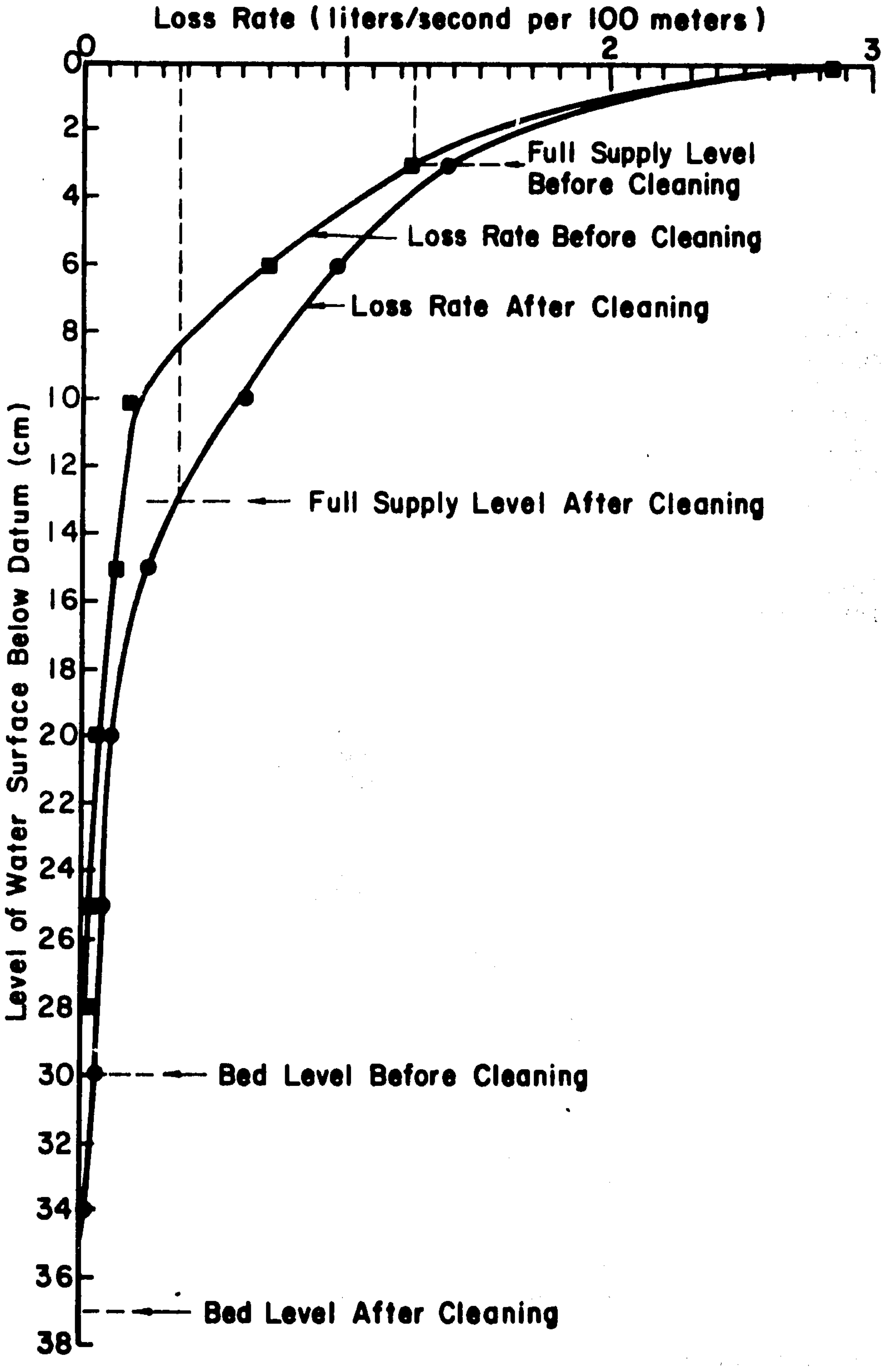


Figure 6. Water Surface Elevations and Loss Rates on Section No. 3 (Tubewell 78) Before and After

when the water was within 5 centimeters of the datum elevation. This was apparently a result of the closure of a couple of rat holes which were just a few centimeters below the "before cleaning full supply level." After the water level had fallen below the level of these rat holes the rate of water loss after cleaning actually appears to have exceeded the loss before cleaning until the water had receded to below the depth of about 14 centimeters below the datum. This tendency for the water loss after cleaning to be greater than the water loss before cleaning, when comparing them at equal levels of water, was corroborated in sections 2 and 3 as indicated in Figures 5 and 6. Apparently this slight increase in water loss when the surface is at a comparable level is due to the removal of the sediment which had settled on the sides and bottom of the watercourse. Removal of this sediment, along with the grass, leaves an open somewhat porous soil with a large number of open earthworm holes. These small holes tend to silt in and cover over again as irrigation water is brought into this section but immediately following the cleaning they do increase the rate of outflow.

The operating levels of water in these test sections following cleaning was 10 to 11 centimeters below the operating level prior to cleaning. In section 3 this was due partially to the excavation of about 7 centimeters of grass roots and sediments from the bottom of the channel as indicated in Figure 7. However, in sections 1 and 2 only 1 or 2 centimeters of the soil was taken away with the roots. While there was also some expansion of the channel by taking away some soil on the sides, the removal of this soil alone cannot account for the reduction in operating level following cleaning.

The major factor which lets this water flow faster and thereby allows a reduction in the average filled cross sectional area of the channel is illustrated in Figure 8. Before cleaning there was considerable grass along the sides and even some grass on the bottom of the channels. This caused roughness coefficients in the range of 0.07 to 0.10. After the cleaning the roughness coefficient had been reduced down to about 0.035. Since watercourse capacity is a direct function of roughness, this allowed the operating level near the head of the channel to be reduced from 17 centimeters above the level of the adjacent fields down to only 7 centimeters above the level of the adjacent fields. This reduction in the operating full supply level of water in the watercourse caused the decreases in loss that occurred following cleaning, as indicated in Figures 4, 5 and 6 and summarized in Table 1. The average loss rate in liters per second per hundred meters of watercourse was 2.4 prior to the cleaning and only 0.51 after the cleaning (Table 1). It should be emphasized here, as was pointed out by Ashraf et al. 1977 that these losses in the straight sections of the watercourse do not include all the losses which occur during actual operation of such watercourses. Losses at junctions, dead storage

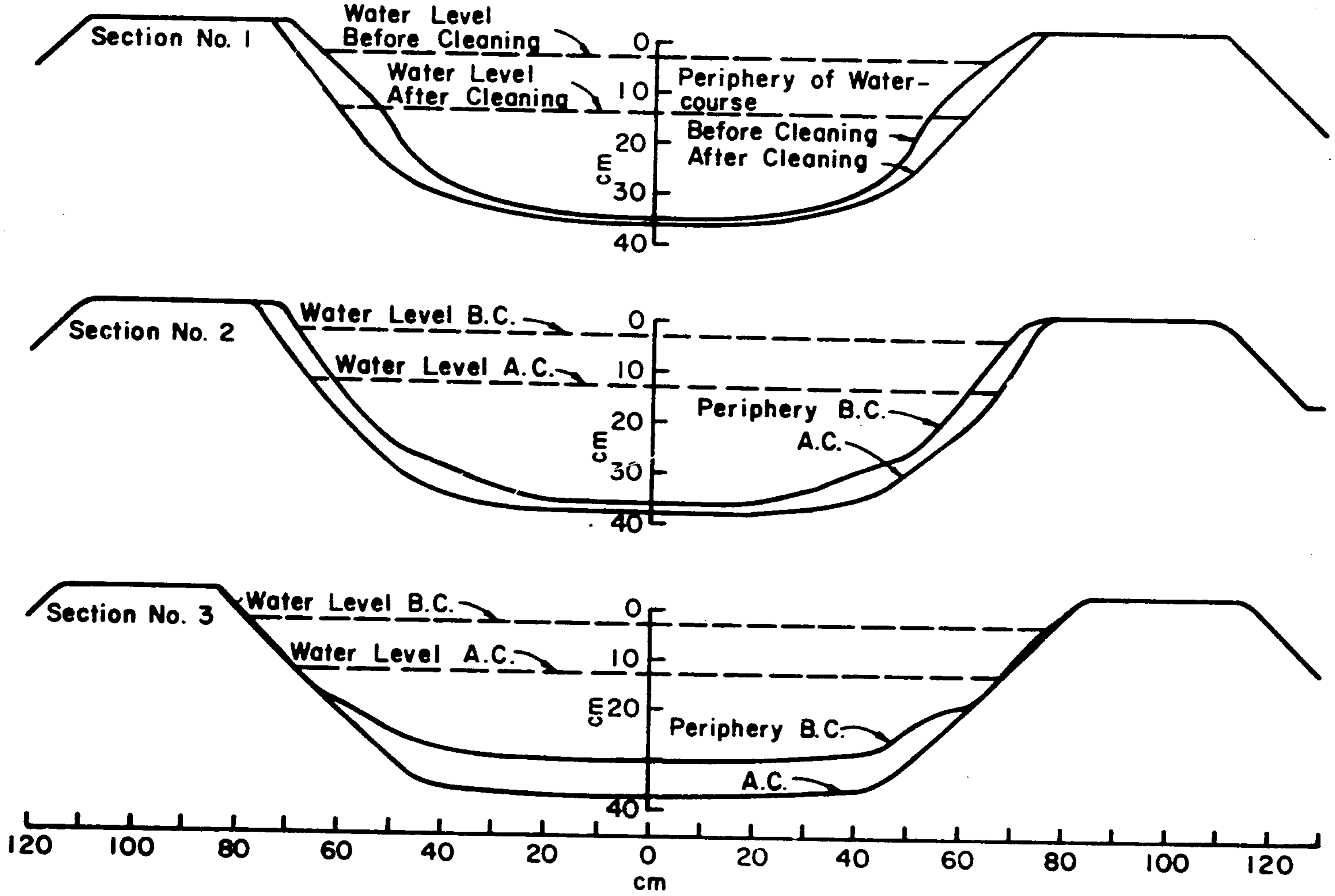


Figure 7. Watercourse Cross Sections at Tubewell 78 Prior to and After Cleaning.

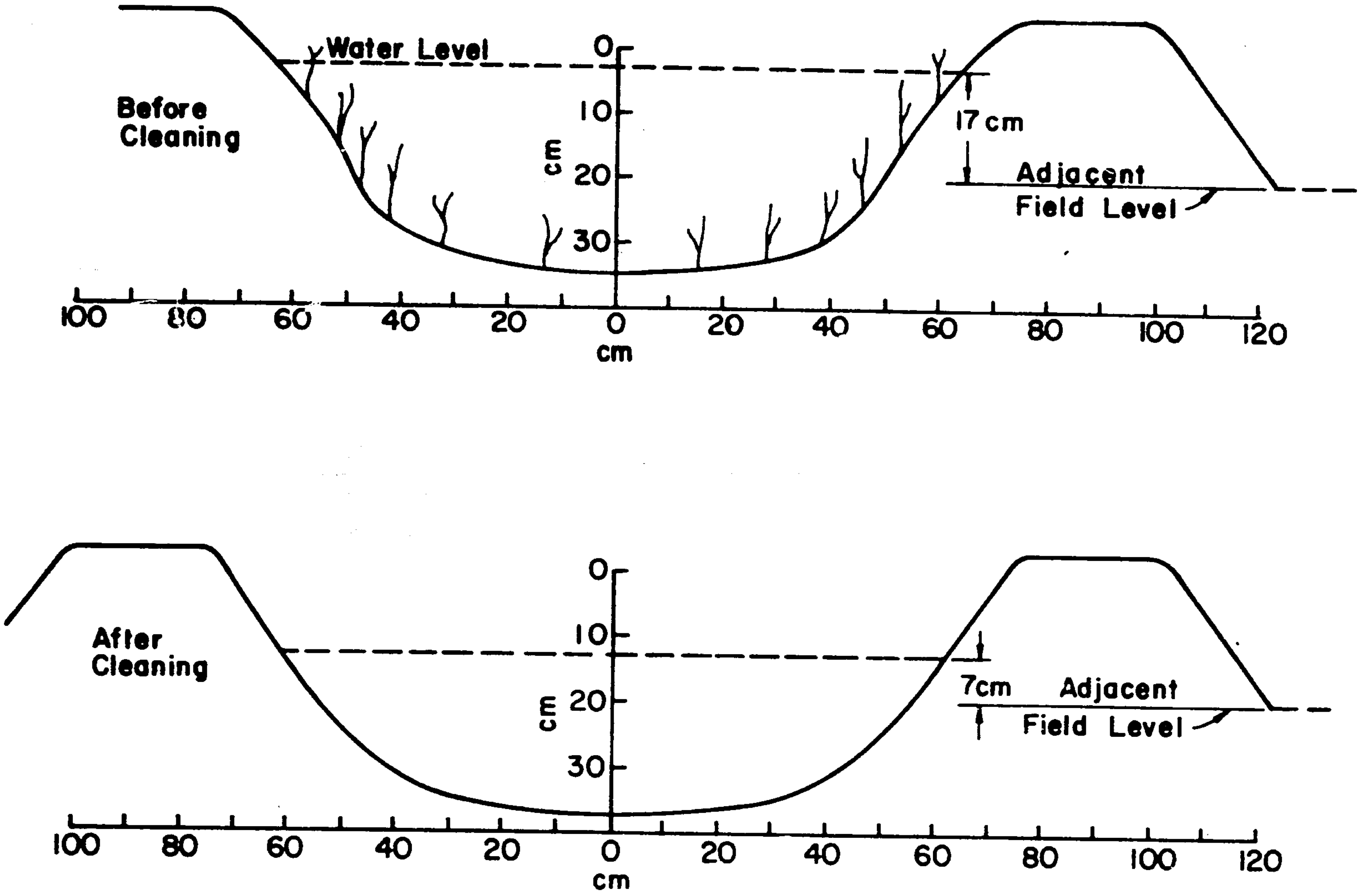


Figure 8. Average Conditions at Tubewell 78 Watercourse Before and After Cleaning.

Table 1. Watercourse Loss Rates at Full Supply Operating Level as Affected by Cleaning.

	Branch I, T.W. 78 (Previously improved)		Private Branch, T.W.56	
Sect. #	Before cleaning	After cleaning	Before cleaning	After cleaning
1	3.4 liters/sec/100m	0.65	3.6	1.10
2	2.7 " " "	0.50	3.5	1.55
3	1.2 " " "	0.37	5.7	0.50
Average	2.4	0.51	4.3	1.05

losses, and losses involved in wetting dry banks and so forth must be added to the losses which we are considering in this study to obtain the total operational losses (e.g. Trout et al. 1977).

In the unimproved section on the branch watercourse serving Tubewell 56, the loss rates were higher to begin with than at Tubewell 78 and the closing of obvious rat holes by the laborers caused such marked reductions in the rate of loss that increases in the infiltration rates into the banks due to removal of the sediment was not apparent (Figures 9, 10 and 11).

The reduction in full supply level at the head of this branch did occur as before at Tubewell 78 watercourse although this reduction was now only about 7 or 8 centimeters. However, this reduction in full supply level, coupled with filling some of the rat holes, resulted in the average loss of water from these sections reducing from 4.3 liters per second per hundred meters of watercourse to 1.05.

The loss resulting from a farmer not cleaning his branch watercourse is not restricted to losses from his private branch. The effect on water levels in the whole delivery system of allowing the head loss in his branch of the watercourse to be larger than those designed are illustrated in Figure 12. The top half of that figure shows a designed operating level for both the sarkari khal and the farmer's branch. Assuming the sarkari khal receives adequate cleaning but that the farmer does not adequately clean his branch and allows the grass to grow, as is commonly the case, the results are shown in the bottom half of Figure 12. The head loss in the farmer's branch increases to compensate for the increased roughness coefficient. This raises the water level back to the beginning of the farmer's private branch and it also raises the water level back in the sarkari khal. This rise in the water level causes increased losses in both sections and if the farmer's fields happen to be near the top of the sarkari khal, so that the rise in water level caused by his failure to keep the grass out of his watercourse extends clear back to the mogha, it may even reduce the amount of water that is able to come through the mogha from the canal.

Reviewing Table 1 and comparing the previously improved branch watercourse at Tubewell 78 to the farmer's branch it appears that the effects of the improvements may persist over a period of at least 16 months. However, the data before and after improvement on each watercourse show that a major part of the improved delivery efficiency desired can be achieved through a cleaning and maintenance program. The same data show that improvement must be accompanied by a regular cleaning and maintenance program to obtain the potential improvement in delivery efficiencies.

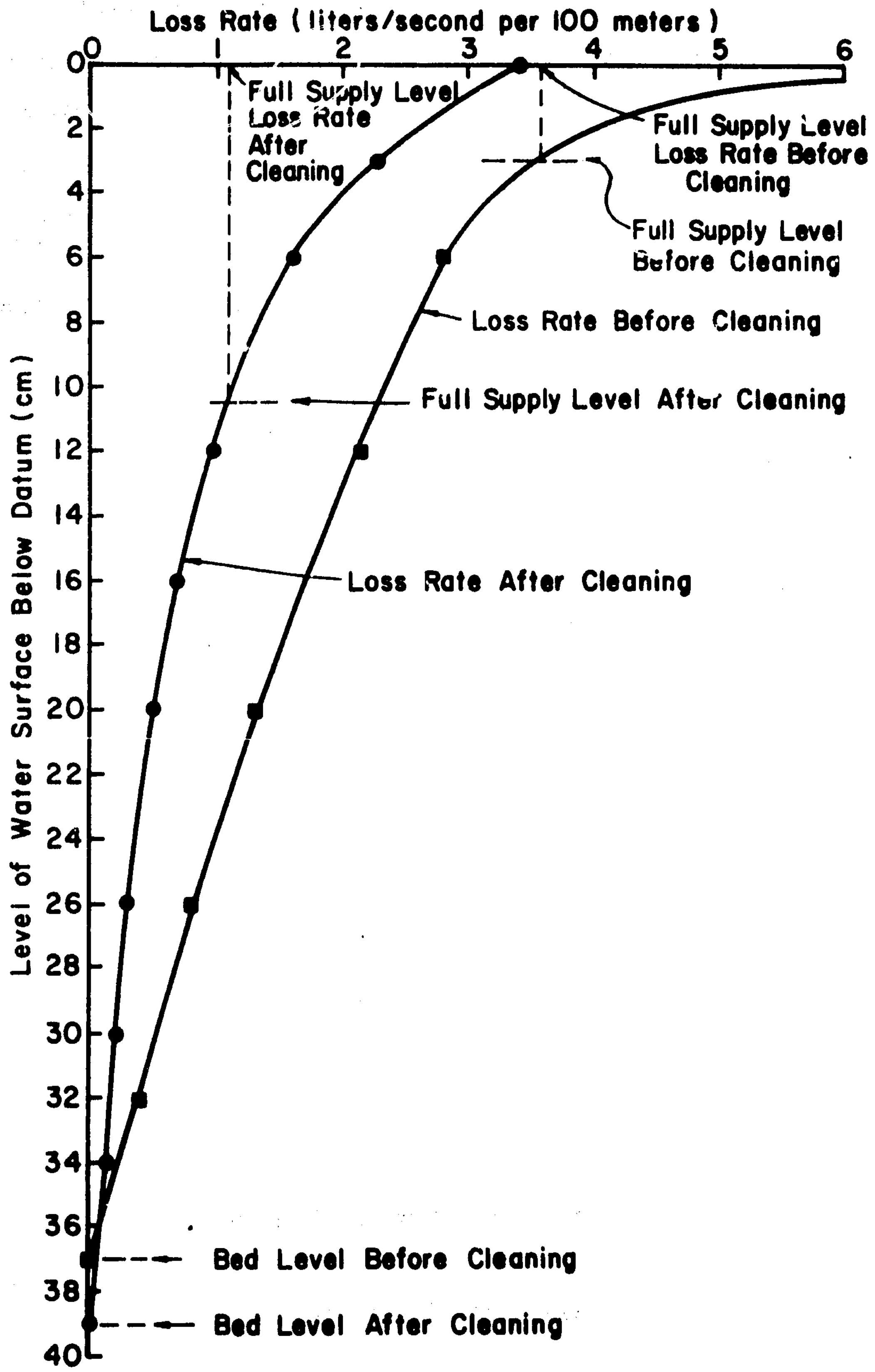


Figure 9. Water Surface Elevations and Loss Rates Before and After Cleaning Section No. 1 of the Watercourse at Tubewell 56.

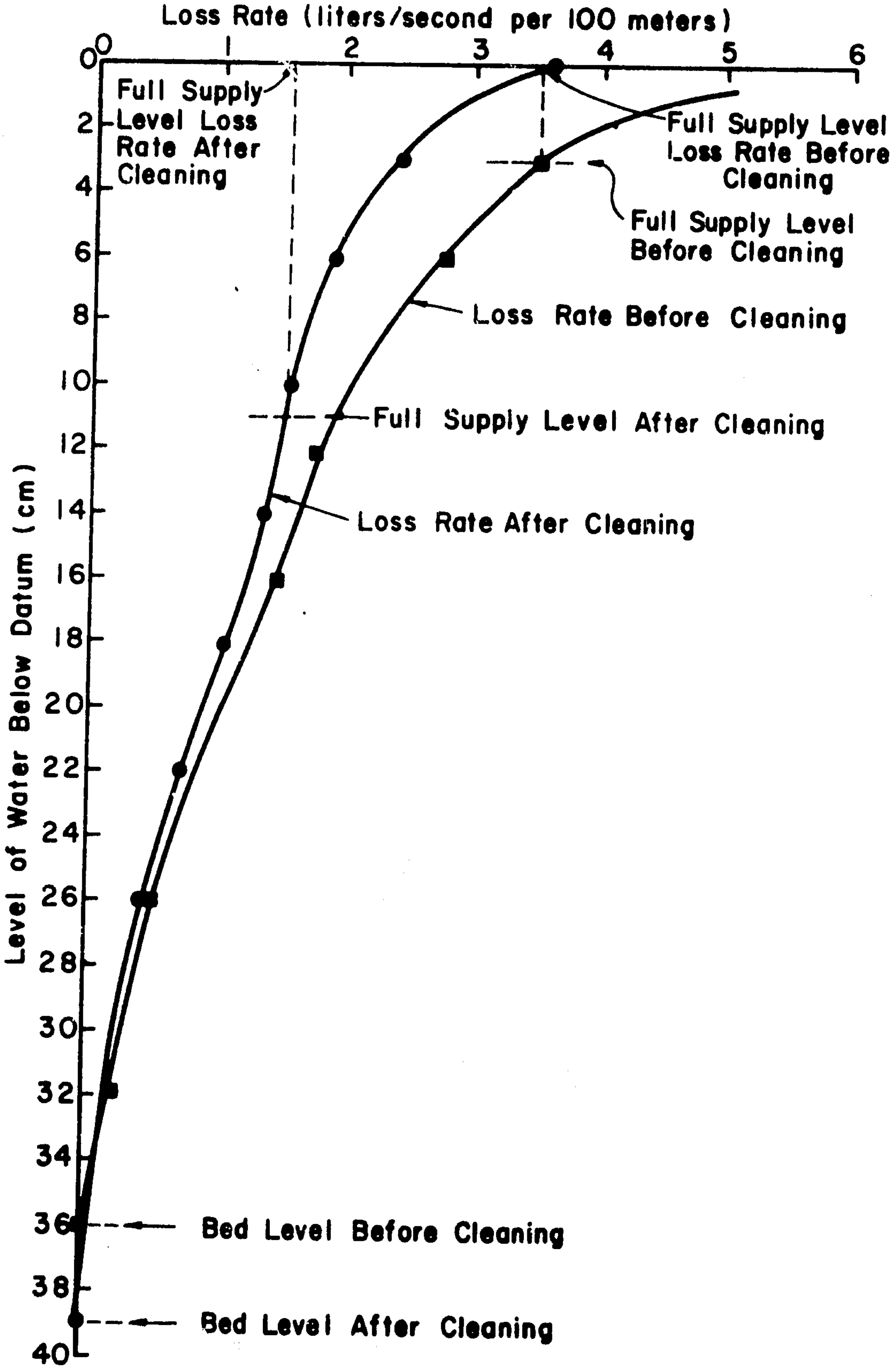


Figure 10. Water Surface Elevations and Loss Rates Before and After Cleaning Section No. 2 of the Watercourse at Tubewell 56.

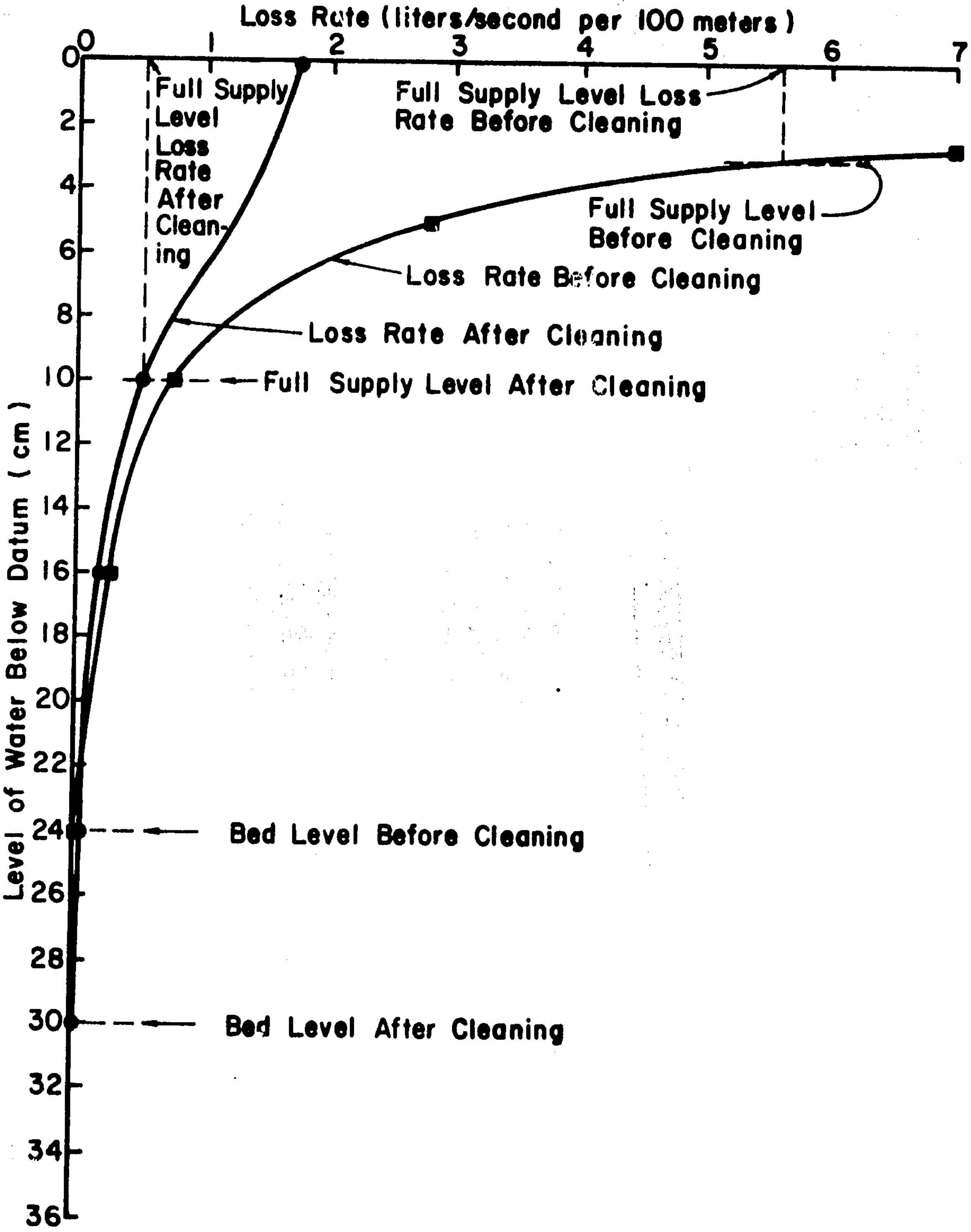
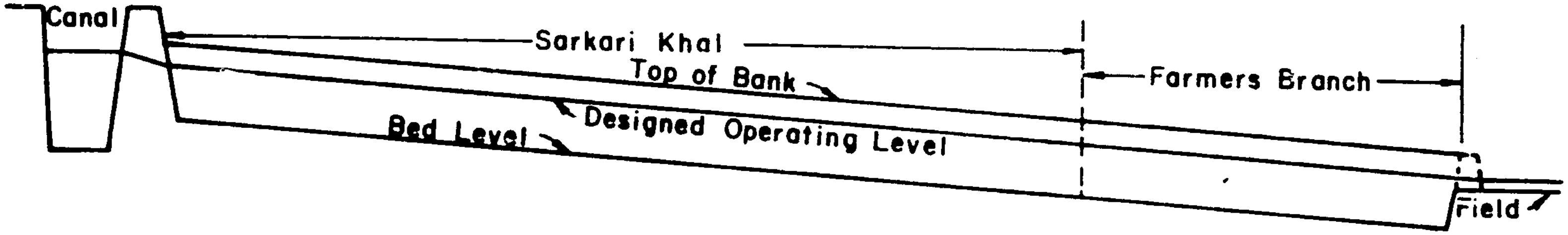


Figure 11. Water Surface Elevations and Loss Rates Before and After Cleaning Section No. 3 of the Watercourse Serving Tubewell 56.

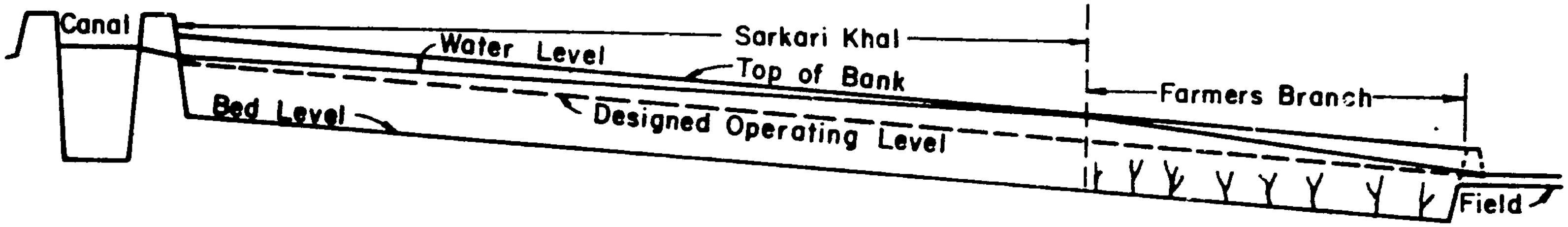
Figure 12. Why the Farmers Should Keep the Grass Cleaned from Their Branch Watercourses.

Watercourses are designed with sufficient slope and cross section to carry the authorized supply of water to the farmers fields - generally assuming that the sides and bottoms of the watercourse are made of earth and have a roughness coefficient of about 0.04.



In those portions of the sarkari khal where the water flows most of the time and cleaning takes place frequently, the roughness of the bottom and side of the channel stays near the design criteria and consequently the surface level of the water stays near the design level.

If the farmer also cleans the grass from his branch regularly, the level of the water in the whole watercourse will stay near the design level as indicated above.



However, if grass is allowed to grow it increases resistance to flow and head loss becomes larger, which raises the water level in this branch causing much more leakage through these banks and also raises the water level in the sarkari khal causing more of this farmers water in the watercourse to be used by the farmer who has the next turn. There is also a possibility that the water may rise clear back to the mogha and if the level of water in the canal is only a few inches higher than the designed watercourse level a rise in the water level in the watercourse may also reduce the rate of flow from the canal.

IV. CONCLUSIONS

Loss rates from watercourses are smaller when the levels of water in the watercourses are lower. Each watercourse section has its own unique set of holes and loss characteristics. However, lowering the operational level of water in the watercourse by 5 cm commonly reduces the water loss to 1/2 of its former value.

Vegetation in the watercourse increases the "roughness coefficients" of the beds and sides and the head difference required to push water through the watercourse increases. Since the elevation of water required at the delivery point is constant the increased head difference results in higher levels of water in the farmers watercourse. If there are no drop structures in the delivery system and the slope of the watercourse is small, the higher water level can extend far upstream in the sarkari khal, even when the "sarkari khal" has been properly cleaned.

The increased elevation of water in the watercourse caused by presence of vegetation and sediment is a primary cause of raised operational levels and increased water loss. A cleaning program which would keep the operational level within 2 or 3 cm of designed operational levels appears to have the potential of delivering up to 40% more water to many farmers fields. Increased supplies to average fields of 25 to 30% appear to be achievable.

Because of the close relationship between water loss and height of water in the watercourse, the height of water in a watercourse under operating conditions can serve as a good indication of when cleaning should occur to keep losses at tolerable levels.

Figure 13. Proposed Bench Marks for Monitoring Water Levels in Watercourses so Farmers Will Know When Cleaning is Needed.

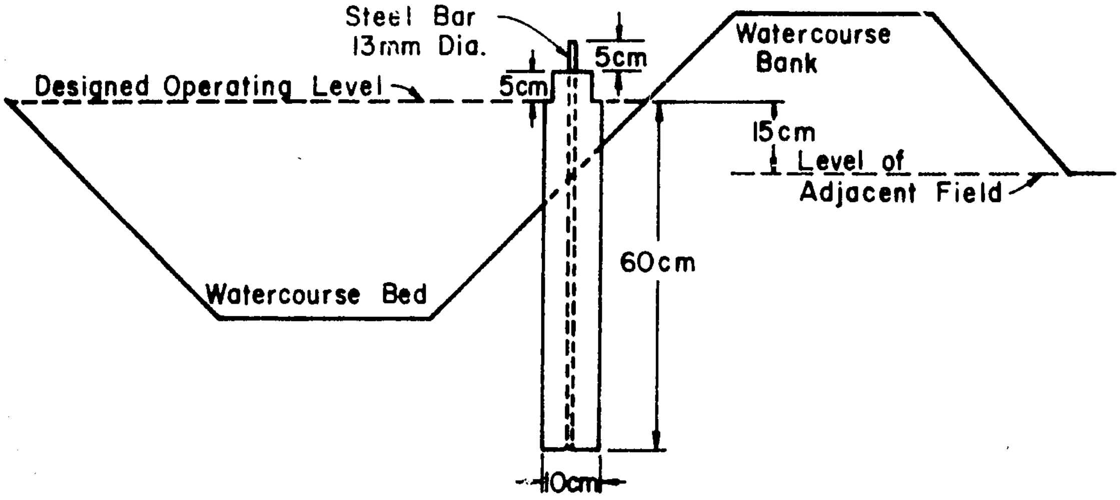
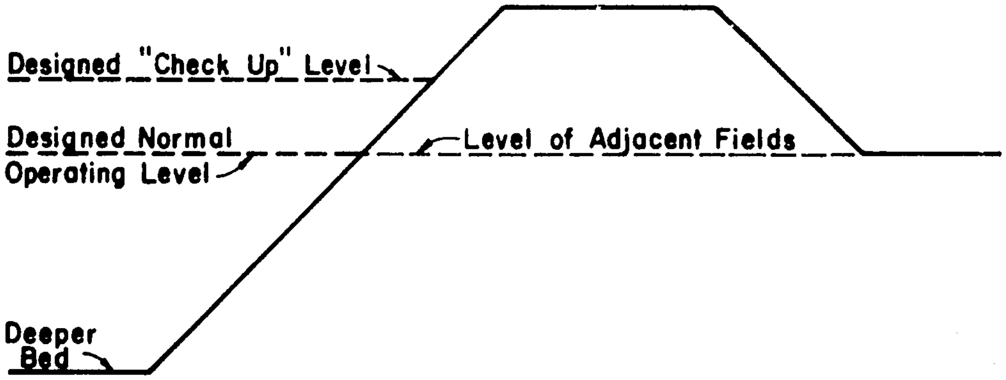


Figure 14. Lowering the Normal Operating Level of the Watercourse and Checking the Water Up Above the Adjacent Land Surface Only Where Necessary for Proper Delivery as a Means to Reduce Water Loss.



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APPENDIX 20

POTENTIAL FOR BUILDING AND UTILIZING FRESH WATER RESERVOIRS IN SALINE AQUIFERS[1]

W. D. Kemper, Mian M. Ashraf,
Munir Chaudhry and S. H. Johnson[2]

SCARP Tubewells

The SCARP tubewell program was designed to lower the water table, provide additional water for irrigation, stop salinization and reclaim salinized land. This program has accomplished at least part of these objectives in many areas. The excellent aquifer has proven to be the best storage site available in the Indus Basin except where the saline water has been pushed up near the surface by hydrologic factors as shown in Figure 1.

Recharge to the aquifer from the rivers has pushed salt water to the centers of the doabs and the layers of fresh water in the centers of these doabs are often so thin that pumping for irrigation use is not feasible. This is a self aggravating problem because lack of pumping in these areas leaves the water table high, so when monsoon rains come, there is little room in the aquifer for this good fresh rain water. It accumulates on the surface, causing flood conditions and runs off slowly through the available drains. The net effect is loss of this good water to the sea, retention of saline water in the aquifer and negligible increase in thickness of the layer of fresh water.

It was hoped that continued pumping of fresh water from the wells in the fresh water area would reduce the hydraulic pressure there and allow the saline water mounds in the centers of the doabs to subside as a result of movement of the saline water back toward the pumped areas. In other words, the thickness of the fresh water layers should tend to decrease in the pumped areas (increasing salinity in many pumped wells

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[1] Contribution from the Survey and Research Section and Mona Reclamation Experimental Project, WAPDA and Colorado State University. The Skimming Well studies were begun with a grant from USAID through CARE. The major installations were completed by June 1976. Since that time, the MREP, WAPDA has assumed responsibility for the operation of this study. Colorado State University input is made possible through USAID/ Washington Contract No. AID/ta-C-1411.

[2] CSU Field Party Chief, Chief Engineer, Survey and Research, Project Director, Mona Reclamation Experimental Project, WAPDA, and Economist, CSU Field Party, respectively.

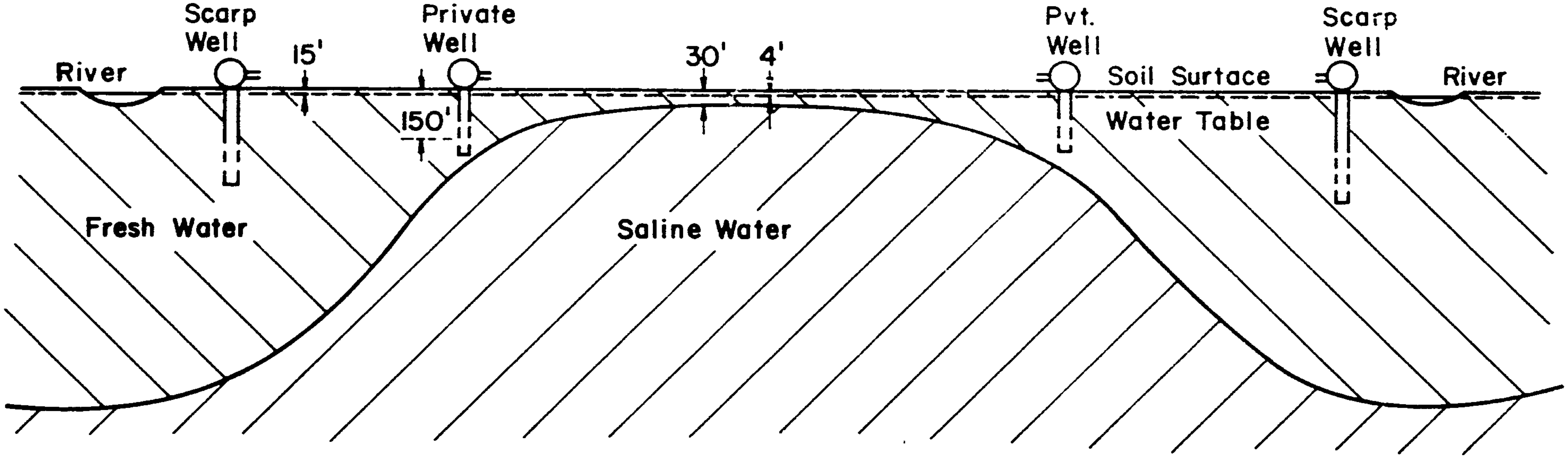

Figure 1. Present distribution of salt and fresh water and wells.

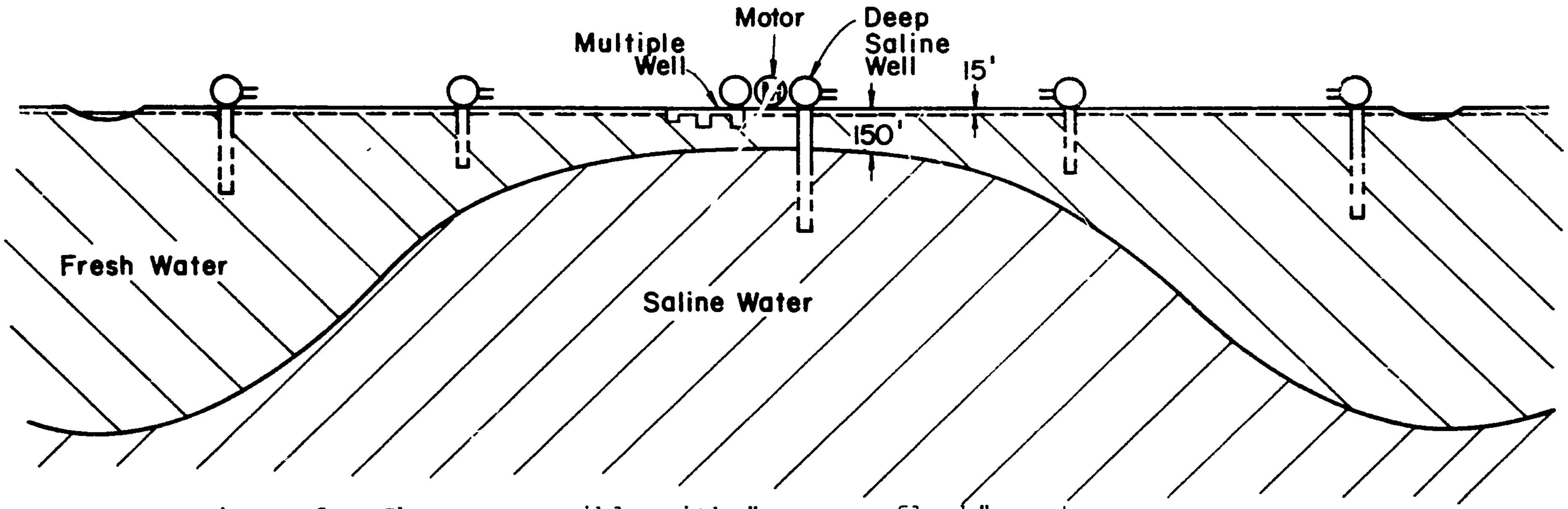

Figure 2. Changes possible with "monsoon flush" system.

indicates that this is occurring) and increase in the center of the doabs. If the latter process is occurring, it is so slow that it has not yet provided an appreciable thickening of the layer of fresh water in these "saline groundwater zones" in the centers of the doabs.

Shifts to Shallower Wells in Marginal Areas

In fact, deep (280 ft.) high capacity (2 to 4 cusecs) SCARP tubewells placed near the saline mounds where the fresh water layer was from 300 to 600 feet deep have continued to draw saline water from below them and in hundreds of cases farmers have demanded that these saline deep wells be closed. In many of the cases the same farmers have dug shallower (60 to 150 ft) tubewells with lower capacities (.5 to 1.5 cusecs) and are obtaining water of satisfactory quality from near the saline water mound in Figure 1.

Areas with Saline Ground Water Near the Surface

In areas where there is no pumpable fresh water in the aquifer on top of the saline water, the SCARP program has not been initiated because the water is not considered usable. Consequently no one has been willing to pay the cost of well construction and pumping. These areas, which are generally in the middle of the doabs[3] between the rivers, constitute about 25% of the irrigated lands of Pakistan. Estimates indicate a 50% reduction in yields of kharif crops and a 40% reduction in yields of rabi crops in these areas during the last 20 years as the water table has continued to rise and the salinity of the soil increased. These areas which are potentially among the most productive in Pakistan have been populated by some of Pakistan's best farmers. The holdings per farmer are generally small and their water supply is limited to about one cusec per 300 acres which can be obtained from the canal system. Consequently these farmers are being forced into subsistence agriculture with continually declining yields. These lands, so commonly deficient in water during peak crop use periods, are also commonly flooded during the monsoon period. A primary factor causing floods in these areas is the high water table which reduces infiltration of excess rains and causes standing surface water and crop damage. A considerable portion of the land in this area has already been abandoned because of salinization and high water tables, and the remainder of the land faces the same fate unless the technology is developed and a broadscale program is initiated to lower the water table, lower the saline-fresh water interface and provide for the use of disposal of the saline water.

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[3] Land areas lying between rivers.

The solutions of the water management problems of lands lying in the areas with fresh ground water are relatively simple and have generally been brought within the economic and technical capabilities of the private sector. Public and private tubewells to furnish irrigation water and achieve lowering of the watertable are a well established part of the Indus Basin production unit.

The individual now in most critical need of government assistance is the farmer with a small land holding and limited water supplies whose land is steadily being salinized by saline ground water. At present the government is not able to give him help on this problem. He believes the water is too saline to use and therefore he will not invest in a tubewell to pump the water. If he does pump the water, the area of influence on the watertable may be so wide that he will only receive a small fraction of the benefit in terms of watertable drawdown on his holdings. His future appears to lie in eking out a subsistence from a continuingly degrading resource until it goes out of production entirely and he is forced to migrate to other areas and join the multitude of landless laborers.

A government program to help the millions of people dependent on these salinizing farms will be essential in the near future.

It has long been recognized that removal of some of the saline water would help solve this problem by lowering the saline, fresh water interface. However, there has been considerable reluctance to pump saline water because (1) no one wished to pay the cost and (2) there is concern that saline water added to the river will damage downstream lands which use river water for irrigation. These are valid reasons and should eventually be evaluated in depth, but a preliminary evaluation is needed now and is attempted as follows.

Cost of Pumping to Create Fresh Water Reservoirs in the Top Portion of a Saline Aquifer

The cost of pumping saline water should be evaluated and compared to its benefits. Let us assume that we want to add 20 million acre feet of fresh water storage capacity, to the center portions of these doabs from which water can be pumped during high demand seasons, which can absorb 20 million acre feet of water during the monsoon flooding periods. This can be done if 20 million acre feet of saline water can be extracted from below the saline-fresh water interface in the central areas of these doabs in such a manner that the saline-fresh water interface lowers as indicated in Figure 2. The salt content of these waters is about 5000 parts per million or about 7 tons per acre foot of water. Deposition of all this salt on downstream lands would not be a good practice.

However, during the monsoon season, 60 to 90% of the water presently flowing down the Indus usually goes to the sea, and this may be used as a carrier to move most of this salt to the sea.

Consequently, let us assume that the water must be pumped from the saline zone of the aquifer to the rivers during the two months of each year when most of the river water is going to the sea.

Assume for discussion purposes, pump capacities of two cusecs, pump life of 20 years (when run only 2 months of each year) and well depths of 350 feet, with blank casing from 0 to 200 feet and screen from 200 to 350 feet. Then each well, if run continuously for two months (monsoon) of each year, would pump 240 acre feet of water per year, or 4,800 acre feet of water in twenty years.

Extraction of 20 million acre feet of water would require the installation of about 5000 wells. If each of these costs Rs. 375,000 the total cost of building this 20 million acre feet of fresh water storage capacity in the saline central portions of the doabs will be Rs. 1,875,000,000 or about 7% of the cost of surface reservoir type of storage. In making this comparison, it should be recognized that surface reservoir storage can serve the additional function of electric power supply and that recovery of water from the aquifer storage requires power. The facts that surface reservoir storage requires construction of canals to deliver the water to the mogha and that about 30% of the water is lost from the canals, should also be included in the final comparison.

Filling of this storage reservoir in the aquifer would be from excess water during monsoon rains (which would decrease flooding and crop damage), from canal and watercourse seepage, and from the overirrigation which occurs in low spots as a result of unlevel land and at certain seasons when irrigation and rainfall exceed crop needs. During this period of saline water pumping (fresh water reservoir building) extraction would exceed recharge and the overall watertable should recede to reduce the waterlogging.

The wisdom of pumping saline water into drains which are already often overloaded during monsoon season should be questioned. However, in these areas where the groundwater is near the surface the soil profile quickly fills up under present conditions and additional rainfall runs off. For each acre foot of water pumped, an acre foot of storage is made available for the excellent quality rain water. Consequently, if the hydraulic conductivity is not limiting the downward movement of water during the monsoon season there will be little, if any, extra load on the drains. Moreover, the downward movement of this excellent quality water will move salts which have accumulated in the surface down through the profile and play a major role in reducing the salinity in the plant root zone.

Since a pumping system will be needed to extract water from the new fresh water layer for irrigation, and since this irrigation will be needed in times other than the monsoon rain period, the possibility exists of using the same power unit for both functions. The electric motor used for pumping saline water could be used during periods of high demand for pumping irrigation water. This coordinated use of the electrical connection and motor could reduce the costs that would otherwise be ascribed completely to "reservoir building."

Salinity Increases in Downstream River Water

About 30 million acre feet of water now escapes to the sea during the monsoon season (July 20 to September 20) and about 10 million acre feet of water is diverted at points below the doabs in question for irrigation purposes. Consequently if one million acre feet of water at a salinity of 5000 ppm is pumped into the river each year, it will be diluted by a factor of about 40, and the increase in salinity of the river water would be about 125 ppm during the monsoon season. During other seasons, the salinity in the river water should actually be decreased because there should be a slight reduction in the amount of saline drainage waters flowing out the doabs.

The increase in salinity (125 ppm) of downstream water caused by creation of the "fresh water reservoirs" in the saline aquifers of the Punjab doabs during the monsoon still leaves the monsoon water delivered to the Sind in the "very good" category.

Origin of the Supply to Fill the New Fresh Water Reservoirs in the Aquifer

Basically this fresh water to fill the reservoir would come from seepage from canals and watercourses and localized overirrigation (which are presently not pumpable and are causing the extreme waterlogging and salinity problems in the center of the doabs) and from excess monsoon rains (which presently cause flooding and crop damage). These fresh waters would be absorbed into the fresh water aquifer.

Questions Requiring Solutions Before an Efficient Development Program Can Begin

1. Can good water in shallow surface layers be recovered without major contamination from underlying saline water?

To help answer this question a "skimming well" study was initiated by CSU and the MREP with USAID-CARE support in 1974. The following results are taken from the 1976 report (Kemper et al., 1976). A shallow multiple well system and a compound well system were evaluated as follows:

a. Shallow Multiple Wells

The installation shown in Figure 3 was constructed. Tubewell #1 was constructed first. It was bored to a depth of 60', with screen from 10 to 60 feet. The pump was run from January 5 to January 20. The water table heights before, during and after pumping are shown in Figure 4. The salinity of the water at 10' depth intervals down to about 110' depth was measured at about 3 day intervals. Salinity (electrical conductivity) is plotted as a function of depth for observation wells T_{1-1} and T_{1-4} in Figures 5 and 6.

The isoconcentration line equal to 5 mmhos of electrical conductivity was chosen to indicate the "saline-fresh water interface" and it is plotted in Figure 7 to indicate the rise of the saline-fresh water interface during pumping, and in Figure 8 to show the fall of the s-fw interface after the pump was stopped.

The concentration of the pumped water was determinec daily and is shown as the top curve in Figure 10.

Wells #2 and #3, each 30' deep, were constructed at the locations and with the dimensions and connections indicated in Figure 3, during April and May of 1976. After disturbances due to the drilling operations had largely dissipated pumping was begun from wells #2 and #3 on July 2 and was continued until August 3.

Salinity profiles at the observation wells were measured and the rise of the saline-fresh water interface is indicated in Figure 9. The salinity of the pumped water was also measured daily and is plotted as the bottom curve in Figure 10.

In general the water pumped from the two 30' deep wells had considerably less salt than the water pumped from the single 60' deep well. The rise of the saline-fresh water interface below the two shallow wells also appears to be slower, except for the high rise indicated as occurring under well #3 during the July 30 to August 3 period. This high rise of the interface under well #3 may be an anomally caused by a malfunction of the measuring system (which is discussed in more detail by Kemper et al. 1976).

The fraction of the water pumped out of the well which has come from the saline water displacing fresh water can be estimated from the volume of the cone times the pore space of the aquifer divided by the volume of water pumped.

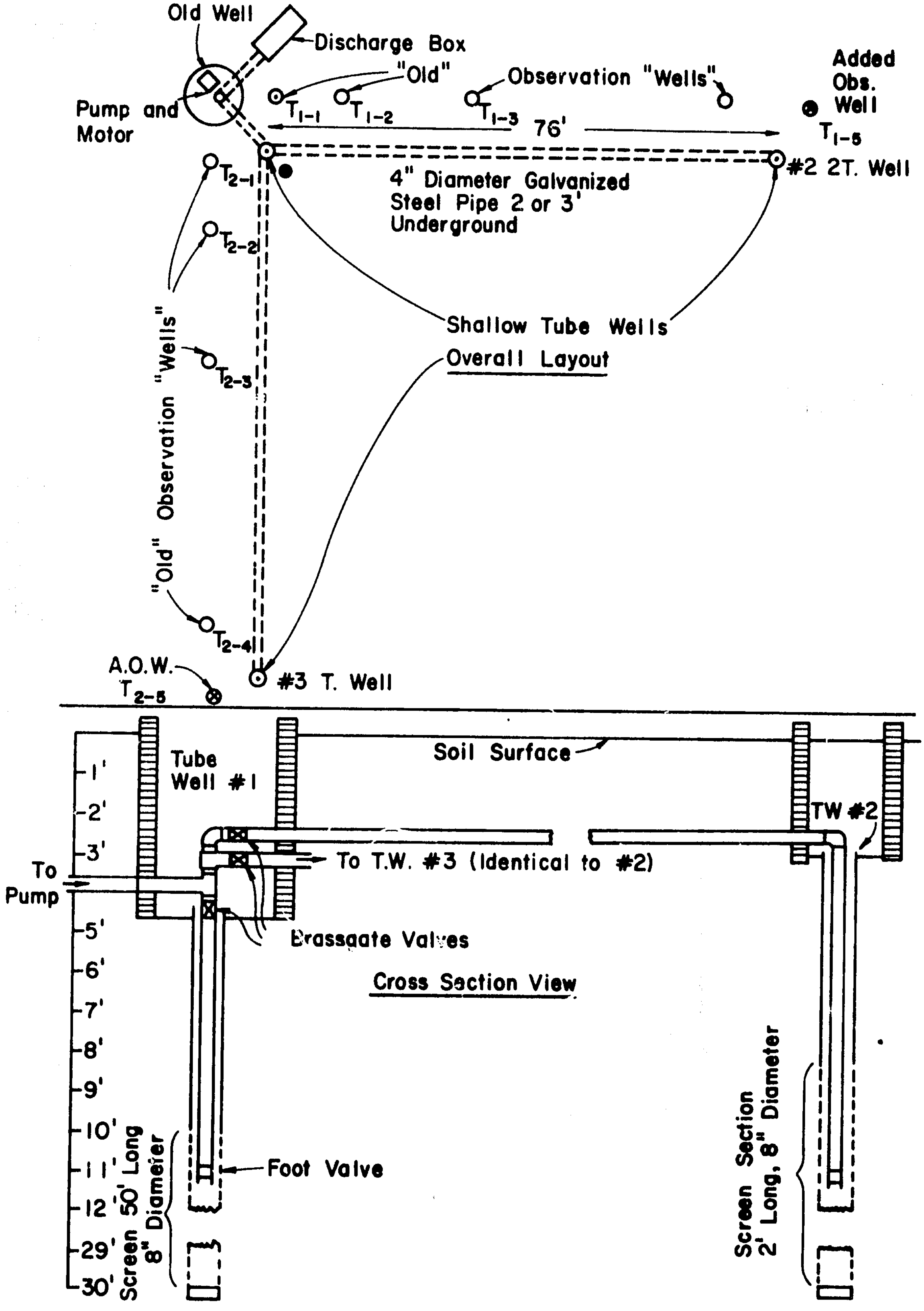

Figure 3. Multiple Well Testing Installation.

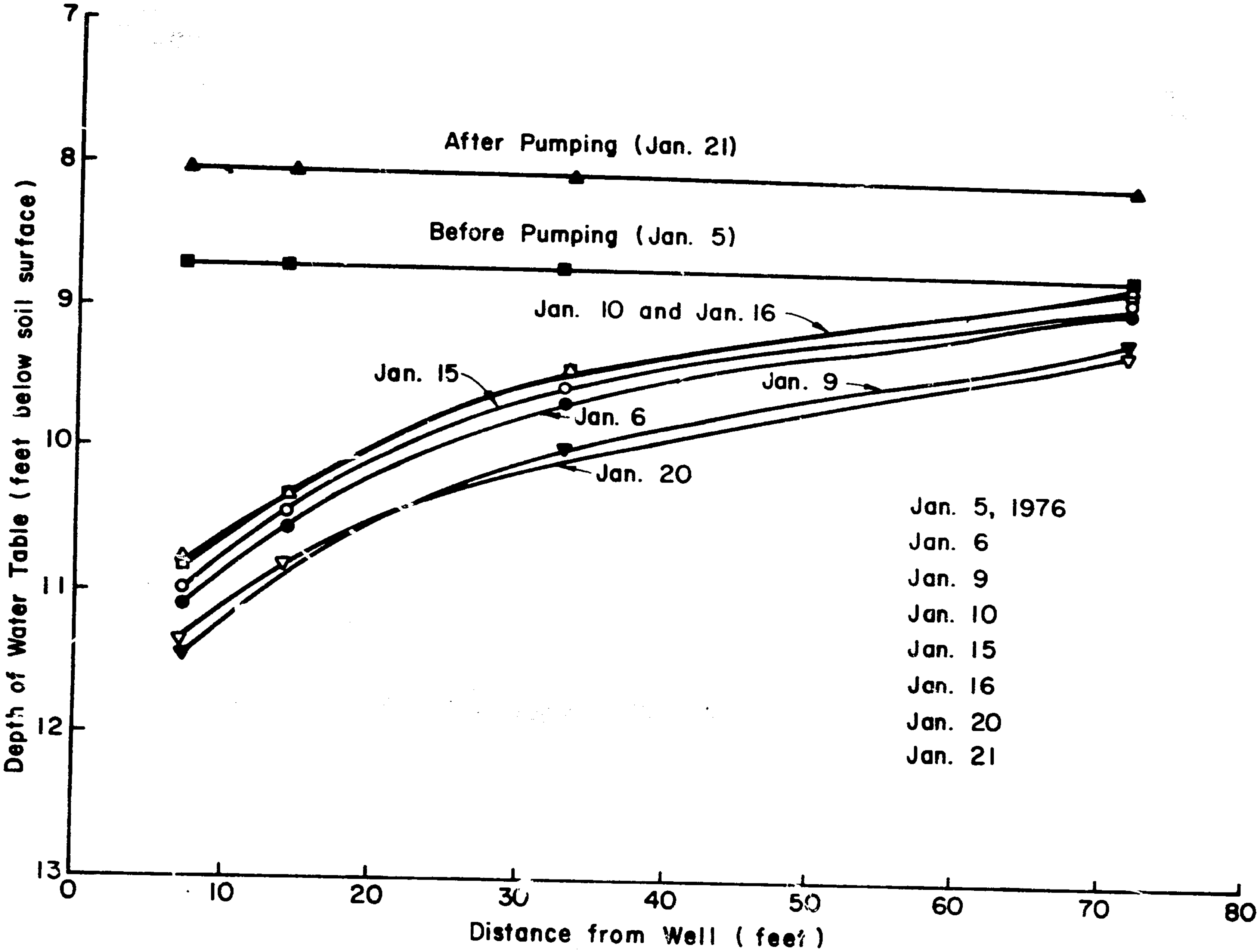

Figure 4. Water Table Before, After and During Pumping.

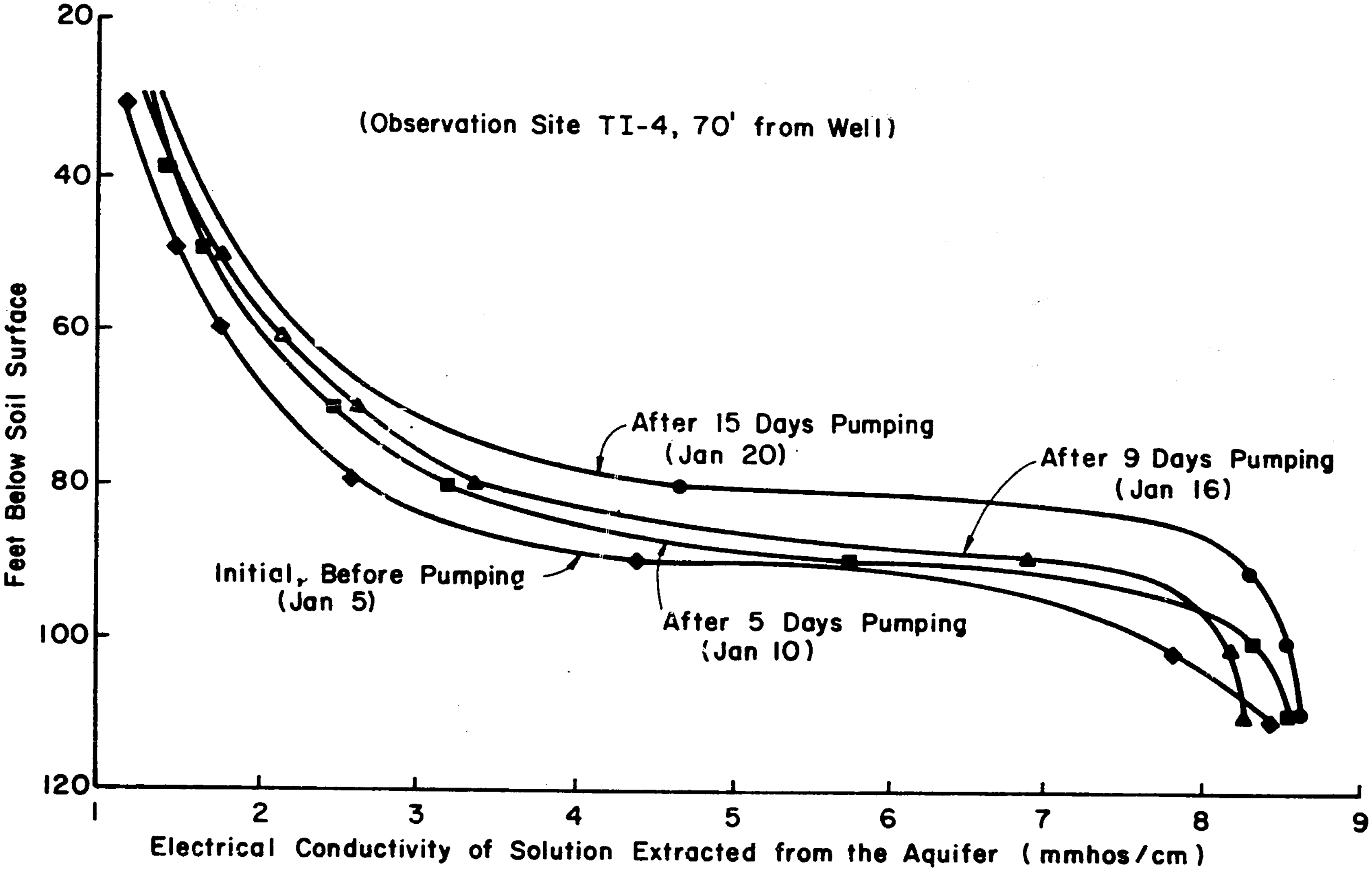

Figure 5. Salinity of water in the aquifer as a function of depth below the surface before and during pumping.

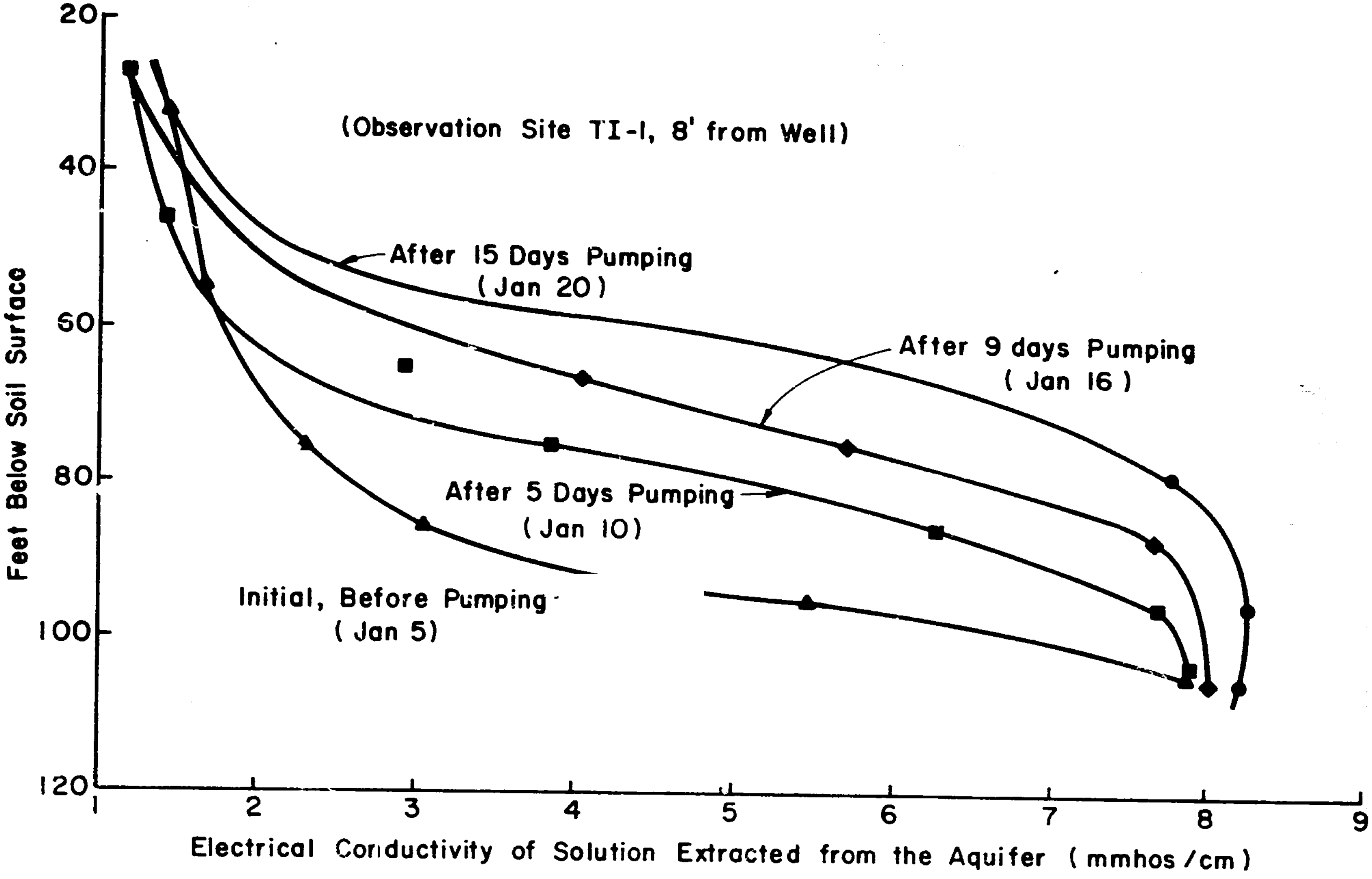

Figure 6. Salinity of water in the aquifer as a function of depth below the surface before and during pumping.

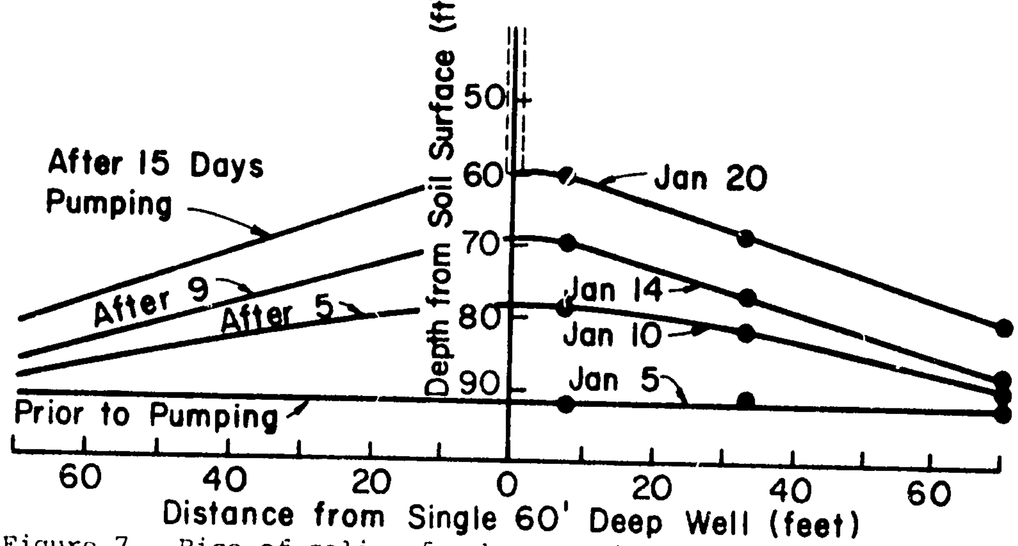

Figure 7. Rise of saline-fresh water intervase as indicated by successive positions on the 5mmho/cm isoconcentration line during pumping.

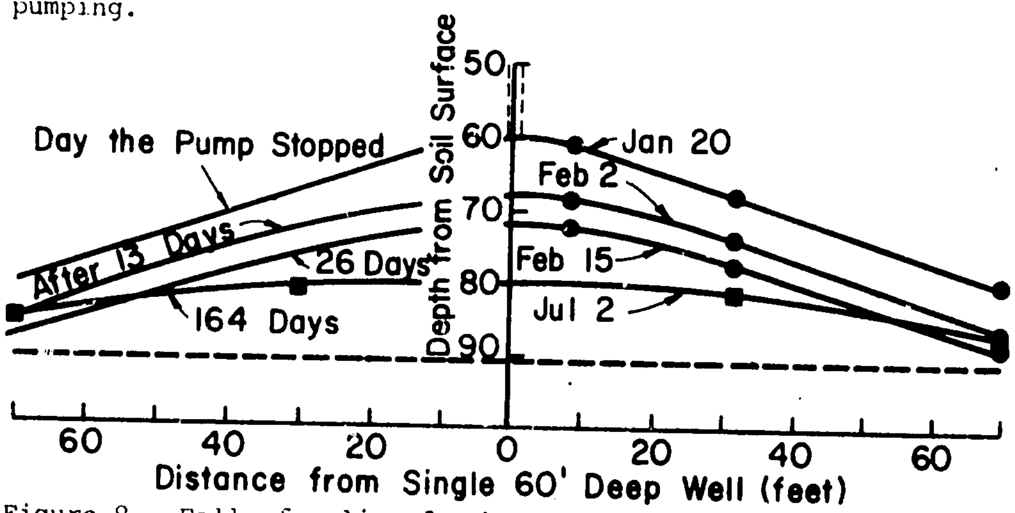

Figure 8. Fall of saline-fresh water interface.

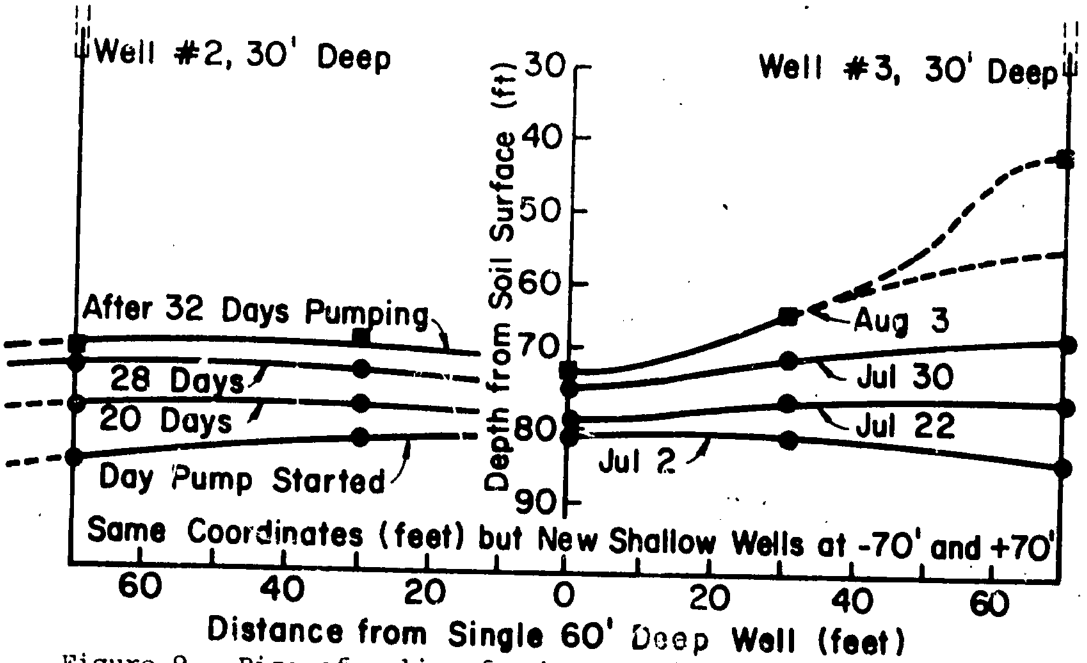

Figure 9. Rise of saline-fresh water interface during pumping of two connected shallow wells (each 30'deep).

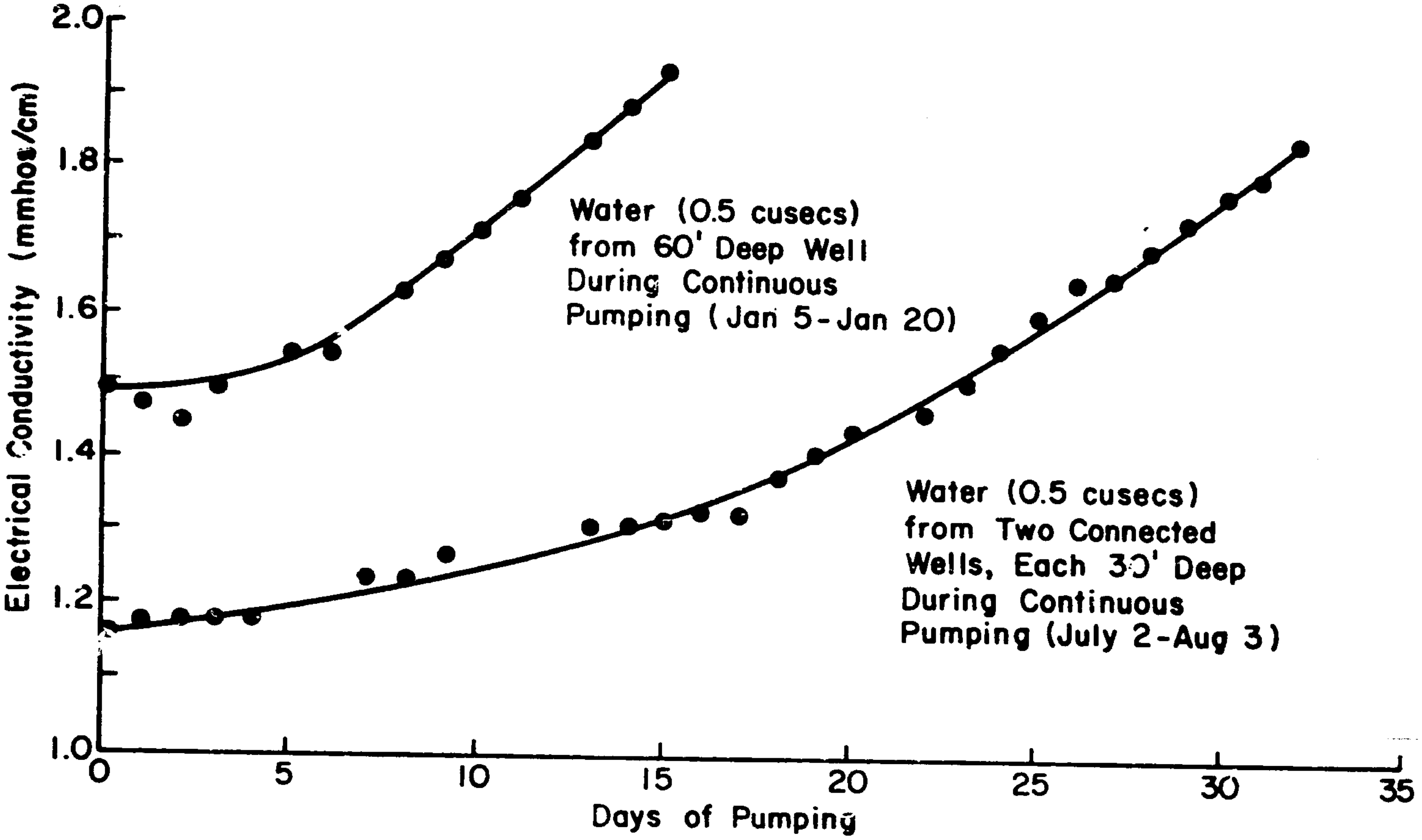

Figure 10. Salt content of water which was being pumped.

The cones were reasonably conical at the single 60' deep well on the 5th, 9th and 15th day during pumping and their dimensions were approximately as indicated in Table 1.

Table 1. Dimensions of the saline water cone which was developed by pumping

Volume of water pumped	Days of pumping	Approximate Cone Dimensions height	radius	volume	% of pumped water that was replaced by saline water cone
216,000	5	14	80	94,000	17
388,000	9	24	90	203,000	21
648,000	15	32	110	402,000	25

Where the volume of the cone was calculated from the equation $V=\pi r^2 h/3$ where h is the height of the cone and r is its radius. Porosity assumed was 0.4.

It appears that continued pumping results in a larger and larger fraction of the pumped water coming from displacement of fresh water by the saline water cone. This is probably a result of the interface coming closer to the well so that a larger fraction of the stream lines are coming through the saline zone and of the relative stabilization of the ground water surface cone after prolonged pumping.

At present, the following tentative conclusions are drawn: (1) The rate of rise of the saline water cone was almost a linear function of the time for which the single well was pumped at 0.5 cusecs. (2) During the first 10 days after pumping, the rate of fall of the cone was about half as fast as its linear rate of rise. However, the rate of fall decreased rapidly and a substantial portion of the cone persisted 5 months after the pump was stopped. (In fact, if one assumes that the base of the cone extends 183 feet from the well, on July 2, the total 402,000 cubic feet of cone estimated on January 20 can still be accounted for. The experimental uncertainties in the data are such that this possibility is not completely excluded.) (3) As pumping is continued a larger and larger fraction of the pumped water comes from displacement of fresh water by the rising saline water rather than lowering of the water table in the vicinity of the well. (4) The salinity of the pumped water was reduced by 25% by using two wells with screens from 8 to 30' in depth instead of one well with screen from 10 to 60 feet depth. (This percentage reduction in salt content of water pumped may be even larger when observation wells are not serving as conduits for the rise of saline water to the surface.) (Kemper et al. 1977.)

b. Compound Well

The installation shown in Figure 11 was constructed during April and May 1976. Nazir Ahmad (1976) has proposed that the potential of this type of well for separating fresh and saline water should be evaluated. A set of observation sites were located around this well in a manner similar to those shown around the first well in Figure 3. These observation sites allowed sampling of the solution at 10 foot intervals from 30 down to 120 ft. depth.

The larger pump (extracting water from the 8" dia. screen from 13 to 63' deep) was started on October 28 when the water table was at a depth of 5.7 feet below the mean ground surface as indicated in Figure 12.

The salinity of the pumped water increased as indicated in Figure 13 from 1.7 mmhos/cm to 2.0 mmhos/cm during the first four days of pumping (at a rate of 0.5 cusecs). The salinity profiles were determined at the observation sites and profiles for the D_{2-2} and D_{2-5} sites are shown in Figures 14 and 15. Since the salinity ranged from about 1.5 to 7 mmhos/cm the isoconcentration line of 4 mmhos/cm was chosen as the interface. The 4 mmho isoconcentration line at 4 days is plotted in Figure 16. The objective of having the small well with its screen in the saline area is to intercept saline water rising from below the main well, so that water pumped from the main will have better quality. One day of pumping this saline water interceptor well at 0.03 cusecs (while the main well kept pumping at 0.5 cusecs) did not appreciably improve the quality of fresh water. In fact, the salt content of the water appeared (Fig. 13) to continue its increase. Consequently the rate of pumping at the interceptor well was increased to 0.05 cusecs (while the main well continued pumping 0.5 cusecs). After 4 days of pumping at this rate it was obvious that the salinity of the water was still increasing in the main well.

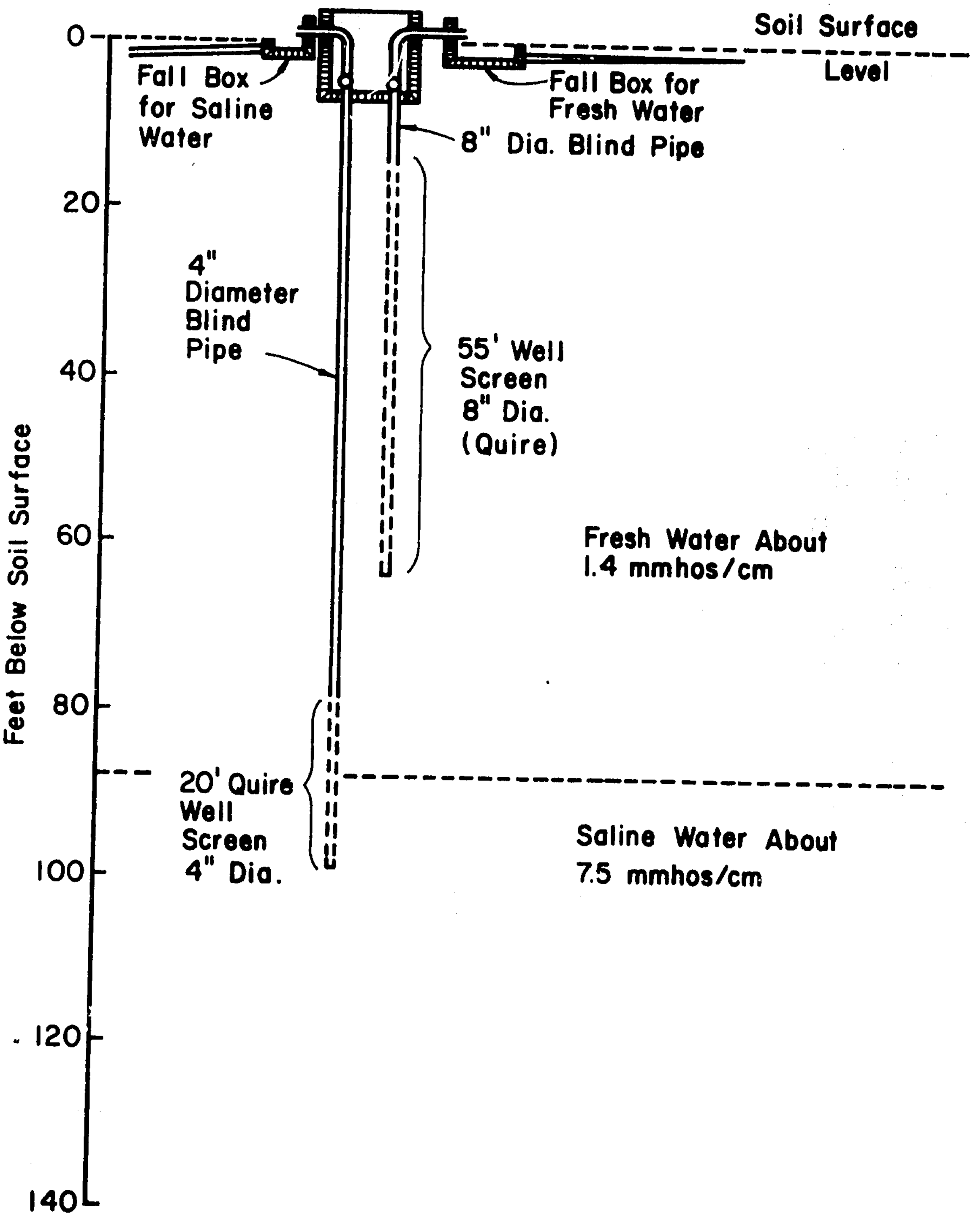

Figure 11. Compound Well Testing Installation.

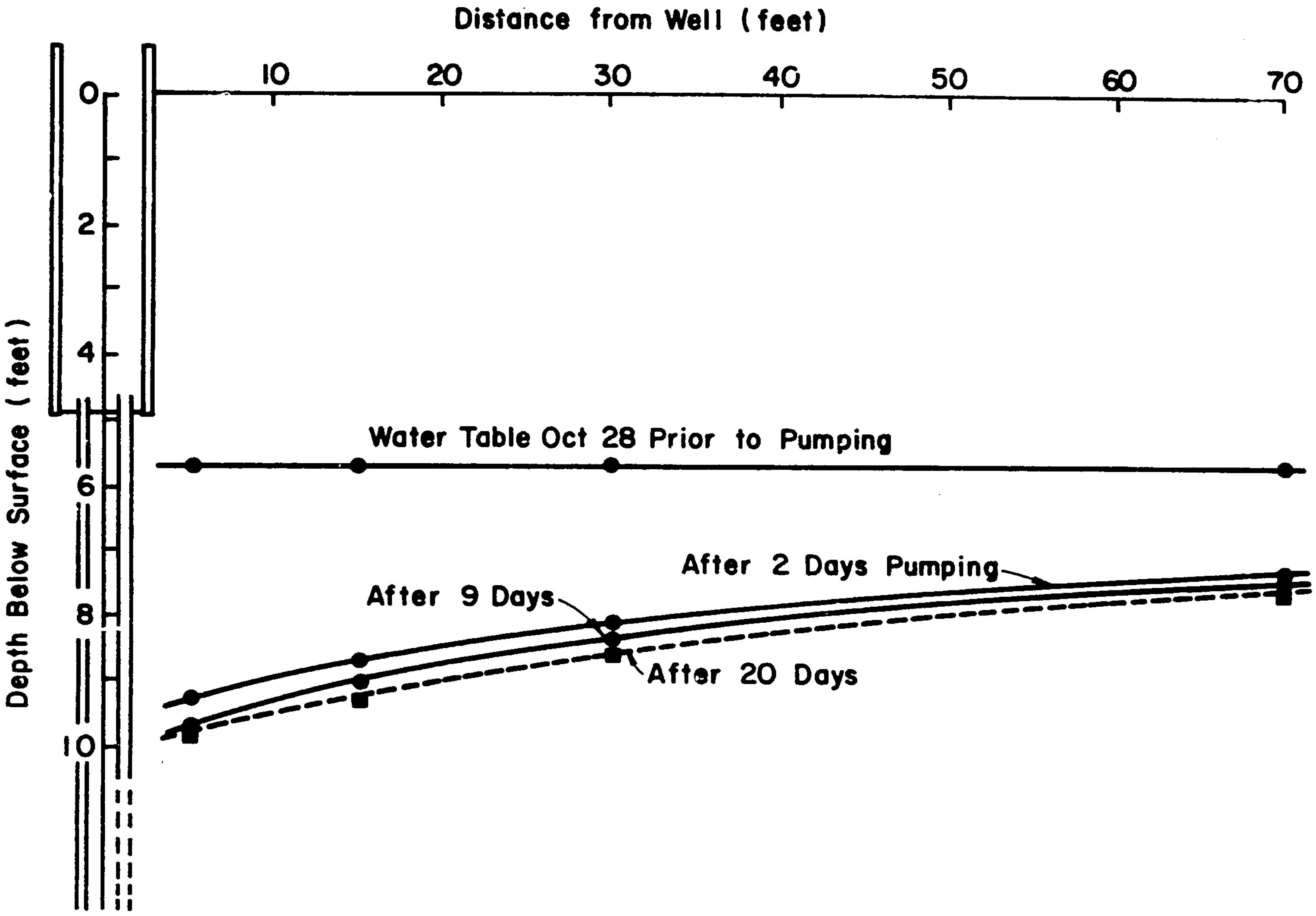

Figure 12. Drawdown of Water Table Near the Compound Well.

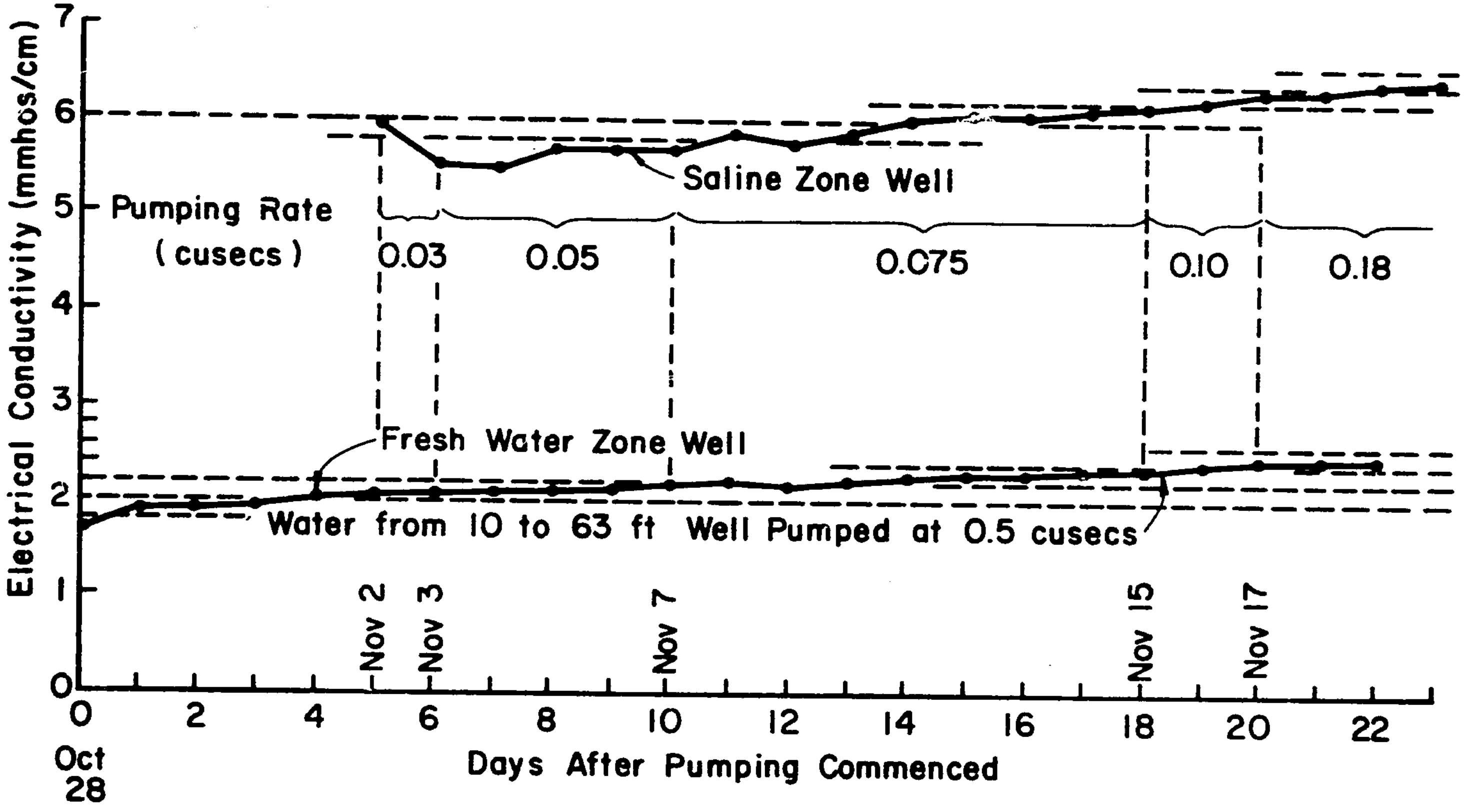

Figure 13. Discharge Rate and Salinity of "Saline" and "Fresh Water" Wells in Compound Well Installation.

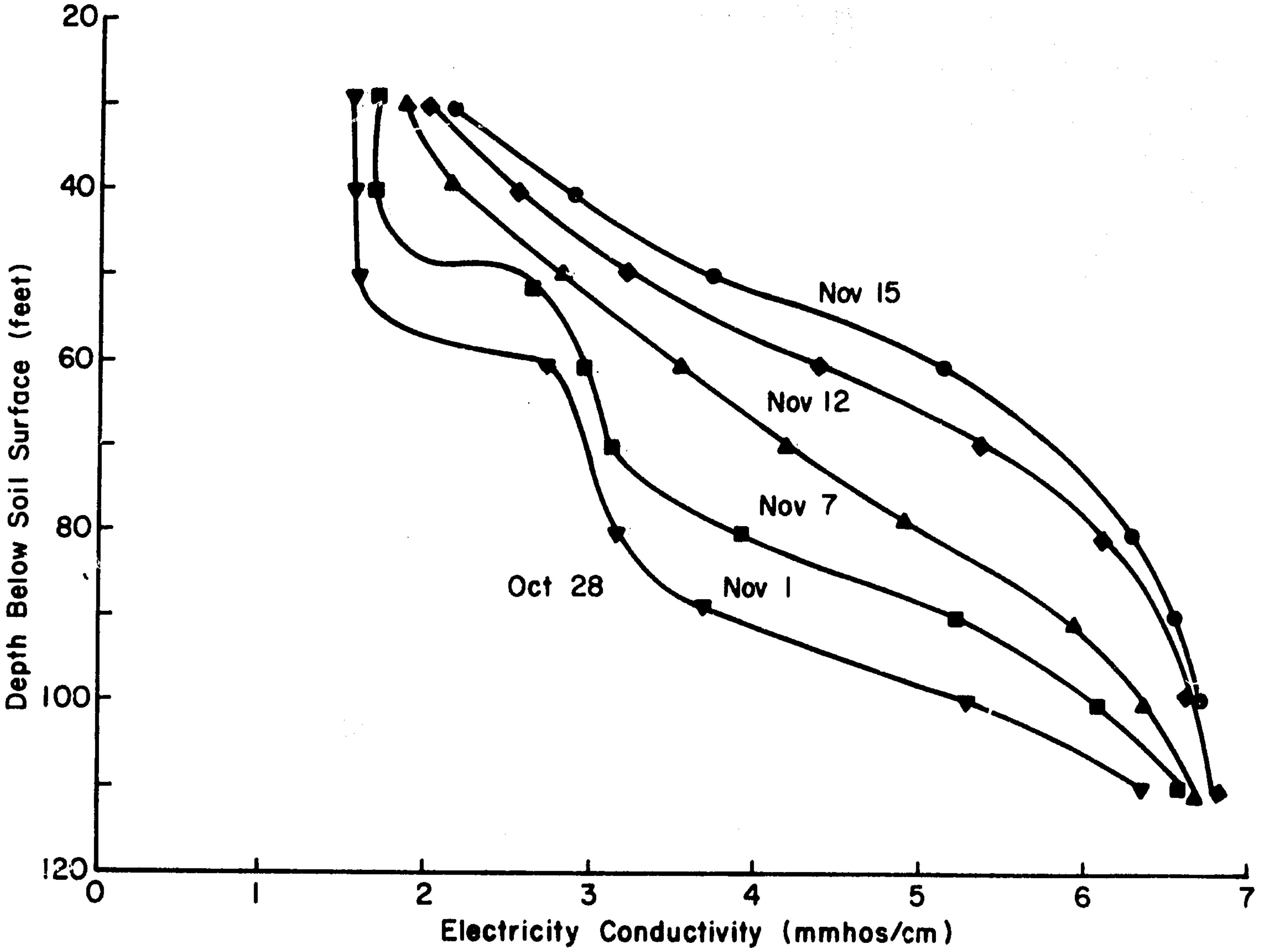

Figure 14. Salinity Profiles at the D_{2-2} Observation Site Adjacent to Compound Well During Pumping which was Initiated

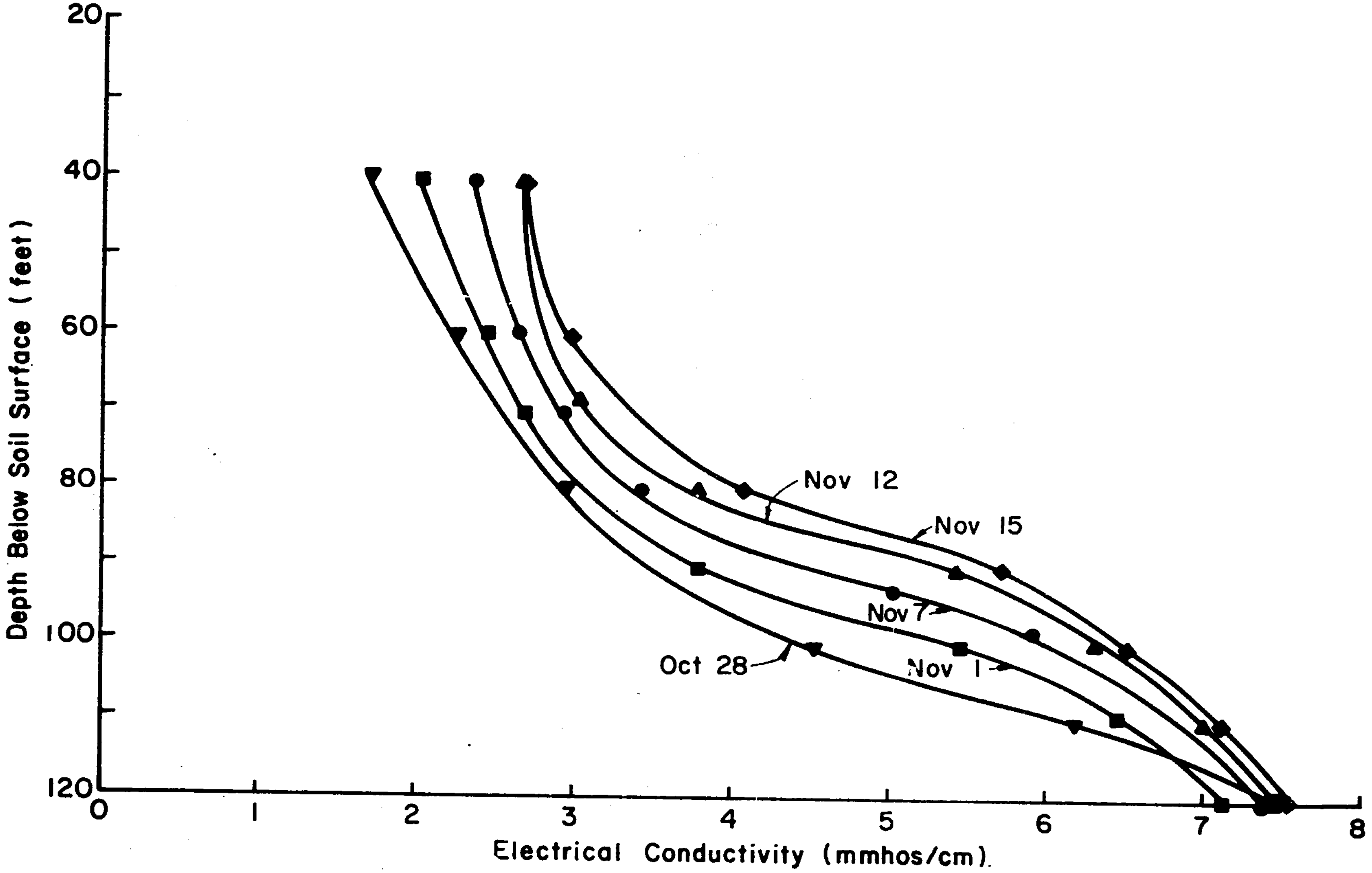

Figure 15. Salinity Profiles.

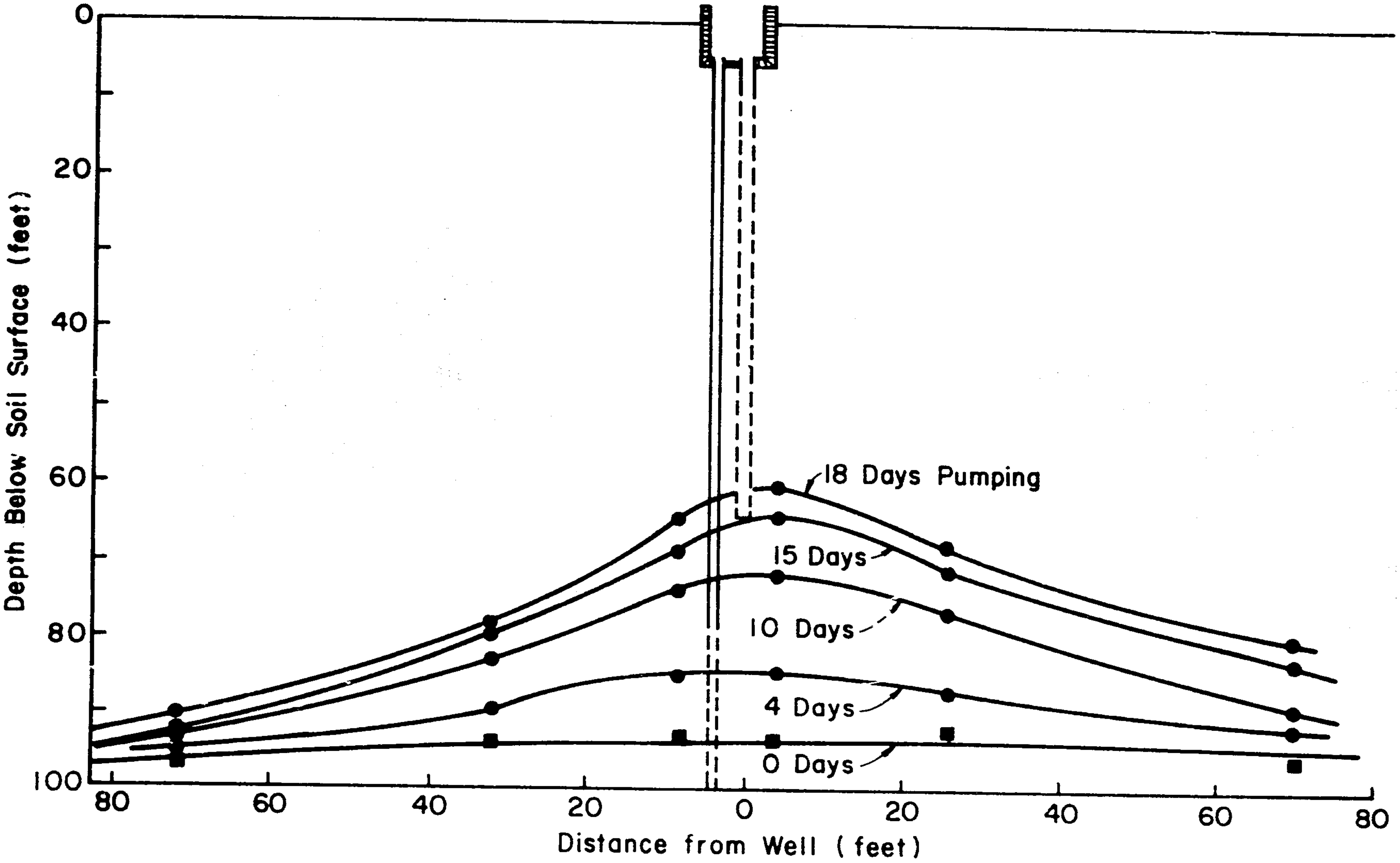

Figure 16. Effect of pumping the compound well on the saline-fresh water interface.

Subsequently the rate of pumping the interceptor well was raised successively from 0.075 to 0.10 to 0.18 cusecs on the 10th, 18th and 20th day of pumping successively, while the main well continued pumping at 0.50 cusecs. None of these rates of pumping the saline well were sufficient to reverse the time trends toward higher salinity in the pumped water (Figure 13) and toward higher coning of the saline water below the main well (Figure 16).

This failure of pumping rates in the interceptor well of up to 36% of those in the main well to reduce the salinity, or even stabilize the salinity is disappointing. It had been hoped that pumping of a relatively small amount (i.e. 10% of the rate of the main pump) of saline water by the interceptor well would stabilize the stream lines into the two wells and allow separation of the saline and fresh water. The primary reason for continuing increase in salinity of the pumped water is indicated in Figure 17 where streamlines have been sketched in qualitatively for the case in which pumping of the interceptor well is about 40% of the pumping from the main well. Note that the origin of most of these streamlines (when extended several hundred feet) is the underlying saline portion of the aquifer. The difference in density between the saline and fresh water tends to balance the hydraulic pressure gradient force causing the upward lift of the saline water cone. When similar phenomena are considered for oil and water, the difference in density is about 0.2gm/cc. However, the difference in density of water containing 500 ppm salt and 5500 ppm salt is only 0.005 gm/cc and the resulting gravitational force tending to hold the cone down is only 1/40 as large as for the oil-water systems which have been studied extensively. The fact that this gravitational force is still appreciable is indicated by the recession of the cone of a single well as shown in Figure 8. However, the hydraulic gradients caused by pumping the well are definitely the dominant forces when the pumps are operating.

It would be possible, by increasing the pumping rate of the interceptor well to values as high, or higher than those of the main well to hold down the concentration of water pumped from the main well. However, the amount of salt that would have to be pumped and disposed of is large (i.e., see upper curve of Figure 13).

The conclusion that a large amount of saline water will have to be pumped to maintain a steady state pumping system in which the saline layer

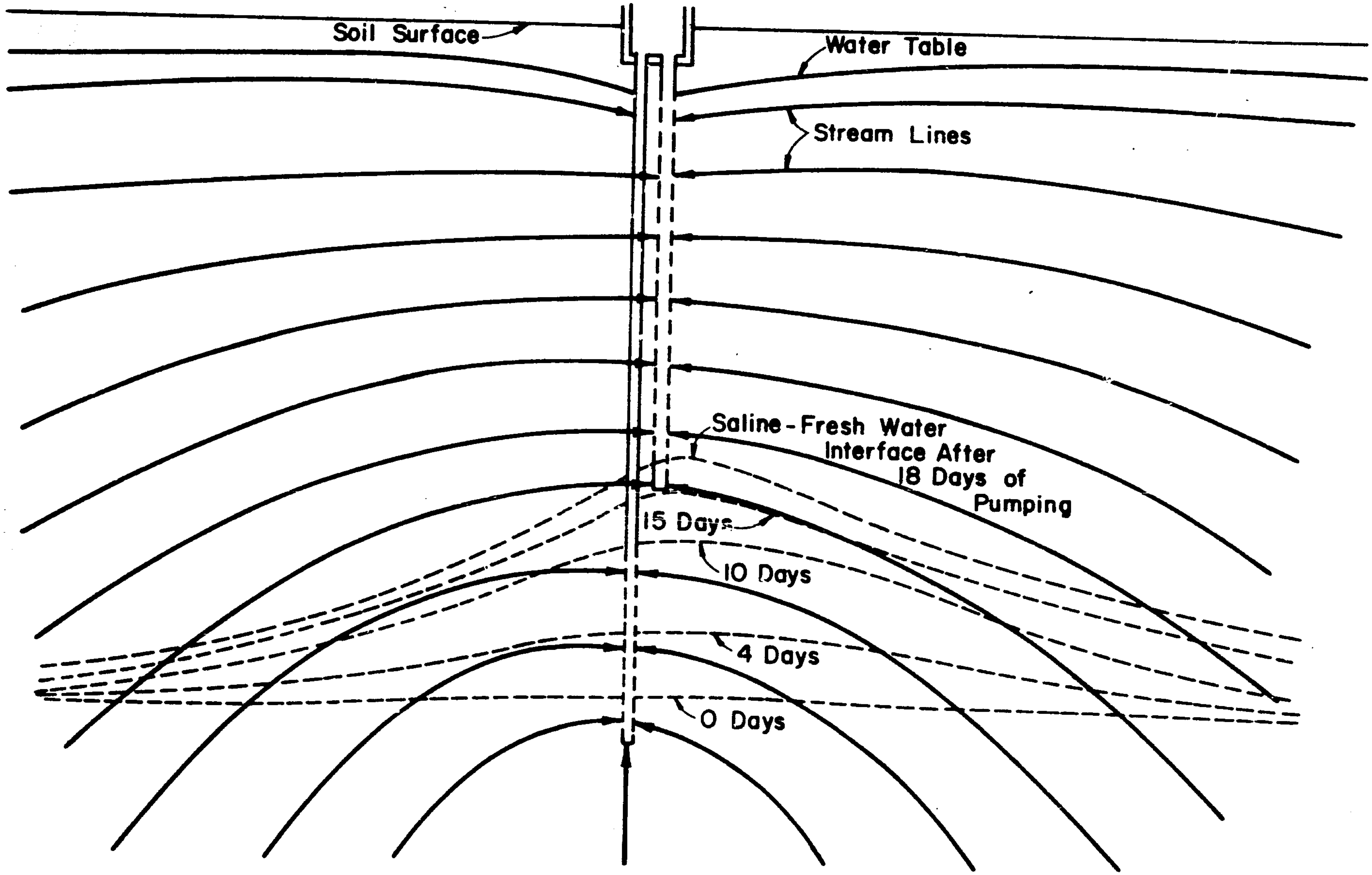

Figure 17. Stream Lines and Saline-Fresh Water Interfaces Before and During Pumping.

does not continue to rise is born out by the calculations of the origin of water coming to the single simple well, as shown in Table 1. Note that as time progresses, a larger and larger fraction of the pumped water comes from displacement of the fresh water by saline water and the fraction of pumped water coming from watertable recession and lateral transmission of fresh water from greater distance through the fresh water layer decreases (partly because the thickness of the fresh water layer is decreasing).

Implications of the Skimming Well Data Regarding Possibilities for Creating Fresh Water Reservoirs in Saline Aquifers

The primary means considered for drawing down the saline-fresh water interface is deep wells, cased to 50 to 100 feet below the interface, with screen sections from that point down into the aquifer another 100 feet or so depending on the desired capacity. The persistence and localization of the raised saline water cone in the skimming well studies indicates that drawdown cones of fresh water will result from pumping the deep wells, if concurrent recharge is occurring, and that these fresh water drawdown cones will tend to flatten out but will persist for months and even years after pumping from the deep well ceases.

The extent to which the drawdown is localized will be directly related to the amount of recharge taking place near the well during the drawdown. If there is no recharge taking place the saline water from the surrounding area will come in to replace the water being pumped and the recession of the fresh water-saline water interface will take place over a wider area.

The saline-fresh water interface will have much greater elevation variation than the watertable has as a result of pumping. Consequently the saline-fresh water interface will not be flat as idealized in Figure 2 in the mid doab areas, but will include drawdown cones similar to those shown in Figures 18 and 19, centering on the deep wells which pump water from the saline zone. While these factors will not move the saline-fresh water interface down uniformly in an agricultural area, they do provide the opportunity of studying the potential of building fresh water reservoirs in saline aquifers on a localized basis. The density difference between air and water is so large when pumping lowers the water table, in the vicinity of the well, that the associated hydraulic gradients pushing water toward the wells are large and water moves toward the well rapidly and the drawdown remains fairly small. Consequently, a single farmer with a private well in the Indus Basin aquifer cannot lower the watertable very much on his farm because the effect of his pumping is spread over a broad area.

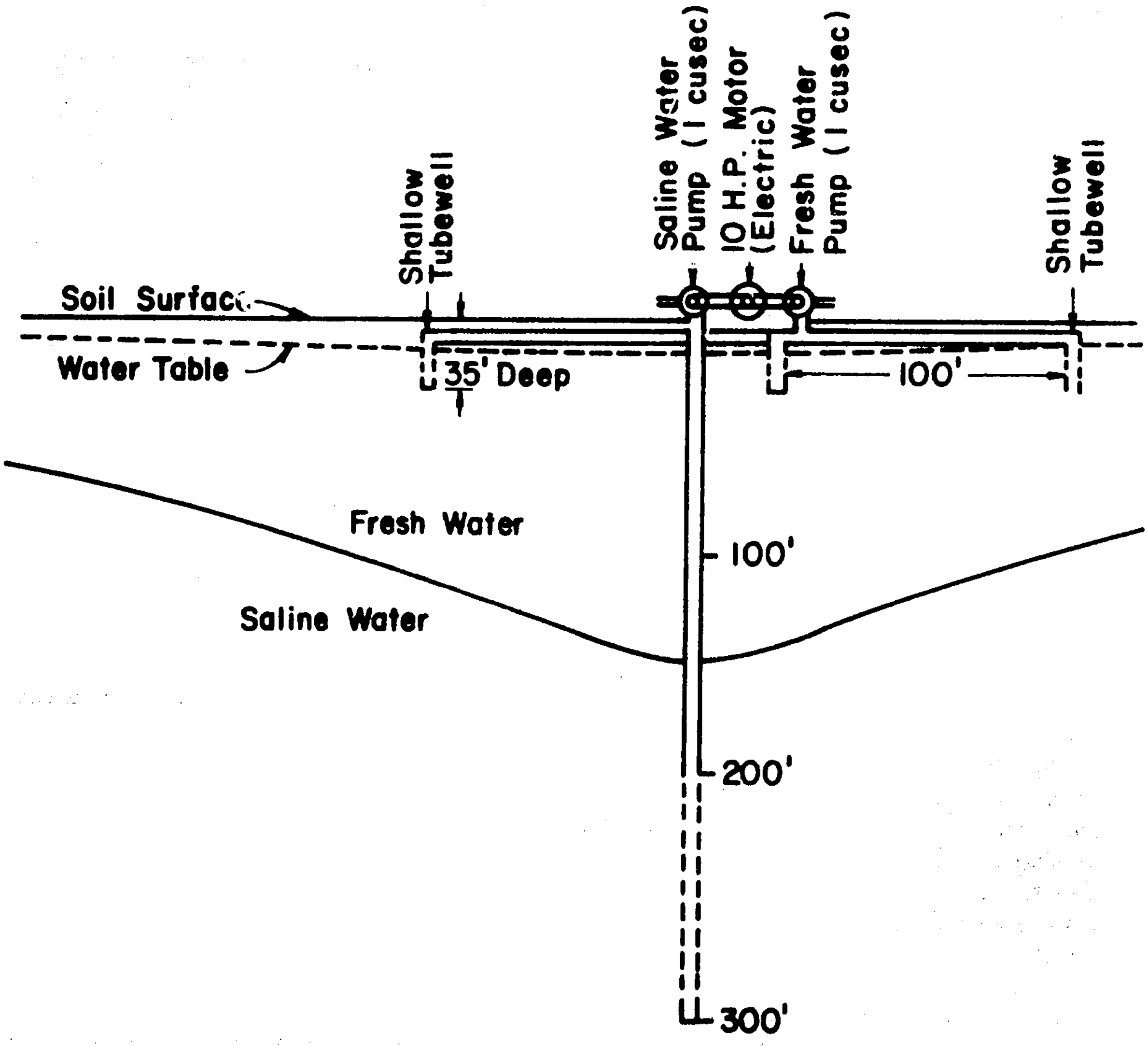

Figure 18. Site #1: Serving 300 acres with one cusec of canal supply and requiring access to a drain.

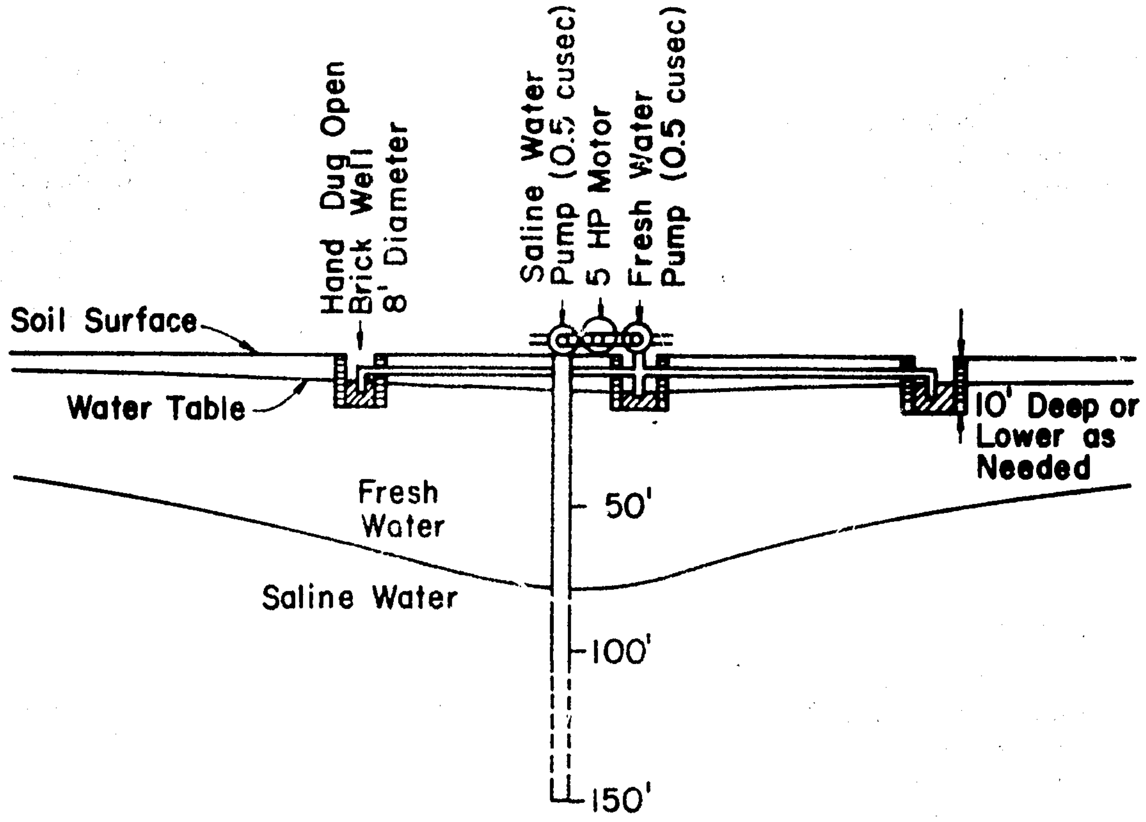

Figure 19. Site #2: Serving 150 acres with 0.5 cusecs of canal supply and requiring access to a drain.

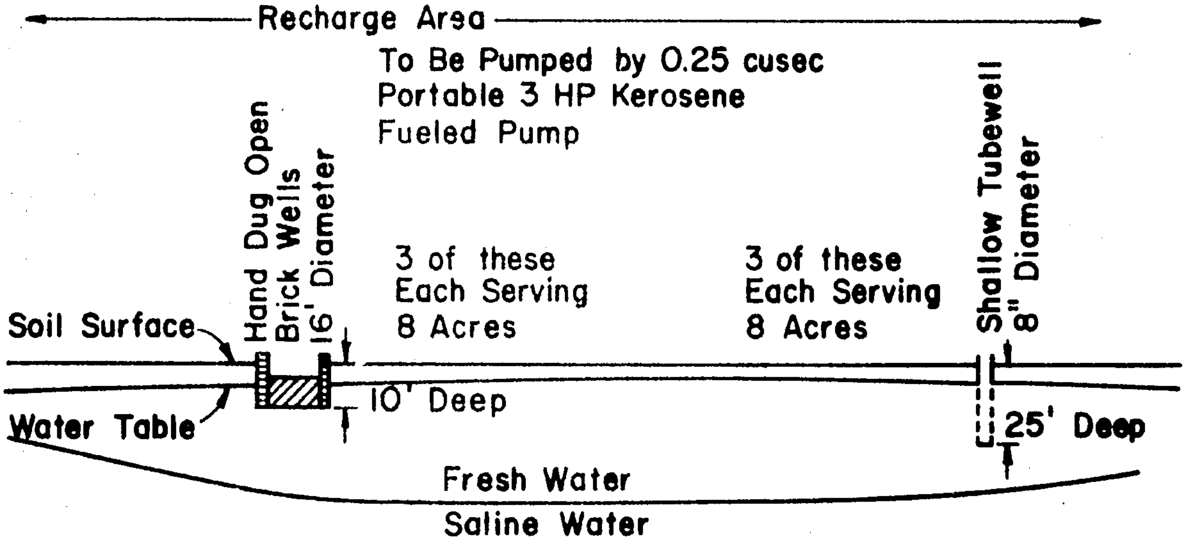

Figure 20. Site #3: Serving 48 acres with 0.3 cusecs of canal supply (i.e. 2.1 cusecs for 24 hours each week)

However, recharge with fresh water can create a lens of fresh water in the saline water as indicated in Figure 20. This lens is like an iceberg in that only a small portion of it lies above the surrounding water. Only 1/200th of the fresh water lens needs to remain above the surrounding saline water, and consequently only slight gradients in the watertable and hydraulic potential exist to dissipate or spread out such lens. Consequently, recharge to form such a lens near a well could take place for weeks or months preceding the time when the deep water pump was to be operated and the rate of spread or dissipation of the lens will be very slow. Then when the saline deep well is pumped, the lens of fresh water will turn into cones similar to those shown in Figure 18 and 19.

How Should the Deep Saline Well, the Skimming Wells and the Recharge Area be Positioned with Respect to Each Other?

Having reasonable understanding of how the deep saline wells and shallow skimming wells will affect the saline-fresh water interface, we should be able to make reasonable estimates of how these wells and recharge areas should be positioned with respect to each other.

In general it appears that if a farmer wishes to create a lens of fresh water to insulate the root systems of his crops from saline water, the lens should be formed under the fields to be served by overirrigating the fields prior to the time of pumping the deepwell. Then the pumping from the deep saline well will draw the saline-fresh water interface and the watertable down in the whole area. However, if the farmer wishes to localize his fresh water reservoir for easy withdrawal by shallow wells during peak crop use seasons, he should probably localize his recharge and his shallow wells near the saline deep well. It will generally be advisable to build the well installations in areas where recharge will be aided by natural topography and soil conditions. A configuration of the wells similar to those indicated in Figures 18 and 19 (for government and private types of installation respectively) may be workable, but they should be tested.

The possibilities of building a shallow fresh water lens in areas where saline water cannot presently be pumped and exported is indicated in Figure 20. The water stored in the aquifer during monsoon (or times when all of the canal supply is not needed for crop use) could be tapped for use during heavy crop use seasons by a series of small hand dug wells or shallow tubewells serving about 8 acres each. To minimize coning these might be pumped successively using a small (0.25 cusec) portable pump. However, persistence of a reasonable thickness of the fresh water lens would depend on maintaining a watertable over the area which is at least 0.1 ft. higher than in the surrounding area.

How Much Mixing of Fresh and Saline Water Will Take Place as the Interface Moves Up and Down in Response to Pumping From the Saline and Fresh Water Zones?

This factor can degrade the fresh water reservoir, tending to decrease its usefulness by salting its lower zones much as sediment tends to fill up the lower zones of surface reservoirs. Some data is being collected in the MREP-CSU Skimming Well studies from which dispersion coefficients can be determined which can be used to predict how much of this "saltation" will take place as a function of how much distance the interface moves.

However, these data may be site specific and additional data is needed. In general they will indicate how much maintenance (pumping of saline water to lower the saline-fresh water interface) will be needed each year to compensate for the upward dispersive movement of the salt and keep the quality of water in the reservoirs at acceptable levels.

Can Infiltration be Increased to the Point Where Monsoon Water Can All Be Absorbed for Recharge?

It should be possible to absorb up to 20" of water into most soils during 2 months. However, the high sodium, low organic matter and high silt contents of many Indus Basin soils, combined with horizontal surfaces which seal up as a result of clay particles settling on them, may require special treatments to allow this much water to pass through them to aid in filling the fresh water reservoirs in the aquifer. Treatments, including gypsum, organic matter and cultivation (e.g., ridging and furrowing), should be tested to develop the most effective means for accomplishing this recharge (and decreasing surface flooding).

Purposes of the System

The purposes of systems such as those indicated in Figures 2, 18 and 19 are:

1. To create fresh water reservoirs from which water can be pumped at peak use seasons.
2. To lower the watertable by the combined deep and skimming well pumping to levels where it will not damage crops and where monsoon rain water can be absorbed to reduce surface flooding, and
3. To move the salt away from the soil surface and the root zone into the deeper ground water and away (if possible) to the sea to achieve the salt balance which is essential to the continued productivity of irrigated agriculture.

The costs of construction and operation of systems, such as those shown in Figures 2, 18 and 19, can be estimated (i.e. on p. 5 & 6) and these estimates can be further refined after construction and operation of pilot units of the type indicated in Figures 18, 19 and 20. Such pilot units can provide answers to the critical questions discussed above and better estimates of the amount of water which can be saved and recovered for crop use. A first approximation is that the recharge will vary from 6 to 24 inches per year, depending on rainfall and other factors associated with the hydrologic system. Ten or twenty percent of this recharge water will probably be contaminated by mixing with salt water to the extent that its use for irrigation is questionable. Consequently, it is probable that an average of only about one acre foot of good water per irrigated acre, can be recovered per year from these fresh water reservoirs if they are constructed and managed properly.

The economic feasibility of the installation is discussed in the following section.

Potential Benefits

The benefits of a multiple purpose saline drainage cum skimming well are: (1) a lowering of the saline groundwater level; thus reducing waterlogging and soil salinizations and also significantly reducing crop damage due to standing monsoon flood waters and (2) the ability to provide up to an acre foot of fresh irrigation water per irrigated acre in the vicinity of the multiple purpose well.

The benefits due to the lowering of the saline groundwater are immediately obvious to the farmer. The increased drainage in the fields allows him to prepare his seed bed sooner, reduces the incidence of disease in the crops and increases his yields. The reduction in soil salinization provides the farmer with a better crop stand due to higher germination, increases the rate of infiltration of irrigation and rainwater and eliminates crop damage due to harmful salts.

It has been estimated (page 3) that the rise in the water table and resulting soil salinity has resulted in a reduction in yields of kharif crops by 50 percent and a reduction in yields of rabi crops by 40 percent. For a typcial kharif crop such as cotton this reduction costs the farmers about Rs. 250/acre (net return) and for a typical crop such as wheat this reduction costs the farmers about Rs. 200/acre (net return). For other kharif crops such as rice, sugarcane and fodder and other rabi crops such as sugarcane and fodder the reduction percentage is less. However, the reasonable estimate of the average value of the crop loss due to salinity in these areas would be Rs. 150/acre for kharif and Rs. 100/acre for rabi. Thus, on a 300 acre watercourse in the Sargodha area with an average cropping intensity of 100 percent (one crop/year) the potential long term increased net return to the farmers on the watercourse is about 37,500 Rs./year.

In addition to reducing the losses due to water logging and soil salinity (and consequently increasing the net returns to the farmers) the proper use of the available supplemental tubewell water will allow the farmers to either plant additional acreage (increasing cropping intensity) and/or to increase the yields on the existing acreage. Computer simulation of a typical watercourse in the Sargodha area indicates that supplemental water during the planting seasons for rabi crops and for kharif crops has an average value of Rs 289 per acre foot at the root zone during rabi season and Rs 155 per acre foot at the root zone during kharif season. If the skimming wells can provide an additional 120 acre feet of irrigation water delivered to the root zone (i.e. 200 acre feet at the well with 60 percent irrigation system efficiency) and half this water is available during rabi planting and peak rabi ET requirement and the rest of the water is available during kharif planting and peak kharif ET requirement, the farmers can increase their net return on the watercourse by Rs 26,400.

Thus the combination of tubewell drainage cum skimming well system has the potential to increase the net returns on a 300 acre watercourse by Rs 63,900 per year. An installation such as the one shown in Figure 19 is estimated to cost about Rs 60,000, including electrical connection. Two would be needed to cover an area of 300 acres. To pump 200 acre-feet of fresh water plus 120 acre-feet of saline disposal water, assuming a twenty year life on the tubewell and components amortized at 10 percent, costs Rs. 30,000 per annum or Rs. 93.75 per acre foot of water pumped. With potential benefits of about 63,900 per year and costs of Rs 30,000 per year the benefit/cost ratio for the project on a 400 acre watercourse appears to be slightly greater than 2. With increased yield from the skimming well and/or improvement in the agronomic practices of the farmers it is possible that the benefits will increase and, since the bulk of the costs are fixed capital amortization costs of the tubewell, the costs for additional pumpage of the tubewell will not increase significantly, therefore, higher benefit/cost ratios are potentially obtainable. The installation and operation of a pilot scheme is necessary to document the assumptions concerning the safe yield of good quality water and the increased yields due to reduction of waterlogging and soil salinity.

Summary

Recent studies of effects of pumping wells on saline-fresh water interfaces indicate the possibility of creating and maintaining "fresh water reservoirs" in the saline aquifers of the mid doab areas of Pakistan. The fresh water to fill these fresh water reservoirs would come from localized zones of overirrigation, seepage from watercourses and monsoon rains and will probably average only about one acre foot per acre per year at the well. The water in these reservoirs could be pumped to provide water during critical need periods. Consequently, although its volume would be low, the value of the water could be high.

Preliminary estimates of costs indicate that this type of storage would cost less than 10% of the cost of surface storage reservoirs. Preliminary estimates of potential benefits indicate a benefits to cost ratio of greater than 2. The deep well-skimming well combination, required to extract the saline and fresh water for reservoir building and irrigation respectively, could provide the needed assistance to farmers who are most severely afflicted by salinization and waterlogging, and are not being assisted by SCARP programs. Considerable additional information regarding the mixing of fresh and saline water during rise and fall of the interface, effects of recharge and pumping timing on the extension of the fresh water reservoir, etc. is needed before an optimized development program can be initiated.

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APPENDIX 21

UTILIZING IRRIGATION SEEPAGE FOR GROUNDWATER STORAGE

Tom Trout and John Reuss[1]

INTRODUCTION

In order to maximize agricultural production from the scarce water resources in the Indus Basin, it is necessary to redistribute the naturally occurring surface flows from periods of high flow to periods of peak crop requirements. Large scale surface storage can help in this regard, but appropriate sites in Pakistan are limited and their development is extremely expensive. The effectiveness of this approach is also limited by the capacity of the conveyance system to distribute the increased supplies when needed.

Therefore, the fresh water aquifer underlying extensive areas in the basin is being exploited by groundwater pumpage to augment supplies during peak demand. This aquifer is recharged by a combination of percolation from rainfall, rivers, canals, watercourses and fields under irrigation.

Recent efforts to improve the efficiency of the irrigation system at the farm level through watercourse improvement programs have prompted concern that the recharge of this aquifer would thereby be diminished, thus interfering with pumping programs and their potential for redistribution of fresh water supplies over time.

This brief analysis addresses the question of the probable effect of watercourse improvement programs on groundwater recharge. Simplifying assumptions are harsh, as they must be for any analysis short of the construction of a detailed hydrologic model. However, we believe the assumptions overall are conservative in their estimation of recharge rates and the analysis is mathematically accurate within the assumptions.

ANALYSIS

The two basic simplifying assumptions used are:

1. The area under consideration, whether a single watercourse command area or a large group on contiguous command areas, is a horizontally closed system, i.e. there is either no flow across the boundaries or, if flow occurs, inflow equals outflow.

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2. All water that enters the watercourses through the mogha outlets from the distributaries goes to either the soil moisture storage in the field or the groundwater.

The inflows not considered include percolation from rainfall, recharge from rivers during high water, and probably most important, seepage from canals and distributaries. Most estimates of this source alone are in excess of 20 million acre foot per year or nearly two thirds of an acre foot per acre of irrigated land. The assumptions that all water that is not stored in the fields for crop use goes to the groundwater, does not take into account evaporation losses and evapotranspiration from the plants growing along the watercourse and from seep and spill areas. Our estimates based on potential evapotranspiration from the area involved suggest that 10-15% of the mogha flow may be lost by this pathway. Outflows to drains and rivers during low flows are also not considered. Because of the relatively high estimates of losses from the canal system to the groundwater, the assumptions undoubtedly are conservative in the sense that total recharge in fact will exceed that estimated from only the conveyance and application inefficiencies on the watercourse system.

With the assumptions, the mass balance equation for groundwater is thus reduced to:

$$\Delta S_{GW} = V_{in} - V_{out} \tag{1}$$

Where ΔS_{GW} = change in groundwater storage

V_{in} = inflow in groundwater

V_{out} = outflow in groundwater

Or

$$\Delta S_{GW} = (100 - E_c)\ V_c + (100 - E_p)\ V_p - 100\ V_p \tag{2}$$

Where E_c = irrigation efficiency of canal water (%)

E_p = irrigation efficiency of pumped water (%)

V_c = volume of canal water flowing in the watercourse

V_p = volume of water pumped into the watercourse system from the groundwater

Irrigation efficiency (%) = conveyance efficiency time field application efficiency

Seepage losses (%) = 100 - irrigation efficiency

To maintain a long term balance in the groundwater system, $\Delta S_{GW} = C$, and

$$V_p/V_c = \frac{100 - E_c}{E_p} \tag{3}$$

Table 1 presents pumped volume as a ratio of surface supply to a watercourse as a function of pump and canal water delivery efficiencies. It should be noted that throughout Table 1, the amount of water delivered to the field is the same. For instance at E_C = 50% and E_p = 30%, the ratio 1.67 indicates that pumped water must be equal to 1.67 times canal delivery simply to deliver the water that flows through the mogha to soil moisture storage.

For the present, let us consider the irrigation efficiency of pumped water to be the same as canal water ($E_p = E_c$), thus we are concerned with values lying on the diagonal of Table 1. The best estimate of overall irrigation efficiency in Pakistan presently available is undoubtedly that of Early, Lowdermilk and Freeman[2] who conducted extensive field measurements. Their value is 41%. At 40% efficiency, the pumped volume must be equal to 1.5 times the mogha flow to maintain groundwater equilibrium.

To convert this to pumping costs, assume a watercourse with a canal delivery of 1 cusec per 350 acres flowing for 330 days per year for an annual delivery of 1.87 acre feet per acre and a pumping cost of Rs.. 50/acre ft. Results of these calculations are shown in Table 2. Note that in the case of a 40% efficiency, the annual pumping costs are about Rs. 140 simply to delivery the water from the mogha to the soil storage for crop use. If the overall efficiency can be raised to 50%, this cost decreases to Rs. 94 and at 60% efficiency it is Rs. 63.

The 41% efficiency results from an overall conveyance efficiency of about 53% and 77% application efficiency. This could be increased to 50% with a conveyance efficiency of 63% and no change in application efficiency, well within the range of present watercourse improvement programs. Probably the best that can be hoped for with earthern improvements is a 60% efficiency, resulting from 75% conveyance and 80% application efficiency.

Tables 1 and 2 are based simply on relative volumes. Let us relate this to common Salinity Control and Reclamation Project (SCARP) design criteria. Common water duties in non-SCARP areas are 1 cusec for 350 acres and in SCARP areas are

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[2] Early, A. C., M. K. Lowdermilk and D. M. Freeman. Farm Irrigation Constraints and Farmers' Responses: Comprehensive Field Survey in Pakistan, Colorado State University. In Press.

TABLE 1. The ratio of pumped volume to surface supply to a watercourse (V_p/V_c) for various surface and pumped supply irrigation efficiencies to maintain groundwater storage at equilibrium.

		E_p (%)						
		30	40	50	60	70	80	90
E_c (%)	30	2.33	1.75	1.40	1.17	1.00	0.88	0.78
	40	2.00	1.50	1.20	1.00	0.86	0.75	0.67
	50	1.67	1.25	1.00	0.83	0.71	0.63	0.56
	60	1.33	1.00	0.80	0.67	0.57	0.50	0.44
	70	1.00	0.75	0.60	0.50	0.43	0.38	0.33
	80	0.67	0.50	0.40	0.33	0.29	0.25	0.22
	90	0.33	0.25	0.20	0.17	0.14	0.13	0.11

TABLE 2. Annual pumping costs as a function of irrigation efficiency of canal water and pumped water assuming Rs. 50 per acre ft.

Canal Water Irrigation Efficiency (E_c)	Pumped water irrigation efficiency (E_p) %						
	30	40	50	60	70	80	90
%	--- Rs. per acre ---						
30	218	164	131	109	94	82	73
40	187	140	112	94	80	70	63
50	156	117	94	78	66	59	52
60	124	84	75	63	53	47	41
70	94	70	56	47	40	36	31
80	63	47	37	31	27	23	21
90	31	23	19	16	13	12	10

1 cusec for 150 acres. Thus, while the tubewell is operating the tubewell discharge is 1.33 times mogha flow. In fact, tubewells commonly operate in substantially less time than canal deliveries, and if flexibility is to be obtained they must operate at peak demand periods and not at times when demand is low. In order to examine the tubewell capacity required to maintain groundwater equilibrium when tubewells are operated for less time than canal deliveries, we re-write equation (3) as follows:

$$\frac{Q_p \, T_p}{Q_c \, T_c} = \frac{100 - E_c}{E_c} \tag{4}$$

Where Q_p = pumping rate

T_p = pumping time

Q_c = surface supply rate

T_c = surface supply time

Assuming again equal irrigation efficiencies for canal and tubewell water ($E_c = E_p$) and canal delivery of 330 days per year, the ratios of pump flow to canal delivery (Q_p/Q_c) have been calculated assuming different irrigation efficiencies and days pumped per year (Table 3). The lines drawn through the table indicate the approximate combination of irrigation efficiencies and pumping days required for the SCARP system with tubewell flows equal to 1.3 times canal deliveries to maintain groundwater equilibrium. Note that at 40% irrigation efficiency, groundwater equilibrium could not be attained in the SCARP systems with continual pumping, except for systems where substantial outflow occurs either to drains or to evapotranspiration from high watertable areas.

At 50% efficiencies, pumping would be required for about 260 days per year or a puming intensity of 69%. Even with 60% overall efficiency, which is probably the maximum that could be achieved with earthen improvements, pumping would be required about 170 days per year to maintain equilibrium. If pumping rates are less than those required, the remainder must be removed as drainage outflows or water tables will rise until the extra water is carried to the surface by capillary flow and waterlogging and salinity are the inexorable result.

We must also consider the need for meeting peak demand requirements of the crops. As efficiencies decrease more water must be pumped to achieve a certain delivery rate to the field. The delivery rate to the field (Q_f) is described by:

TABLE 3. Ratio of Q_p to Q_c for various days pumping (T_p) and efficiencies ($E_c = E_p$) for T_c = 330 days.

	Days Pumping per Year (T_p)								
E_c (%)	40	80	120	160	200	240	280	320	360
30	19.3	9.6	6.4	4.8	3.9	3.2	2.8	2.4	2.1
40	12.4	6.2	4.1	3.1	2.5	2.1	1.8	1.5	1.4
50	6.3	4.1	2.8	2.1	1.7	1.4	1.2	1.0	0.9
60	7.3	2.8	1.8	1.4	1.1	0.9	0.8	0.7	0.6
70	3.5	1.8	1.2	0.9	0.7	0.6	0.5	0.4	0.4
80	2.1	1.0	0.7	0.5	0.4	0.3	0.3	0.3	0.2
90	0.9	0.5	0.3	0.2	0.2	0.2	0.1	0.1	0.1

Solid line indicates Q_p/Q_c approximately equal to 1.3 or about SCARP situation.

$$Q_f = \frac{E_cQ_c + E_pQ_p}{100} \qquad (5)$$

Assuming again that $E_p = E_c$, field delivery is:

$$Q_f = \frac{E_c(Q_c + Q_p)}{100} \qquad (6)$$

Where Q_f is the delivery rate to the field. This can be rearranged to calculate the pumping requirement for any desired Q_f.

$$Q_p = \frac{100Q_f - E_cQ_c}{E_c} \qquad (7)$$

If the water requirement at the field is 5 acre ft/day and the surface supply is 2 acre ft/day (1 csc), the tubewell of 5.3 csc will be required if the efficiency is 40%, while only 3.2 csc will be needed if the efficiency is 60%. Not only pump fuel and maintenance costs but capital costs as well increase with decreasing efficiencies.

So far we have only considered the situation were the efficiency of canal and pump supplies are equal. The possibility for combinations of different tubewell and canal water conveyance efficiencies are endless, but at least a couple of important systems should be mentioned. First, in unimproved watercourses the efficiency of tubewell supplies added to the head of the watercourse is often much less than the efficiency of the original canal supply. Thus if flow is doubled in a system previously operating at 50% efficiency the efficiency of the total supply will probably drop to 40% so that efficiency of the added water is only 30%. From Table 1 we see that with $E_c = 50\%$ and $E_p = 30\%$, the volume of pumpage must be 1.67 times the mogha flow to maintain equilibrium. If the pumped water were conveyed as efficiently as the canal water, the pump volume would only need to be 1.0 times mogha flow. On improved watercourses designed for canal plus tubewell flow there is much less difference in efficiency between the two sources.

Another case to be considered is that in which smaller discharge wells are installed at various locations on the watercourse command area so that the average distance from pump to field is half the average distance from mogha to field. In order to analyze this system we must separate the irrigation efficiencies E_p and E_c into their conveyance and application components so that:

$$E_c = \frac{(E_{cc})(E_a)}{100} \qquad (8)$$

$$E_p = \frac{(E_{cp})(E_a)}{100} \tag{9}$$

Where E_{cc} = canal water conveyance efficiency

E_{cp} = pump water conveyance efficiency

E_a = application efficiency

If the tubewell serves the entire watercourse, then $E_{cc} = E_{cp}$ and $E_c = E_p$. On the other hand, if the average distance from tubewell to field is only half that of mogha to field, the conveyance losses of tubewell water will only be about half of those of the canal water.

$$100 - E_{cp} = \frac{(100 - E_{cc})}{2} \tag{10}$$

and

$$E_p = \frac{1/2(E_{cc} + 100)(E_a)}{100} \tag{11}$$

For this case, equation (5) becomes:

$$Q = \frac{(E_{cc})(E_a)(Q_c)}{100} + \frac{1/2(E_{cc} + 100)(E_a)(Q_p)}{100} \tag{12}$$

With the above assumptions we can calculate the delivery rate to the fields for any pump rate and canal delivery efficiency for the multiple and single tubewell cases. We have assumed a canal flow of 1 csc for Table 4. The pumping time required to maintain groundwater equilibrium was calculated by rearranging equation (4). Application efficiencies of 80% were assumed throughout. It should be noted that the previously discussed tendency for conveyance efficiencies to decrease when pumped and canal water are mixed has not been considered in this analysis.

An important principle is illustrated by Table 4, i.e., if watercourse conveyance losses are high, the small tubewells located near the point of use deliver a much higher proportion of their discharge to the field than does the single tubewell located near the mogha. For instance, at 2 csc pump delivery, and 50% canal water conveyance efficiency, the single tubewell system field delivery should be 1.20 csc out of a possible 3.0 while the multiple system would deliver 1.60 csc. Pumping time required to maintain groundwater equilibrium would be reduced from 248 to 165 days. If canal water conveyance efficiency is increased to 70%, the increase in delivery is from 1.68 to 1.80 csc and the pumping time is reduced from 130 to 107 days.

TABLE 4. Effect of using multiple tubewells on field delivery and pumping time required to maintain groundwater equilibrium assuming the multiple tubewells will decrease tubewell water conveyance losses by 50%.

Canal Water Conveyance Efficiency (E_{cc})

Pump Rate csc	Canal plus tube-well csc	50%				60%				70%			
		Single TW		Multiple TW		Single TW		Multiple TW		Single TW		Multiple TW	
		T_p days	Q_f csc	T_p days	Q_f csc	T_p days	Q_f csc	T_p days	Q_f csc	T_p days	Q_f csc	T_p days	Q_f csc
1	2	495	.80	330	1.00	358	.96	262	1.12	259	1.12	214	1.24
2	3	248	1.20	165	1.60	179	1.44	134	1.60	130	1.68	107	1.80
3	4	165	1.60	110	2.20	119	1.92	89	2.08	86	2.24	71	2.36
4	5	124	2.00	83	1.80	89	2.40	62	2.56	65	2.80	53	2.93
5	6	99	2.40	66	3.40	72	2.88	54	3.04	52	3.36	43	3.48
E_c%		40		40		48		48		56		56	
E_p%		40		60		48		64		56		68	
E_a%		80		80		80		80		80		80	

There are many other considerations that must be taken into account in the small multiple vs single central tubewell comparison but if conveyance losses are high the single central tubewells are a very inefficient method for either supplying peak crop demands or lowering the water table.

CONCLUSIONS

The results of this brief analysis indicate:

1. Large scale programs of earthen reconstruction of watercourses are unlikely to reduce recharge of the fresh water aquifer to the point that it interfers with the use of this aquifer as a storage reservoir to be used during periods of high demand.

2. Reducing conveyance losses is particularly important when a single tubewell source serves a complete watercourse.

APPENDIX 22

THE ECONOMICS OF PRECISION LAND LEVELING IN PAKISTAN[1]

Sam H. Johnson III, Ch. Mohammad Hussain,
Zahid Saeed Khan and Ch. Barkat Ali[2]

INTRODUCTION

Irrigated agriculture is the mainstay of Pakistan's economy contributing over 43% of the gross national product (Pakistan. Ministry of Food, Agriculture, and Underdeveloped Areas, 1972). Out of 47.5 million cultivated acres only 11.2 million acres are unirrigated. However even in the irrigated areas, the available water supply during certain times of the year is less than the consumptive use requirements for the plants. This supply of water is not available throughout the year because of irregular flows of canal water from the rivers. The river water discharge generally begins to increase in April and is at a maximum rate of flow in the months of July and August, after which the flow decreases rapidly, reaching a low flow level from October to March. About 84% of the annual flow occurs during the six summer months (kharif season) and only 17% during the six winter months (rabi season) (Ghulam Muhammad, 1965). These times of insufficient flow severely reduce the yields of the stressed crops and restrict the production of high value vegetable and tree crops.

To further complicate the irregular water supply problem much of Pakistan is classified as arid and semiarid zones and does not receive sufficient rainfall to make up the water deficit.

Extensive irrigation system expansion and the development of large public tubewell schemes have been adopted to overcome the scarcity of water. However these alternatives are still dependent upon a limited available water supply and will reach their natural limit within the next decade (Pakistan

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Times, 1973). It is essential, therefore, to efficiently utilize this scarce water resource. This entails developing production techniques that minimize the losses of water between the rivers and the plant root zone.

The objective of this paper is to examine the effectiveness of one such technique, precision land leveling (PLL), and to estimate the comparative advantage of investing in PLL over other possible production techniques (e.g. increased fertilizer application, plant protection, etc.). In order to determine the economic and physical effectiveness of PLL a series of precision leveled and traditional leveled fields were selected. The precision leveled fields had been leveled to standard[3] within the last two years (4 cropping seasons) and all of the fields had been in continuous production for at least the last ten years. These fields were first resurveyed to determine the exact degree of levelness and were then monitored throughout the rabi cropping season when all the fields were planted in wheat. The farmers were interviewed four times during the season and cutting samples were taken during harvest in order to determine yields. Regression analysis is used to measure the effect on yields of changes in degree of land levelness where degree of levelness is described by the range of differences between the highest and lowest spots in the field.

BACKGROUND

The farmers in Pakistan use the level basin system of irrigation. In order for this system to function at all, the farmers must expend considerable effort in attempting to maintain an acceptable degree of levelness for their fields. Frequently, even after expending this effort in attempting to level their fields the farmers find that the fields are too uneven and, in order to compensate, they divide the fields into a number of smaller bunded units. This serves to minimize the levelness problem but it increases the time to irrigate the field and it takes land out of production by requiring additional watercourse channels and more bunds. While precision leveling, it may be possible to reshape the fields more efficiently. A recent block of 9 acres that was precision leveled was able to eliminate six out of seven watercourse channels thus adding 0.3 acres to the cultivated area (Ali et al. (a), 1975). Precision leveled fields can also be irrigated in a shorter period of time and require less water to cover all the area to a uniform depth.

3/The standard was a maximum range between the highest and lowest spot in the field of 0.15 foot.

The most universal irrigation practice in Pakistan is for the farmers to cut the side of a bund and then to allow water to flow into the field until all the high spots in the field are covered. If the field is uneven this technique tends to overwater the low spots and underwater the high spots. Table 1 presents a sample set of range of elevations from 46 acres in Pakistan.

From Table 1 less than ten percent of the surveyed area had acres which were within the presently accepted criteria (.15 ft. maximum difference) for level basins. Thirty-three percent had elevation differences of greater than 0.50 feet. With such a wide variation in the range of levelness the farmers are forced to apply variable amounts of water in order to cover all the high spots in the field. This method of irrigating takes more time per acre than is necessary for leveled fields and also forces the farmer to use more water than is required. Data is presented in Table 2 to illustrate this tendency to overirrigate.

From Table 2 it is apparent that farmers' irrigation applications vary from less than one inch to as much as 12 inches. This indicates that at least 10 percent of the fields were underirrigated (less than one inch application) and that over 40 percent of the fields were overirrigated (greater than three inch application).

Studies of traditional leveled fields have proven that even a three inch irrigation will supply more than five inches of water to the lowest areas of the field and less than one inch of water to the highest areas (Ali et al., 1975). When the crop's evapotranspiration rate requires three inches of water, an excess of two inches is applied to the low areas and a deficit of two inches develops on the high area. The same study shows that the tendency to overirrigate, especially the low areas, results in an extensive leaching of the applied nitrogen below the plant root zone.

Table 3 demonstrates the effects of different standards of levelness on field application efficiency.

With fields containing differences of the magnitude of ±4 cm (0.25 feet) it is only possible to obtain a 65 percent application efficiency which means that 35 percent of the water is not used in the root zone but either goes to nonbeneficial evapotranspiration or to the water table.

In addition to extensive leaching of the applied nitrogen fertilizer the excess water required to cover the high areas of the fields results in a rise in the water table. Often more than 30 percent of the water applied to the field surface percolates through to the water table beneath the field. This extensive loss of water to the groundwater has resulted in a

Table 1. Range of elevation between maximum and minimum for a sample of irrigated fields in the Punjab.[1]

Range of elevations (feet)	No. of acres	Cumulative acres	Percent of total (%)	Cumulative percent (%)
0.00 - 0.10	0	0	0	0
0.10 - 0.15	1	1	2	2
0.15 - 0.20	3	4	7	9
0.20 - 0.25	3	7	7	16
0.25 - 0.30	5	12	11	27
0.30 - 0.35	3	15	7	34
0.35 - 0.40	5	20	11	45
0.40 - 0.45	6	26	13	58
0.45 - 0.50	4	30	9	67
0.50 - 0.55	5	35	11	78
0.55 - 0.60	2	37	4	82
0.60 - 0.65	-	37	-	82
0.65 - 0.70	2	39	4	86
0.70 - 0.75	1	40	2	88
0.75 - 0.80	1	41	2	90
0.80 - 0.85	1	42	2	92
0.85 - 0.90	1	43	2	94
1.05 - 1.10	3	46	7	101

1/The fields with more than 0.3 ft of elevation difference commonly have partial or complete bunds within the field which allow the farmer to begin irrigation from the high side and distribute the water across the whole soil surface.

Table 2. Application amounts applied during an irrigation from November, 1973 to January, 1975 for Mona (Ali et al. (b), 1975).

Depth of application (inch)	Number of observations	Percent of total	Total accumulated
0 ≤ 1	38	10	10
1 ≤ 2	82	21	31
2 ≤ 3	101	26	57
3 ≤ 4	84	21	78
4 ≤ 5	46	12	90
5 ≤ 6	16	4	94
6 ≤ 7	9	2	96
7 ≤ 8	9	2	98
8 ≤ 9	2	0.5	98.5
9 ≤ 10	3	0.8	99.3
10 ≤ 11	0	0.0	-
11 ≤ 12	2	0.5	99.8
12 ≤ 13	1	0.2	100.0
Totals	393	100.0	

Table 3. Potential field application efficiency under different standards of levelness (Jones, 1977).

Irrigation	Net water application (inches)	Gross water application ±1 cm (inches)	±2 cm (inches)	±3 cm (inches)	±4 cm (inches)	±5 cm (inches)
1st	2	2.4	2.8	3.2	3.6	4.0
2nd	2	2.4	2.8	3.2	3.6	4.0
3rd	3	3.4	3.8	4.2	4.6	5.0
4th	4	4.4	4.8	5.2	5.6	6.0
5th	4	4.4	4.8	5.2	5.6	6.0
Total	15	17	19	21	23	25
Maximum potential field application efficiency		88%	79%	71%	65%	60%

drastic rise in the water table in the past decade and presently irrigated agriculture in Pakistan is faced with a very severe waterlogging problem (Lieftnick et al., 1968).

PRECISION LAND LEVELING

Land leveling is necessary to allow the irrigation water to spread as evenly as possible over the field surface. It also needs to flow gently with little or no erosion of topsoil. Even distribution of water helps improve the uniformity of seed germination and, of course, reduces the loss of nutrients through leaching. Further, land leveling reduces the amount of irrigation water required and, consequently, reduced the amount of labor required to irrigate a field. Finally, land leveling improves drainage and helps avoid crop damage due to oxygen deprivation.

Precision land leveling consists of two distinct operations. The first operation is earth-moving, which consists of actually cutting off the high areas and filling in the low areas in order to rework or modify the general slope of the field. The second step in land leveling is the actual leveling (smoothing) of the surface through planing or floating. This second step eliminates any minor surface irregularities left over from the first operation. The earth moving stage is where the majority of the costs are incurred. These are largely a function of the machinery used, size of area to be leveled, haul distance and the amounts of earth to be moved (Dimick, 1972). Table 4 presents representative data from a series of fields that were precision leveled in Pakistan.

From Table 4 the average quantity of earth moved is about 200 m^3. When surveying and designing costs are included the current rate per cubic meter of earth moved is Rs. 3.5[4]. Thus the average precision leveled acre costs about Rs. 700 or U.S. $70 per acre using a tractor and scraper.

Land can also be leveled using indigenous tools and bullock power but up to now it has not been possible to move enough earth or to maintain the accuracy required to obtain a precision leveled field.

Post-leveling costs are essentially those costs necessary to bring the finished field surface to its greatest crop production potential. In most cases, this involves three activities: (1) restoring fertility to those areas suffering a loss of soil nutrients as a result of earth-moving operations, (2) relieving any compaction resulting from the land leveling operation and (3) maintaining a level field. Very

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[4] One U.S. dollar equals approximately 10 Pakistan rupees (Rs).

Table 4. Cost data for precision leveled fields (Karim and Bashir Ahmad, 1977).

Sr. No.	Area Leveled	Quantity of Earth Moved	Total Cost	Cost Acre	Max. Cut	Max. Fill
	acres	m^3	Rs	Rs	foot	foot
1	2.0	230.75	692.00	346.00	0.25	0.30
2	3.0	522.00	1566.00	522.00	0.35	0.55
3	2.25	712.00	2136.00	949.00	0.80	0.50
4	3.0	900.00	2700.00	900.00	0.80	0.40
5	2.75	1007.00	3021.00	1098.00	0.95	0.70
6	2.0	124.00	372.00	186.00	0.30	0.20
7	3.5	600.00	1800.00	514.00	0.50	0.60
8	3.5	435.00	1305.00	373.00	0.40	0.35
9	2.75	633.86	1901.58	397.00	0.50	0.55
10	2.0	643.00	1929.00	964.00	0.65	0.40
11	2.25	422.00	1266.00	562.00	0.45	0.40
12	5.0	683.76	2051.10	410.00	0.30	0.25
13	4.0	910.00	2732.70	683.00	0.80	0.45
14	3.75	309.80	929.40	248.00	0.30	0.30
Average	2.98	580.94	1742.98	582.29	0.53	0.43

Table 5. Availability of nitrogen/phosphorus in cut/fill areas of a leveled field in Texas, 1959 (Bashir Ahmed and Ronald L. Tinnermeier, 1974).

Soil Characteristics	Cut (lbs/acre)	Fill (lbs/acre)
Nitrate Nitrogen	53.6	93.2
Mineralized Nitrogen	135.4	160.6
Phosphorus Available	16.0	24.3
Soluble Salts	1228.0	1112.0

little data from Pakistan is available to determine fertility decline due to land leveling but in the United States this has often been a significant factor. Table 5 provides an example from an experimental field in Texas.

The data in Table 5 definitely indicates that the cut areas were lower in nitrogen and phosphorus as compared to the fill areas.

Another problem is that of maintaining level of the field over time. Using the small scale bullock drawn equipment in Pakistan tillage operations are not likely to disturb the level to the same degree as the use of large scale mechanization does in the more advanced farming areas of the world. Yet, the poor irrigation practices, heavy monsoon rainfall and resulting runoff and silt load in the irrigation water can all result in irregularities in the fields. These can totally erase the benefits of a precision leveling job unless post-leveling touch-up operations are carried out to keep the plot in the same condition.

RESULTS

A sample of 24 precision leveled fields was selected. These fields had been leveled to a standard of ±2 cm within the past two years. At the same time a sample of 26 traditional leveled fields were selected. The plan was to locate fields (precision leveled and traditional leveled) that were operated by the same farmers. These fields were monitored throughout the winter cropping season with the farmers providing all information concerning the inputs to the crop. Two cutting samples per field were taken to provide accurate information concerning the level of yields in the fields. Table 6 presents a summary of the data collected from the fields.

The data in Table 6 indicates that the level of fertilizer, both N and P, applied to the precision leveled fields is significantly higher than the level applied to the traditional leveled fields. The time to irrigate the precision leveled fields is also much shorter which reflects an ability to more closely control the water applied to the field. This increased level of inputs and superior water control is a major factor in the difference in yields. The difference of 6.42 maunds is statistically significant[5] and clearly details the higher level of investment provided the precision leveled fields compared to the traditional leveled fields.

The actual effectiveness of the precision leveling can be compared against the traditional leveled fields. These comparisons are contained in Table 7.

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[5] The .001 level.

Table 6. Characteristics of precision and traditional leveled fields, Mona Reclamation Project, Pakistan.

Level Technique	Average Yields		Average Fertilizer - N		Average Fertilizer - P		Time to Irrigate	
	mean	median	mean	median	mean	median	mean	median
	(mds/acre)[a]		(lbs/acre)		(lbs/acre)		(hrs/acre)	
Traditional	18.18	16.33	43.36	50.00	23.08	0.00	2.12	1.50
Precision	24.60	23.17	60.42	70.00	31.25	50.00	1.13	1.00

[a] One maund equals approximately 82.5 pounds.

Table 7. Precision leveled versus traditional leveled fields (median values).

Field level	Max-min range (feet)	Maximum range (feet)
Before level	0.55	1.10
After level	0.20	0.36
Traditional level	0.40	0.66

The data in Table 7 indicates that the precision leveled fields are significantly smoother than the traditional leveled fields, although they are not all within the specifications for precision leveled basins. Assuming that the precision leveled fields were within specifications when the job was originally completed the change in levelness indicates excessive settling of the fill areas, disturbance of level due to cultural practices, and/or erosion due to irrigation water application.

Statistical analysis comparing the degree of levelness of the traditional leveled fields to the original degree of levelness of the precision leveled fields before leveling indicates that the farmers selected their most unlevel fields to precision level. This comparison is significant at the .01 level and clearly details the fact that the control group of traditional leveled fields were not the worst set of unlevel fields the farmers were operating.

REGRESSION ANALYSIS

In order to separate the complex interactions between yields, fertility, cultural practices and land levelness a regression equation that relates to yield to these other variables was developed. Sixteen independent variables were used to explain the change in the one dependent variable, wheat yields. Table 8 describes the variables used in the model.

The variables from Table 8 were fitted to a series of linear models of the form

$$Y = a_0 + a_1X_1 + a_2X_2 + \dots + a_nX_n$$

with y representing wheat yields and the X's representing various combinations of the dependent variables. These 17 variables were submitted to the computer and initial regression equations were developed. From these initial computer runs the relevant policy variables were extracted and again submitted to the computer but excluding the other less important variables. The results of two computer regression analyses, one for the precision leveled fields and one for the traditional leveled fields are presented in Table 9.

These numbers provide a number of useful insights. The variables examined for the precision leveled fields are able to explain 60 percent of the variation of wheat yields from the sample plots. This equation is significant at the .01 level. However, the same variables applied to the traditional leveled fields are only able to explain 38 percent of the variation of wheat yields from the sample plots and this equation is only significant at the 0.2 level. In equation 1,

Table 8. Regression variables.

No.	Description	PLL		TL	
		Mean	Std.Dev.	Mean	Std.Dev.
1	Wheat Yields (mds/acre)[a]	24.60	12.12	18.18	7.22
2	Seed Rate (seers/acre)[b]	40.08	3.66	39.22	3.66
3	Number plowings	8.00	1.89	6.50	1.77
4	Fertilizer - N (lbs/acre)	60.42	16.01	43.36	21.74
5	Fertilizer - P (lbs/acre)	31.25	24.73	23.08	25.42
6	Number Irrigations	4.29	0.95	4.23	0.95
7	Seed Source (dummy)	--	--	--	--
8	Sowing Technique (dummy)	--	--	--	--
9	Time to Irrigate (hrs/acre)	1.13	.44	2.12	1.42
10	Seed Variety (dummy)	--	--	--	--
11	Salinity Percentage	1.28	3.60	0.08	0.18
12	Max-Min Range (feet)	0.22	0.14	0.39	0.14
13	Planting Date (from 1 Oct.)	32.92	15.97	37.04	18.15
14	Area (kanals)[c]	7.83	2.12	7.15	1.64
15	Manure (donkey loads/acre)[d]	9.17	27.49	5.38	20.04
16	Preirrigation (hrs/acre)	1.57	0.53	2.90	2.00
17	Irrigation x N interaction	--	--	--	--

[a] One maund equals approximately 82.5 pounds.

[b] One seer equals approximately 2.05 pounds.

[c] One kanal equals one-eighth of an acre.

[d] One donkey load equals about 3 maunds or 247.5 pounds.

Table 9. Regression equations.

	Equation 1 - PLL	Equation 2 - Traditional
Intercept	44.36	15.02
	$R^2 = 0.600$	$R^2 = 0.38$
	F = 4.23	F = 1.93
X_2		
X_3	0.07	1.37
	(0.06)	(0.99)
X_4	-0.07	-0.084
	(0.34)	(1.16)
X_5	0.21	.0005
	(1.61)	(0.007)
X_6		
X_7		
X_8	-24.44	-5.88
	(2.80)*	(0.66)
X_9		
X_{10}		
X_{11}		
X_{12}	-26.98	-1.23
	(1.82)**	(0.09)
X_{13}	-0.33	-0.063
	(1.55)	(0.58)
X_{14}		
X_{15}		
X_{16}		

t values are in parentheses.

* significant at 0.05 level.

** significant at 0.10 level.

the precision leveled fields, the most significant variables are sowing technique and max-min range. The max-min range variable illustrates that for every tenth of a foot increase in range between the maximum and minimum spots in a field the decline in yields is 2.7 maunds. This indicates a field that is leveled from 0.40 foot max-min range to 0.20 foot can expect to increase the yields by 5.4 maunds. It must be emphasized, however, that this yield increase is only valid within the small range of max-min differences examined and does not necessarily hold for all ranges. From equation 2, the traditional leveled fields, the change in levelness (max-min range) is not significant and only changes yields by .12 maunds per tenth of a foot change.

Both equations have a negative sign for nitrogen fertilizer which indicates that levels used, 60.42 lbs/acre and 43.36 lbs/acre, are sufficient for the yields obtained, 24.6 mds/acre and 18.18 mds/acre, respectively. However, the positive signs on phosphorus, especially for the precision leveled fields, indicates that the current levels of phosphorous used are too low and that the farmer can expect a little over two maunds for each additional ten pounds of phosphorous. This, of course, is applicable only within the range of the data and will not hold true for very large increases over the present levels.

The last variable that, while only significant at the 0.20 level, is important is the sowing date. Every day past October 1 that the farmer delays sowing decreases yields by 0.33 maunds. Earlier sowing is an important management variable as indicated by the fact that on the average the precision leveled fields were sown five days earlier than the traditional leveled fields which resulted in 1.65 mds/acre increased yields.

ECONOMIC ANALYSIS

Precision land leveling experience has indicated that up to 200 cubic meters of soil at a cost of Rs 3.5 per cubic meter are required to level the average field in Pakistan. If this field is presently ±4 cm difference in elevation and after leveling it is ±2 cm difference then the change in max-min difference will be 4 cm or approximately 0.15 feet. From the regression analysis a change of 0.15 feet is expected to yield 4.0 maunds of wheat increase assuming the other management variables are also provided. In addition between one half and one hour of water is saved which can be used on alternate crops. This water is estimated to average a flow rate of two cubic feet per second (cusecs) or one acre inch for an additional half hour of flow. From a previous study (Johnson, 1977) an acre inch of supplemented water is worth about Rs. 20 at the root zone in nonpublic tubewell areas and about Rs. 15

at the root zone in public tubewell areas. The return from 0.15 foot change in elevation is then 4.0 maunds of wheat worth Rs. 148 (Rs. 37 per maund) and Rs. 15.80 (72% application efficiency) worth of water per irrigation or a total return per season of Rs. 211.20 per acre leveled assuming four irrigations per acre per season.

The estimated life of a precision leveled field is ten years assuming that the field is maintained at a cost of Rs. 30 per year. Using 15 percent interest and amortizing over the ten year life the annual cost of a precision leveled field is Rs. 139.48 plus Rs. 30 for maintenance or a total annual cost of Rs. 169.48. With a 130% cropping intensity the farmer is receiving an annual return of Rs. 274.56 per leveled acre for an annual investment of Rs. 169.48 or a return of Rs. 1.62 for every Rs. 1.00 invested. He is operating at a point where the value of the marginal product is greater than the price of the associated input which means he is accruing a short run profit. The farmer is justified in investing more in precision land leveling, if required, up to the point where the price of leveling is just equal to its value.

CONCLUSIONS

Precision land leveling appears to act as a catalyst for increasing agricultural production. The fields that had received precision land leveling, even though a portion of them are not presently within specifications, are able to efficiently respond to increased fertilizer inputs and improved water management. For the sample of traditional leveled fields the fertilizer inputs are not efficiently utilized and the water management problems result in longer periods of time required to irrigate. Reducing the range between maximum and minimum heights in the field results in a yield increase estimated at 2.7 maunds per 0.1 foot reduction in difference. The economic value of the return to precision land leveling, Rs. 274.56, exceeds the annual price of precision land leveling, Rs. 169.48, and therefore economically justifies precision leveling of fields.

The per unit return for additional unit of phosphorus fertilizer is greater than the return to precision leveling *per se* but since precision leveling also increases the efficiency of fertilizer utilization it can be justified as a catalyst for the whole range of production increasing inputs.

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APPENDIX 23

CROPPING INTENSITY AND WATER SHORTAGES

The Response of the Punjab Farmer

Sam H. Johnson[1]

Pakistan's canal system was originally designed to support a cropping intensity of 75% (Buckley, 1905). However, on most canal systems today the average cropping intensity is around 100% and often as high as 125% in some areas. The object of this paper is to analyze the water management techniques used by the Punjabi farmer to obtain these higher cropping intensities. A linear programming (LP) model is developed for a typical 500 acre watercourse on a perennial canal in the Sargodha area. The available water is varied to determine the farmers' optimum response to different levels of available water. The second part of this paper applies sensitivity analysis to determine the value of additional water during the rabi[2] and kharif[3] seasons.

INTRODUCTION

Pakistan's system of fixed delivery canals often leaves the farmer in a situation where the water supply is deficit in one month and surplus in the other months. The situation for a 500 acre watercourse with a typical crop mix for the Sargodha (Punjab) area is illustrated in Figure 1.

From Figure 1 it is apparent that overall the farmers have sufficient water to support a higher cropping intensity. However, three times during the year, notably March-April (peak water demand for wheat), in May-June (cotton and rice planting), and in September-October-November (rice and fodder peak water demand and irrigation for wheat) the farmers are short of water. This shortage of water during these critical periods especially during wheat and cotton planting times severely constrains the acreage that can be planted to these important crops. The interesting question to analyze is how farmers organize their cropping schedule to minimize the effects of these

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[1] Assistant Professor, Department of Economics, Colorado State University.

[2] Rabi - winter of season; November to May.

[3] Kharif - summer season; May to November.

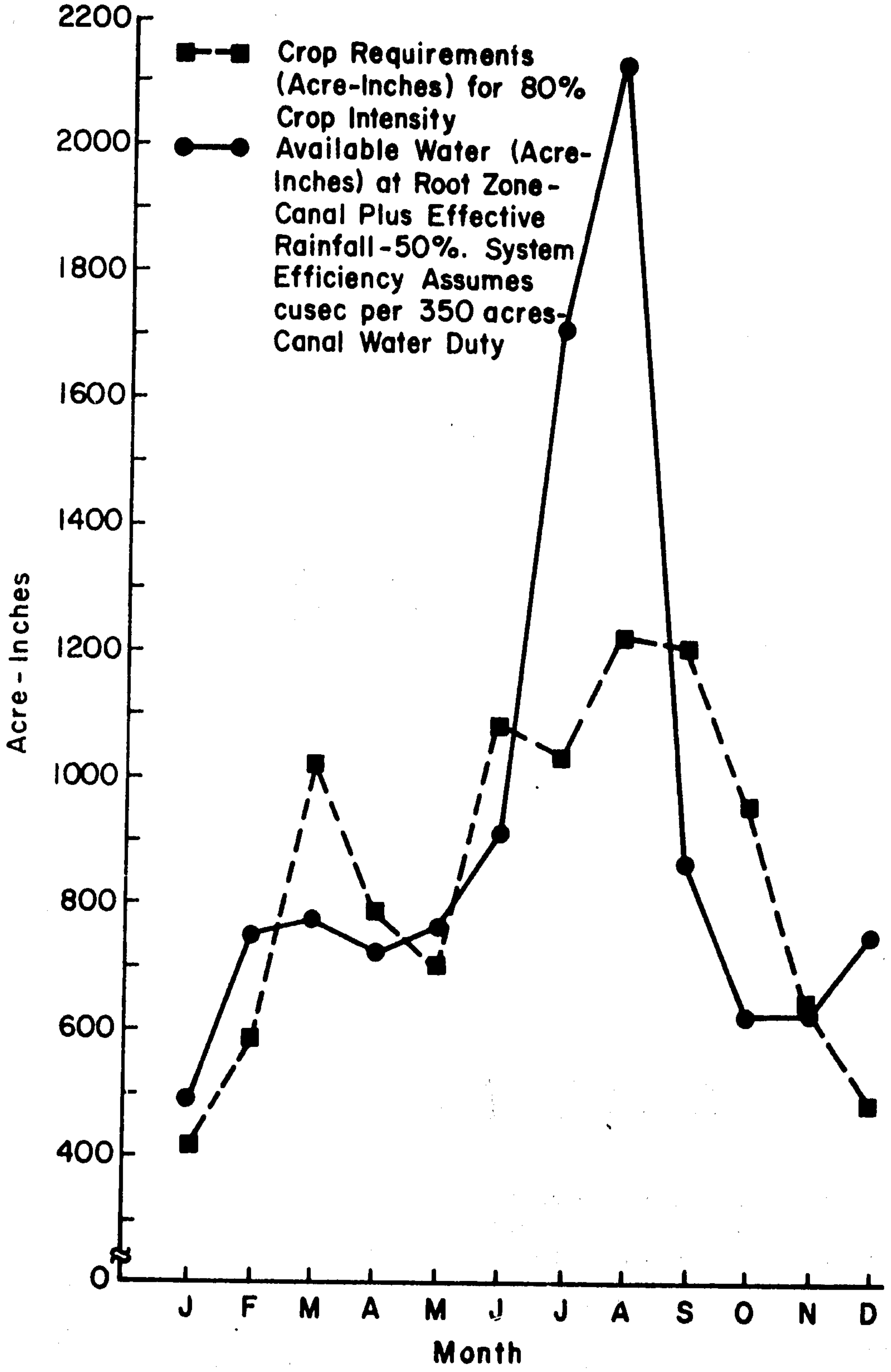

FIGURE 1. Available Canal Water Plus Rainfall Compared to Actual Crop Requirements: 500 Acre Punjab Watercourse

shortages. Rather than irrigation scheduling to meet the demands of the crops, which is impossible with the fixed capacity delivery system, the farmers have developed over time crop rotations that match the available water supplies while accepting some water stressing as necessary to obtain higher cropping intensity.

LP MODEL

In order to model farmer's response over time, a LP model was developed. This model is designed to capture the complex nature of the farm environment by breaking the year down into monthly increments (Wagner, 1969). The crop activities are entered into the model not only at optimum yield levels, but also at various reduced levels of yields due to missed or short irrigations (this is discussed in Appendix A). Table 1 illustrates this concept for four different levels of wheat.

TABLE 1. Wheat activities under stress

		W1	W2	W3	W4
Percent of optimum yield		100%	90%	80%	60%
Gross margin (a)		410	369	327	246
(b)					
Irrigation -	November	4.0	4.0	3.0	0.0
	December	3.0	0.0	3.0	3.0
	January	0.0	3.0	0.0	0.0
	February	3.0	3.0	0.0	3.0
	March	3.0	3.0	3.0	0.0
	April	0.0	0.0	0.0	0.0
TOTAL		13.0	13.0	9.0	6.0

(a) Gross return minus variable costs (excluding water costs) in Rupees.

(b) Irrigation water applied in acre-inches at the root zone excluding available rainfall.

In Table 1, W1 represents wheat yielding 30 maunds per acre (high average for Sargodha watercourse under typical cultivation practices) with a full consumptive use requirement (13 inches) at the root zone. W2 and W3 are wheat activities with reduced yields due to slight water stress and W4 is late planted wheat with extensive water stress that yields less than one half as much as W1 (Anderson and Maass, 1974). The model develops similar ranges of yields and stress for the other crops including rabi and kharif fodder, sugarcane, cotton, and rice. Since citrus is such a high value crop, it is not stressed but only enters as a single activity.

Mathematically the LP model is:

Maximize:

$$Z = \sum_{i=1}^{n} c_i X_i - \sum_{i=1}^{n} d_i X_i \quad (1)$$

Where c_i = the gross margin/acre returned from the i^{th} crop activity (Rs/acre)

X_i = the crop activities (acres)

d_i = the variable costs of the i^{th} water producing activity, including application labour, (in Rs/acre) associated with each crop activity.

Equation 1 is maximized subject to a series of constraints:

$$\sum_{i=1}^{n} a_{ij} X_i \leq b_j \qquad j = 1, 2, \ldots s$$

Where a_{ij} = the input-output matrix coefficients of the j^{th} resource used by the i^{th} activity (e.g. the amount of labour required in April to harvest one acre of wheat)

b_j = the resources available during different time periods.

The principle constraints include canal water, labour, land and supplemental tubewell water.

RESULTS AND DISCUSSION

The model was run at an overall system efficiency (delivery efficiency x application efficiency) of 50%.[4] This level of system efficiency is about 10% higher than the efficiencies measured in the survey of 40 watercourses in the Punjab and Sind (Lowdermilk, Early and Freeman, 1975). Table 2 presents the results for an optimal rabi crop mix with only a canal water supply of 1 cusec per 333 acres.

From Table 2 the overall cropping intensity for rabi season is 62%. This intensity is mainly obtained by not attempting to give optimal amounts of irrigation water to the crops. The farmer matches the available water to the crop

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[4] Subsequent work will vary this efficiency to determine the effects of improvement in water delivery efficiencies.

TABLE 2. Optimal Rabi cropping pattern: 500 acre watercourse, Sargodha area.[a]

Crop	Predicted Acreage (acres)	Percent of Area (%)
Wheat 1	0.0	0.0
Wheat 2	95.0	19.0
Wheat 3	0.0	0.0
Wheat 4	63.33	12.7
Fodder 1	0.0	0.0
Fodder 2	0.0	0.0
Fodder 3	70.0	14.0
Fodder 4	0.0	0.0
Citrus 1	80.0	16.0
Sugarcane 1	0.0	0.0
Sugarcane 2	0.0	0.0
Sugarcane 3	0.0	0.0
TOTAL	308.33	61.7

[a] 50 percent overall system efficiency - no supplemental water

mix in such a manner to support a higher cropping intensity with lower overall yields. The high water delta and relatively lower net returns from sugarcane eliminates any acreage of sugarcane from the optimal rabi crop mix. The acreage of fodder in the crop mix is necessary due to the livestock requirements on the farms. However, with fodder valued at market prices the overall gross margin income[5] on the watercourse could be increased by Rs. 165 for every acre taken out of fodder and put in a higher value crop.

Instead of the high average yield for wheat of 30 maunds[6] per acre, the overall wheat yield is 23.4 maunds per acre. A similar situation exists for fodder with a potential high average yield of 300 maunds per acre, the actual average yield on the watercourse is 225 maunds per acre. The farmers have been willing to sacrifice higher yields for higher cropping intensity.

Table 3 presents the results of a simulation run for the kharif season. This run also assumes a water allocation of 1 cusec per 333 acres with no supplemental tubewell water. In addition the monsoon rainfall is simulated using the twenty year averages from the WAPDA weather station near Sargodha.

From Table 3 the overall cropping intensity for kharif season is 49%. This intensity is again obtained by not attempting to provide optimal amounts of irrigation water to the crops. The farmer has increased his cropping intensity by cutting his yields. Again the farmer picks citrus as his main cash crop and then selects fodder, rice and cotton as his other crops. The overall cotton yields are 5 maunds compared to the potential yields of 10 maunds. Similarly for fodder the average yields are 224 maunds per acre compared to potential yields of 320 maunds per acre.

The overall gross margin income on the watercourse with the standard water supply of 1 cusec per 333 acres is Rs. 249,219.8 for the rabi season and Rs. 221,424.0 for the kharif season. Thus the total gross margin income on the watercourse with a cropping intensity of 111% is Rs. 470,643.8. With the theoretical diversion of 1080 acre feet per year the return per acre foot of diversion is Rs.436. With 50% overall system efficiency the return per acre foot of water at the root zone is Rs. 871.

As additional water (tubewell) is made available to the farmers, they can increase the water supply to the present

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[5] Gross margin income equals gross income minus variable costs.

[6] One maund equals approximately 82.5 lbs.

TABLE 3. Optimal Kharif cropping pattern: 500 acre watercourse, Sargodha area.[a]

Crop	Predicted Acreage (acres)	Percent of Area (%)
Citrus	80.0	16.0
Cotton 1	0.0	0.0
Cotton 2	0.0	0.0
Cotton 3	32.0	6.4
Fodder 1	0.0	0.0
Fodder 2	0.0	0.0
Fodder 3	118.0	23.6
Fodder 4	0.0	0.0
Sugarcane 1	0.0	0.0
Sugarcane 2	0.0	0.0
Sugarcane 3	0.0	0.0
Rice 1	0.0	0.0
Rice 2	0.0	0.0
Rice 3	17.0	3.4
TOTAL	247.0	49.4

[a] 50%overall system efficiency - no supplemental water.

crops and/or they can increase the cropped acreage. The optimum combination of these alternatives for the rabi season is presented in Table 4.

From Table 4 it is apparent that it is economically optimal for the farmer to first increase his cropping intensity and once he utilizes all of his land (100% cropping intensity for the rabi season) to then increase his crop yields. The average yields of wheat at different levels of supplemental water availability are presented in Table 5. The wheat yields only begin to approach the upper yield level when the third incremental increase of supplemental water is provided to the system. The change in optimal cropping mix during the Kharif season as supplemental water is provided in Table 6.

Again, from Table 6, it is apparent that the farmer first increases his cropping intensity and then increases his crop yields. It should be noted that, while it is not optimal to irrigate sugarcane during rabi season, it is optimal to irrigate sugarcane during kharif season and thus as the water supply is supplemented the kharif acreage in sugarcane is increased. Due to limitations on the core size of the computer it is necessary to run these two seasons (rabi and kharif) as separate models and, therefore, this anomaly is present.

VALUE OF WATER

Knowledge concerning the time value of additional water into the system is of great value to planners and designers. This knowledge allows the planner to determine what are the potential benefits of increasing the irrigation water supplies and it allows the designer to understand when these supplies should be made available to the farmers.

Using the sensitivity analysis (Sposito, 1975) it is possible to determine the shadow value[7] for additional units (acre feet) of water at the root zone during each time period. Table 7 contains the shadow values for water from the L.P. model for varying amounts of supplemental water applied at the root zone.

The value of additional water is high at the beginning of the rabi and kharif seasons with the highest value coming in December when the farmers provide the first irrigation to wheat after planting. Recent research at the Punjab Agricultural Research Institute has shown that this first irrigation <u>after the soaking</u> dose is the most crucial irrigation in terms

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[7] Shadow value as used here is defined as the unit worth of an additional increment of the associated resource.

TABLE 4. Optimum Rabi cropping patterns with varying amounts of supplemental water: 500 acre watercourse, Sargodha area.[a]

Supplemental Water[b]	150 acre feet		300 acre feet		450 acre feet	
Crop	(acres)	(%)	(acres)	(%)	(acres)	(%)
Wheat 1	0.0	-	163.3	32.7	325.0	65.0
Wheat 2	156.7	31.0	86.7	17.3	0.0	-
Wheat 3	24.4	4.8	0.0	-	0.0	-
Wheat 4	103.3	20.6	100.0	20.0	25.0	5.0
Fodder 1	0.0	-	0.0	-	0.0	-
Fodder 2	0.0	-	0.0	-	0.0	-
Fodder 3	105.6	21.1	70.0	14.0	70.0	14.0
Fodder 4	0.0	-	0.0	-	0.0	-
Citrus	80.0	16.0	80.0	16.0	80.0	16.0
Sugarcane 1	0.0	-	0.0	-	0.0	-
Sugarcane 2	0.0	-	0.0	-	0.0	-
Sugarcane 3	0.0	-	0.0	-	0.0	-
TOTAL	470.0	93.5%	500.0	100.0%	500.0	100.0%

[a] Assumes 50% overall system efficiency.

[b] Available in equal monthly increments during the rabi season.

TABLE 5. Average wheat yield levels with increasing amounts of supplemental water.

Supplemental water (a)	Crop Yield Wheat (mds/acre)	Unit of wheat per unit of water (b) (mds/a.f.)
0 acre feet	23.4	33.42
150 acre feet	23.5	33.33
300 acre feet	25.8	30.18
450 acre feet	29.1	27.94

[a] Available in equal monthly increments during the rabi season.

[b] At the root zone.

TABLE 6. Optimal Kharif cropping patterns with varying amounts of supplemental water: 500 acre watercourse, Sargodha area.

Supplemental water[a]	150 acre feet		300 acre feet		450 acre feet	
Crop	(acres)	(%)	(acres)	(%)	(acres)	(%)
Citrus	80.0	16.0	80.0	16.0	80.0	16.0
Cotton 1	0.0	-	73.4	14.6	84.9	17.0
Cotton 2	49.8	10.0	0.0	-	0.0	-
Cotton 3	0.0	-	22.4	4.5	14.4	2.8
Fodder 1	0.0	-	0.0	-	0.0	-
Fodder 2	0.0	-	0.0	-	3.8	0.8
Fodder 3	120.0	24.0	120.0	24.0	116.2	23.2
Fodder 4	0.0	-	0.0	-	0.0	-
Sugarcane 1	0.0	-	0.0	-	0.0	-
Sugarcane 2	0.0	-	0.0	-	0.0	-
Sugarcane 3	61.1	12.0	124.8	24.9	178.1	35.6
Rice 1	0.0	-	0.0	-	0.0	-
Rice 2	0.0	-	0.0	-	22.6	4.5
Rice 3	20.3	4.0	21.5	4.3	0.0	-
TOTAL	331.20	66.0%	442.1	88.0%	500.0	100.0%

[a] Available in equal monthly increments during the kharif season.

TABLE 7. Shadow values of supplemental water at the root zone: 500 acre watercourse in Sargodha area.[a]

	Shadow Value (Rs/acre foot)				
Supplemental water[b]	0 acre feet	25 acre feet	50 acre feet	75 acre feet	100 acre feet
January	0.0	36.0	0.0	0.0	0.0
February	404.4	456.0	60.0	60.0	0.0
March	404.4	138.0	60.0	60.0	0.0
April	404.4	60.0	60.0	60.0	0.0
May	203.9	117.7	133.1	182.1	231.0
June	416.0	348.0	302.1	192.7	36.0
July	0.0	0.0	36.0	36.0	36.0
August	0.0	0.0	0.0	0.0	0.0
September	0.0	36.8	33.7	36.0	36.0
October	212.0	201.0	180.0	164.0	36.0
November	404.4	537.6	405.6	404.4	60.0
December	531.6	489.6	188.4	60.0	48.0
Average	248.4	201.7	121.6	104.6	40.2

[a] 50% overall system efficiency

[b] acre feet per month

of obtaining a successful return from the wheat crop. At the low levels of availability of supplemental water during this December time period water shortage is most critical and hence the shadow value of water is very high. During January the crop that has received a December irrigation has enough water to carry it through and additional water has little or no value. Similarly during the monsoon rains the crops suffer from too much water and additional water has no positive value and may even have negative value as it compounds the drainage problems on the watercourse.

Figure 2 illustrates the average value of varying amounts of supplemental water over the year. Integrating under this curve and averaging over the entire range, the average value for an acre foot of supplemental irrigation water at the root zone is Rs. 131.1 With 50 percent systems efficiency this means that an additional acre foot of water at the headgate or mogha is worth Rs. 65.5.

From Figure 2 it is apparent that the average value of supplemental water is highest with the first units of water and the value declines as the amount of supplemental water increases. For a watercourse that is provided with a public Salinity Control and Reclamation·Program (SCARP) tubewell the value of additional supplemental water is less than on a watercourse that only has canal water. On Figure 2 the area labeled NON-SCARP indicates the value of additional water to a watercourse that does not have the SCARP tubewell while the area SCARP indicates the value of additional water to a watercourse that is already provided a SCARP tubewell.

CONCLUSIONS

Crop yields in Pakistan are very low compared to other areas of the world with similar agro-climatic conditions. The results of this model explain these low yields as a rational economic response of the farmers to an insufficient water supply. The farmers obtain more return for the first increment of water than he obtains for additional increments and hence it is to his advantage to increase cropping intensity first and then to increase his yields. In order to increase the per acre yields in Pakistan it is necessary to provide additional water during the critical time.

This water can come from increased canal supplies, from increased pumpage of private or public tubewells (in sweet water areas) and/or from increased system efficiency. An increase in either the delivery efficiency and/or the application efficiency will provide additional water at the root zone. Since the canal water supplies in most areas are overallocated and the groundwater is often of hazardous quality, the only viable source of additional water supply for many areas is an

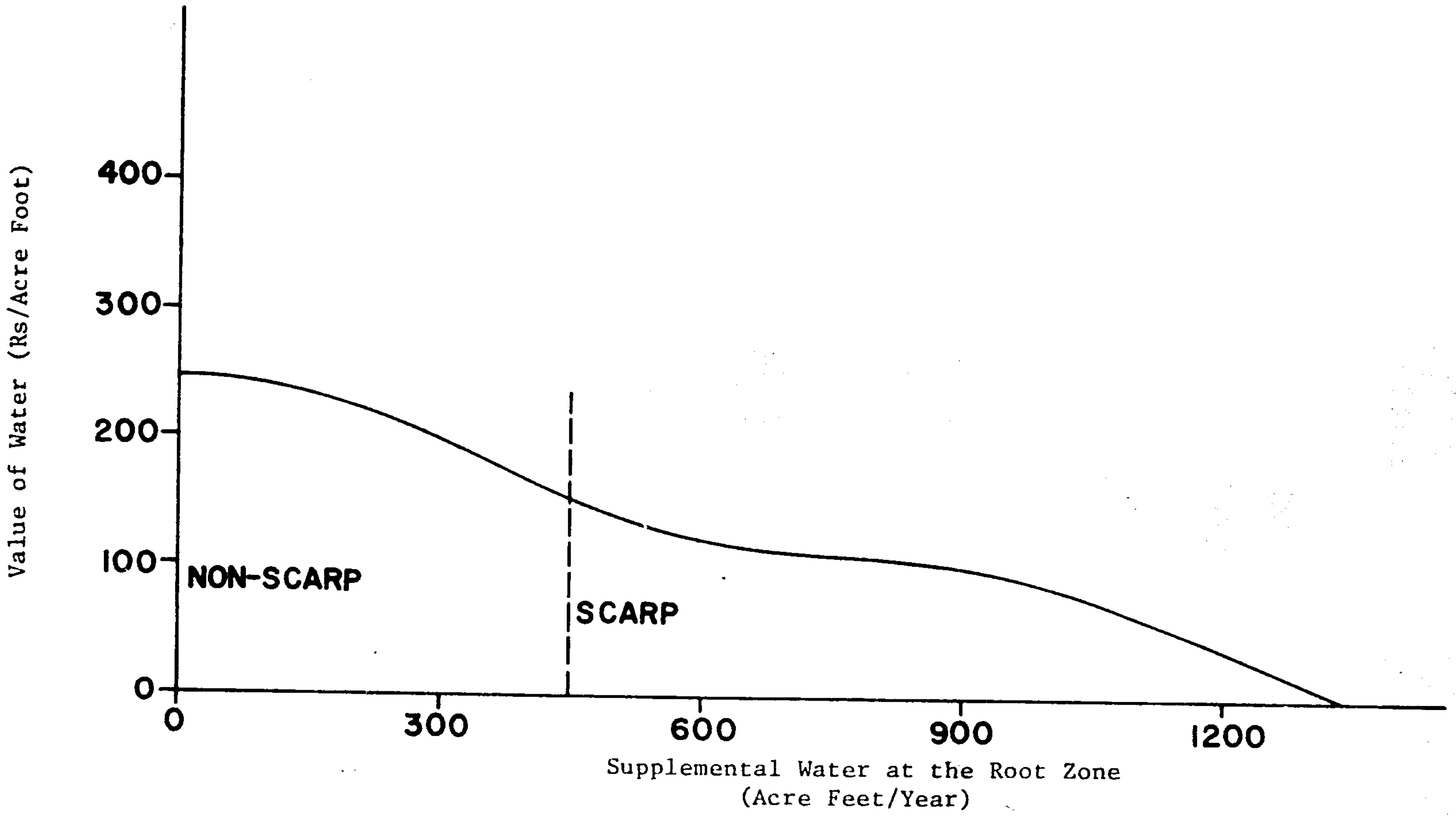

FIGURE 2. The Value of Supplemental Irrigation Water at the Root Zone.

improvement in overall watercourse system efficiency. An alternative method to improve crop yields is to develop crop varieties and crop production techniques that spread out the demand for water. For example, if part of the wheat crop could be planted and irrigated in January when water demand is small this would relieve some of the pressure that now exists in October-November.

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APPENDIX A

Relationships between yield and irrigation application are difficult to determine and therefore are not readily available. Flynn and Musgraves (1967)[8] have provided a significant contribution to this research problem. The Revelle Report (1964)[9] developed an extrapolation of expected relationships for Pakistan. Actual results from field studies under West Pakistan conditions are available in the watercourse studies (1966)[10] Figure 3 presents the results from these two sources.

Using these two sources as well as recent work by Quershi, Chaudhry and Eckert (1975)[11] it is possible to develop stress relationships for wheat. Relationships for other crops in Pakistan are not as well developed and thus this modeling effort used data from the United States and Australia for the stress relationships of the other crops. As additional work on the relationship between yield and irrigation is completed in Pakistan the model can be further refined.

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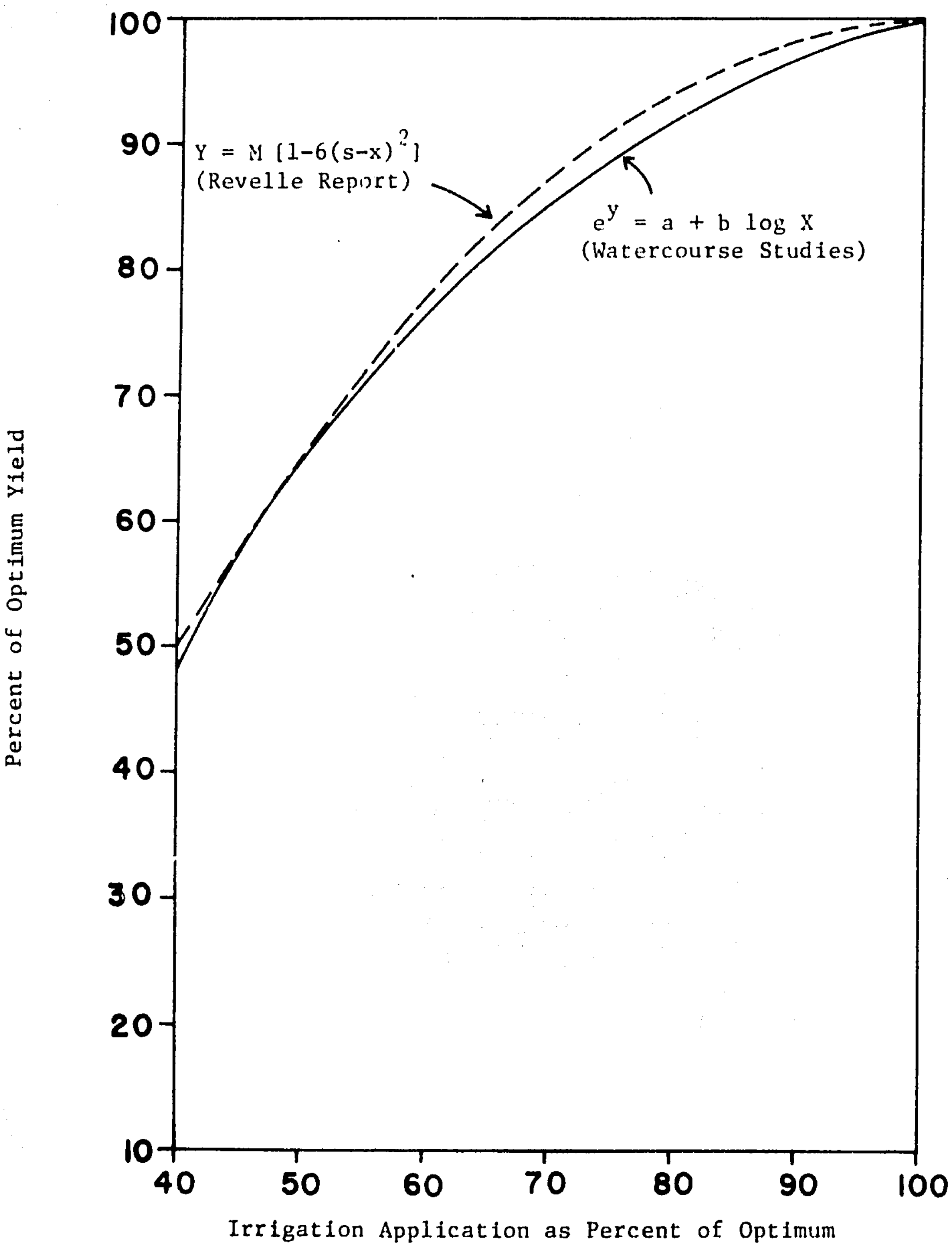

FIGURE 3. Relationship Between Yield and Irrigation.

APPENDIX 24

WATER MANAGEMENT AS AFFECTED BY SIZE OF HOLDING AND CROPPING SYSTEMS[1]

J.O. Reuss and W.D. Kemper[2]

INTRODUCTION

As widespread attention is focused on the problems of matching food production to an expanding world population, the problems of on-farm water management have become increasingly apparent. Many developing nations depend on irrigated agriculture for a major portion of their food supplies, and while inefficient use of water is found in both developed and lesser developed countries, the problem assumes particular urgency where population threatens to outstrip food supplies. The relationships of these problems to size of holding and cropping systems is not necessarily obvious, and in fact may differ markedly in different areas of the world. The bulk of the authors' experience in the systematic study of on-farm water management problems has been in Pakistan, and this paper deals largely with our perception of these problems on the Indus plain. While aspects of the problem may be different in other areas, it seems likely that many components may be common to the irrigated areas of the developing world.

Certainly the problem on the Indus plain is an awesome one, matched in scope only by the vast irrigation works serving over 33 million acres (13.4 million hectares).

SIZE OF HOLDING

The effect of size of holding must be considered in the light of related variables such as the size of the operational unit (size of unit operated by a single farmer) and the field size.

On the 78,000 watercourse command areas (land served by one outlet from the government distributary) located in the Sind and Punjab provinces of Pakistan, the average irrigated acres commanded is 400 with an average of 40 farmers owning land on each watercourse, (Johnson et al., 1977a). Thus we

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[1] Research reported in this paper supported in part by United States Agency for International Development, Contract No. AID/ta-C-1411 and by Mona Reclamation Experimental Project (WAPDA) Bhalwal.

[2] Professor of Agronomy and Professor of Agricultural Engineering, Colorado State University Fort Collins, Colorado, respectively.

would appear to have an average farm size of about 10 acres. Government of Pakistan figures show 97% of the total operational farms comprising some 76% of the farmed area are less than 20 acres, and 89% of the farms representing 57% of the acreage are less than 10 acres (Anon., 1972).

These averages or medians are subject to certain limitations. In some areas large land holdings persist even though government regulations have resulted in some dispersal. In many cases these large holdings are farmed by tenants whose operational units more nearly match those of the small farmer. However, the opposite effect also occurs where small ownership units are combined into larger operational units. Johnson et al. (1977a) concluded that average figures collected on farm size generally tend to show smaller operational units than are actually found in the field.

The operational units as farmed in Pakistan are certainly not small as compared to those of many Asian countries. Still, with the generally low productivity, a high percentage of the farms are operating at or near the subsistence level. There is little capital available for outside inputs, and the general educational level of the farmers is low with a majority of the cultivators being illiterate. Tractor importation has proceeded at a significant rate, with an apparent annual acquisition of about one tractor per 3500 acres (1450 hectares). However, many of these units are engaged in non-farm uses, maintenance is poor, and they cannot be efficiently used on small fields, with the result that the bulk of the field operations are still performed with animal or human power. These large numbers of poor, relatively uneducated farmers operating small units present a formidable challenge to those of us interested in formulating extension programs designed to promote the adoption of improved farm water management practices.

These farm size problems are directly related to the small size of fields, or as we are concerned here from the physical standpoint, with the irrigation unit. The most unique feature of the Indus plain is its flatness. Overall slopes average about one foot per mile (0.19 meters/kilometer). The soils have low infiltration rates and the basin method of irrigation is almost universal. These basins are areas generally of 1/2 acres, (0.20 hectares) or less, surrounded by small dikes known as bunds. Even though the topography is generally flat these bunded areas usually are sufficiently uneven to cause serious inefficiencies in water application. Johnson et al. (1977b) found in a survey of 46 traditionally leveled fields, mostly 1 acre in size, the median range of elevations within the fields was 0.4 ft. (12 cm). The farmer normally applies water at least until the highest area is covered, with the result that the lowest area receives 0.4 ft (12 cm) more water than the high area. Recognizing this problem the Land Reclamation Directorate for the Punjab recommends that each acre be divided into 8 bunded units for irrigation in order to achieve more uniform application. This approach unfortunately adds as much as 60,000 feet (18,000 meters) of field watercourse in a 400 acre (160 hectare) watercourse command area.

Many of us from outside Pakistan, when walking watercourses in the field or examining maps of Pakistani watercourses, immediately notice the extensive network of both official "sakari khal" watercourses and the farmer's field watercourses required to distribute the water to the individual fields. For instance the watercourse in the Mona area near Bhalwal served by mogha[3] number 31574/R of the Fatehpur distributary and supplemented by Tubewell 81 of the SCARP II (Salinity Control and Reclamation Project) project was studied in depth by Trout et al. (1977). A map of this watercourse which commands 366 culturable acres is shown in Figure 1. There are a total of about 75,000 ft. (23,000 meters) of watercourses of which 11,000 ft. (3350 meters) are government authorized sakari khal and the rest are farmer's watercourses required to convey water from the sakari khal to the individual bunded units. The watercourse at Tubewell 56 of the Mona project area commands about 900 acres and the system is comprised of 18,000 ft. (5500 meters) of sakari khal and 210,000 ft. (64,000 meters) of farmer's watercourse. Eckert et al. (1975) concluded after examining a large number of watercourses that we will generally find about one mile (1600 meters) of watercourse, including sakari khal and farmer's branches, for every 20 acres (8 hectares) or about 205 ft./acre (200 meters/hectare).

The implications of this vast network repeated about 80,000 times in Pakistan are manifold. First is simply the amount of land required. On the Tubewell 81 watercourse of 366 (148 hectares) culturable acres if we assume a width of 16 ft. (5 meters), the legal right of way, for the official watercourse, and an average of 10 ft. (3 meters) for the farmer's branches, we find that 18.7 acres (7.5 hectares) or about 5% of the culturable area is taken up by watercourses. In fact, the nonproductive area is much larger on most watercourses in their present condition, due to extensive areas of crop loss due to leaks and seepage, and burrows required to replace earthen bunds at junctions and outlets.

The land lost to watercourses is, of course, only the tip of the iceberg. The cost of the network in terms of water lost is fantastic. Various studies have shown a wide range

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[3] Mogha - An orifice or outlet from the distributary or canal that automatically delivers a designed quantity of water if the distributary is maintained at the design operating level.

of delivery efficiencies[4] on watercourses in Pakistan (Ashraf et al., 1977).

It is not our purpose to detail or defend these studies here but it appears that the overall delivery efficiency of watercourses in Pakistan is not much over 50% and certainly less than 60%. Most of the water lost apparently ends up in the ground water and contributes to Pakistan's well known waterlogging and salinity problem.

The distribution of loss between the sakari khal and the farmer's branches which comprise the bulk of the network, typically 80 to 85% of the total, is an important factor. The loss rate in these branches is much higher than in the sakari khal due to the small size, intermittent operation and poor maintenance. The relative loss rates at Tubewell 81 (Trout et al., 1977) appear to be typical. These authors found losses in the sakari khal averaged 0.21 cusec/1000ft. (20 liters/sec/1000m) while the farmer's branches averaged 0.43 cusec/1000ft. (40 liters/sec/1000m). Relative losses as a percent of inflow rate in the farmer's channel would be even greater as only that water surviving the trip through the sarkari khal enters the main branches. Even though most of the total length and the highest loss rates are found in the farmer's branches the bulk of the total losses are in the sarkari khal. For instance, in the Tubewell 81 study, two-thirds of the total losses were in this section and only one-third in the farmer's branches. This apparent anomaly arises because the frequency of use of the sarkari khal is much higher than that of the farmer's branches. The bulk of the former is used each week and parts of it are in virtually continuous use, while individual farmer's branches are only used a few hours at a time at intervals varying from weekly at most to several weeks or even months. On a studied watercourse near Faisalabad, where the sarkari khal loss rates were low, more than half of the total losses were from the farmer's branches (Trout, 1977).

The loss resulting from the extensive network is particularly severe in much of Pakistan where very little gradient exists and watercourses commonly operate on slopes of 0.2 to 0.3 ft. per thousand ft. (meters/kilometer). It is significant to note that one of the higher overall efficiencies we have encountered on a traditionally maintained watercourse was found at a watercourse near Faisalabad where the general gradient was 0.8 ft. per thousand feet. The operational efficiency of delivery here was 63% (Trout, 1977) measured over a full weeks rotation of irrigation turns, and the water loss rate in the sarkari khal was only 0.06 csc/1000 ft. (5.6 liters/1000m).

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[4] Delivery efficiency (e_d) is here defined as:

$$(e_d) = \frac{\text{volume of water delivered to field}}{\text{volume of water entering watercourse}} \times 100$$

The question immediately arises as to why farmers allow the system to deteriorate to the point where these low efficiencies predominate. One possibility is that they do not realize the magnitude of losses. While this may be a factor, several pieces of evidence (Trout et al., 1977; Johnson, unpublished data; Early and Lowdermilk, unpublished data) suggest that the farmers do indeed recognize significant losses as measured by both their direct perception of loss and the change in the reported time required to irrigate a unit area of land near the mogha as compared to the lower reaches of the watercourse.

An interesting analysis of this lack of adequate maintenance in light of perceived losses is provided by Johnson et al. (1977a) who invoke an analogy to the tragedy of the commons (Hardin, 1968).

Hardin's analysis referred to common grazing lands which could be successfully utilized on a commons basis as long as natural factors kept the population of man and beast below the carrying capacity of the grazing lands. Each herdsman gets the full value of output of each animal that he pastures on the land. As pressures increase the total number of animals exceeds the carrying capacity which is thereby reduced due to overgrazing, the land deteriorates and the total output drops. Even so, it is the advantage of the individual herdsman to increase his number as he gets the total output of the animal while the degradation caused by that animal is shared by all. Thus the free use of the commons results in ruin.

As the above authors point out, the watercourse is common property in which the benefit of improvement is distributed among so many farmers that improvements made by the individual do not provide sufficient benefits to the improver to be a good investment. "Individuals commonly attempt to maximize their benefits from the common property without feeling adequate responsibility to contribute to the system's upkeep," (Johnson et al., 1977a).

Thus the tradgedy of the watercourse on the Indus plain appears to lie in the failure to develop adequate social institutions, either on a local or governmental basis, to insure proper maintenance for the benefit of all.

In the long run the success of programs of watercourse rebuilding or improvement will depend on the development of institutions that will insure the maintenance of the improvements to the benefit of all. While major efforts towards widespread improvements deserve a high priority, in the short run improved maintenance of existing watercourses probably offers the greatest potential for water savings per unit of investment input.

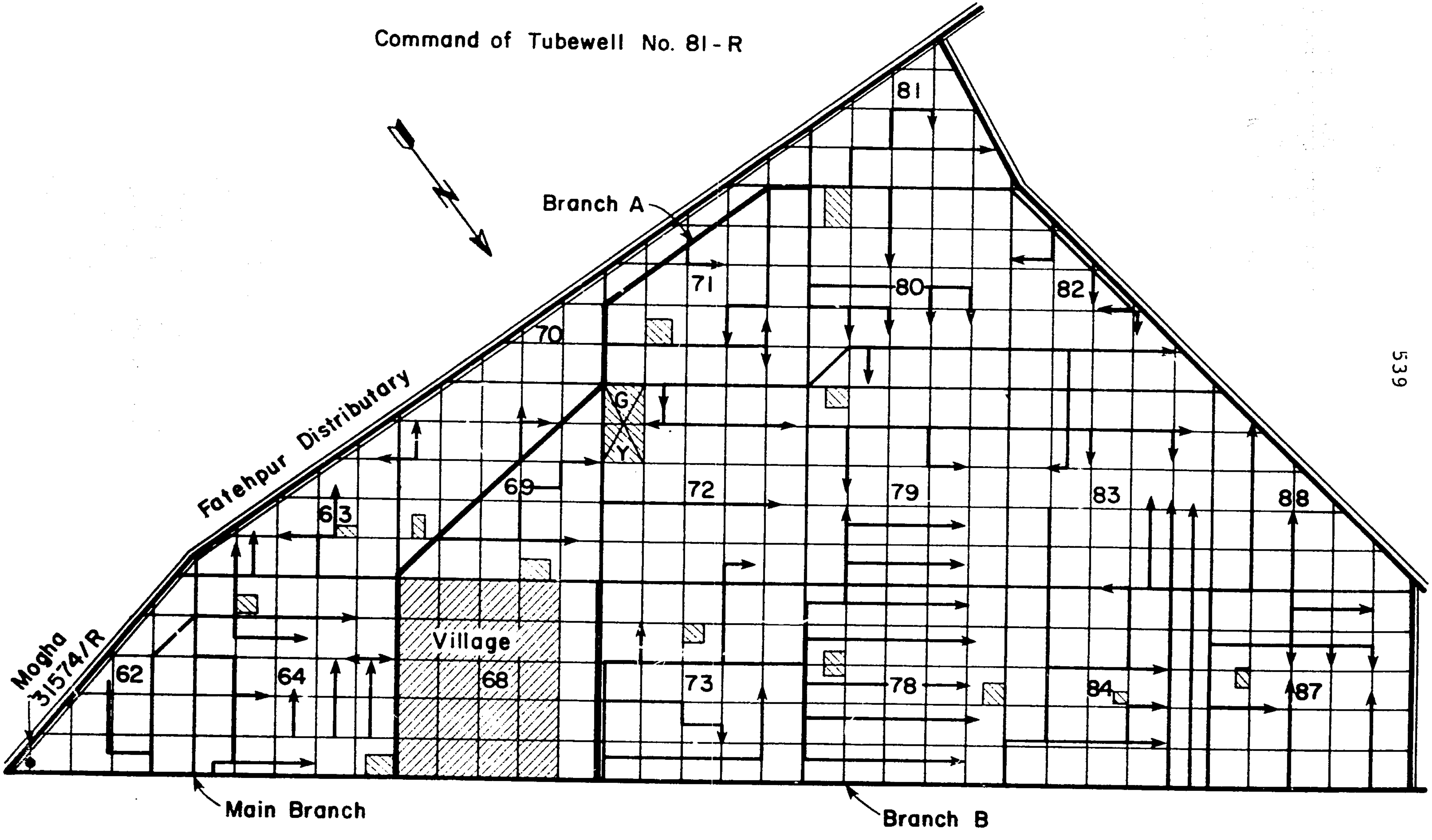
A wide variety of organizational structures for improved maintenance might be envisioned. These could include locally based organizations, either legally constituted or on an ad hoc basis, or government imposed regulation. The expedient of simply refusing to deliver water to improperly maintained channels appears extreme and open to widespread abuse, but if other methods prove ineffective it may have to be considered. Certainly research programs designed to determine the most appropriate type of organizational structures for watercourse maintenance and improvement, and concentrated extension programs designed to create awareness of the potential for water savings and the need for organizational structures must be a high priority item. The size of holding factors again creates problems due to the large number of people that must be reached and the limitations on communication by the low rates of literacy.

Let us now return to the physical implications of size of holding and field size. The watercourse shown in Figure 1 is laid out in a typical pattern consisting of "squares" 1100 ft. (335 meters) on a side. It is then subdivided into 25 "killas" each of which is 220 ft. (67 meters) on a side and contains 1.11 acres (0.45 hectares). Usually either the main sarkari khal or one of its official branches touches each of these "squares" on at least one point. There are about 64,000 ft. (19,500 meters) of farmers watercourses required to distribute the water within the fields to the individual "Killas" and subunits. If instead of the present pattern each square were divided into 5 fields 220 ft. by 1100 ft. (67 x 335 meters), each of which were properly leveled, they could be served by about 15,000 ft. (4, 600 meters) of farmers branch watercourses or about one-fourth of the present amount. This probably is not a feasible approach as each of these fields would contain about 5.6 acres (2.29 hectares) which implies substantially larger fields and thus larger operating units than are envisioned for Pakistan. Nonetheless, with the consolidation of bunded units that can be efficiently accomplished by a reasonable land leveling input, coupled with careful attention to the layout of the sub-branches, substantial reductions in total length cf farmer's branches can be attained. For instance with 2.8 acre (1.13 hectare) fields, the above watercourse could be served by about 35,000 ft. (10,711m) or a little more than one-half the present amount.

CROPPING SYSTEM

Cropping systems that have evolved in Pakistan are adapted to the climate, the pattern of irrigation water availability and the requirements of the farmers and their animals. In spite of these adaptations water shortages occur at various times. These shortages appear to be a major factor in limiting the cropped area in any one season, resulting in an undesirably high percentage of fallow land and low overall cropping intensities.

Figure 1. Layout of Tubewell 81-[redacted]course.



The irrigation water requirements were calculated for a 25 acre farm in the Sargodha area during the kharif (summer season) of 1976. The farmer planned to crop 17.5 (7.08 hectares) acres as follows:

	Acres	(Hectares)
Cotton (Gossipium hirsutum)	9	(3.64)
Citrus (Citrus sp.)	3	(1.21)
Sugarcane (Saccharum officinatum)	1.5	(0.61)
Lucerne (Medicago sativa)	0.5	(0.20)
Bajara (Pannisetum typhoides)	3.5	(1.42)

This farm is on a SCARP (Salinity Control and Reclamation Project) area and the design supply is 1 cusec per 150 acres or about 1.1 inches (2.8 cm) per week. Thus a total of about 28 acre inches per week should be available. Unfortunately the measured supply at the farm is slightly less than 14 acre inches per week which reflects a delivery of about 50% of design at this farm. The 17.5 acres cropped represents a cropping intensity of 70% for the kharif season. The high percentage of cotton is typical for the lower reaches of watercourses where delivery efficiencies are low. Farmers are more willing to plant cotton where water stress may result than many of the other crops.

Figure 2 shows a graph of irrigation requirements (acre in/week) for these crops throughout the season. These requirements are shown for a median rainfall year and a dry year, based on a probability of one year in ten having less rainfall.

On examining the graph we note that demand equals or exceeds supply in the May-June period and again in September. During the July-August monsoon period supply exceeds demand.

The high May-June demand is largely caused by the need for pre-irrigation of the cotton and bajara fields prior to sowing. Pre-irrigation followed by cultivation and sowing in the moist soil is almost universal in Pakistan. Given the flooded basin method of irrigation and soils that tend to develop hard crusts this method of sowing is a reasonable practice. If the crop is sown in dry soil followed by irrigation or if heavy rains fall prior to emergence stands will

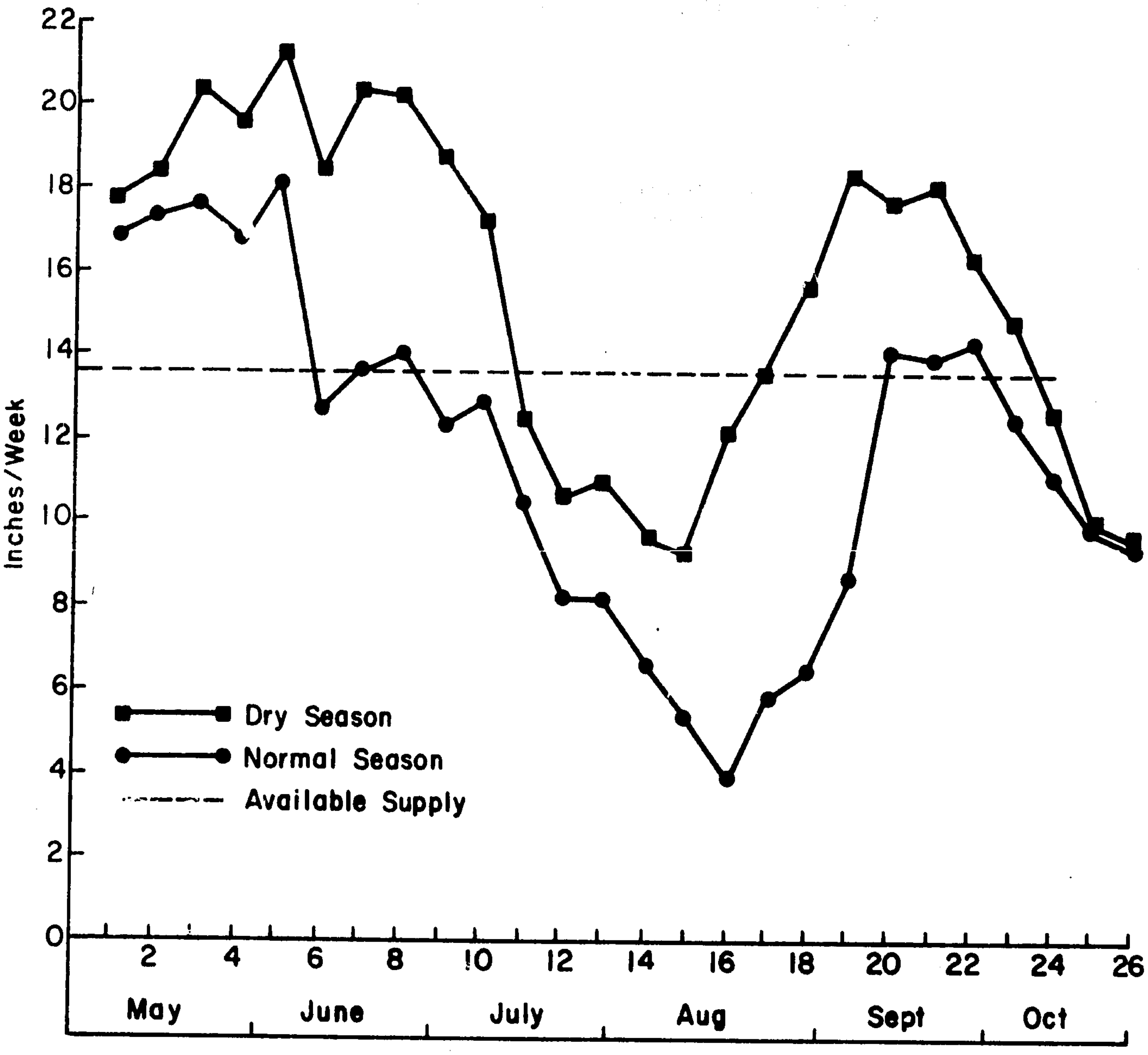


Figure 2. Irrigation water requirements for 17.5 cropped acres near Sargodha in kharif season assuming normal and dry years.

be poor due to crusting. This problem is particularly severe in sodium affected soils which are common on much of the Indus plain.

The farmers response to this May-June shortage is to decrease his crop acreage and to extend his planting season into the monsoon period. As a result heavy rains often occur before the crop is established and stands are poor due to crusting. Virtually no surface drainage occurs and fields often flood to the point that even established stands are seriously damaged. Unfortunately, not even a wet year saves him from his emergence problem. Even in relatively wet years there is little rain during the May-June period, and if rain does occur it will likely cause a crust to form and damage his newly planted field. These calucations were made prior to the season for planning purposes. In fact a wet year did occur with heavy early rains and much of the crop either was not planted or survival was near zero due to a combination of crusting and flooding.

An obvious approach to this crusting and flooding problem would be to adopt row seeding on ridges in dry soil. A relatively small amount of water could be applied in furrows in alternate rows between the ridges, the seeds would be wet by capillary action and crusting would be largely avoided. In this way water demand would be reduced at a critical time and the crop could be established prior to the monsoon thus avoiding crusting and flooding damage. The ridges would also help to prevent flood damage late in the season.

Even though extremely high temperature and rapid drying rates during the pre-monsoon season cause some difficulties, recent field trials and demonstrations have shown that this system can work successfully. Crops such as cotton and maize have long been successfully grown in this manner in many areas of the world.

Unfortunately, the adoption of these practices has met with serious difficulties. Aside from the general problems of extension work in areas of small farmers and low literacy rates some special difficulties are encountered.

Traditional farm equipment available in Pakistan simply is not adapted to these methods and the labor required for furrowing and ridge planting by hand is excessive. Tractor equipment used in other areas is not available and is not adapted to the size and shape of fields found in Pakistan. While various types of equipment have been tried they were not adopted on any significant scale either because of lack of adaptation or an inadequate extension effort. The farmer is not interested in purchasing equipment for a system he does not understand and he cannot understand this system without an opportunity to observe it in some detail. The technology must be adapted to local conditions, thoroughly tested and demonstrations carried out by trained and skilled workers who will work in partnership with the farmers.

Many demonstrations are carried out locally but they are almost universally designed to show how much better the recommended or "government" practice is than the farmers' method. This puts the farmer on the defensive and develops an adversary relationship. Even if the results are good he will likely belittle the practice to his peers because it has shown him to be a poor farmer and put him in a bad light. He would be much more likely to recommend the practice to his peers if it were conducted in such a manner that he would gain status if it were successful. The demonstration should be his, not the extension worker's.

As we progress through the season we are faced with excess water in much of July and August. While public tubewells are often turned off during this period, most canals remain in operation. Surface drainage is lacking, the low lying fields are flooded and crops ruined. In addition to rebuilding watercourses and leveling fields it appears we should design for surface drainage. Where topography permits this may be appropriate, but the topography is extremely flat and in most cases there is no place to discharge the water from a drain.

One proposal is to design watercourses below the ground surface so they can serve as drains. If a drain is available the watercourse can then discharge directly into the drain. If no appropriate discharge is available it could remove water from the high fields and discharge it onto the lowest lying fields. The higher fields can then be used for crops sensitive to flooding while the lower fields could be utilized for non-sensitive crops. The "floating" varieties of rice seem to be particularly well adapted for these low lying areas, and should be fully tested in this regard. One could well imagine that an individual farmer might be interested in a system that would manage his excess surface water in this fashion. It remains to be seen, however, whether farmers could be convinced to accept a system designed to remove water from one person's fields and lead it to those of another farmer who would then be required to grow crops that would withstand flooding. Here again we are faced with the problem of small holdings, and solutions appropriate on a wide scale are inappropriate for the individual farmer. Another problem with this approach is that watercourses cannot always be designed so that they lie below the ground surface and thus cannot always be constructed so that they can also serve as drains. The primary function of the watercourse is to convey water to the fields in an efficient manner. Whether or not this conveyance can be efficiently achieved with a watercourse below the land surface depends on the topography of the particular watercourse command area. Recognizing these limitations, the combination drain-watercourse may have potential and the concept should be thoroughly examined and tested.

As we progress through the season we find another water short period occurring in September after the monsoon rains. Actually this period is usually not critical as at this stage the relatively mature crops can use stored soil moisture fairly well. Our graph in Figure 2 shows only the kharif season crop demands and thus indicates an excess in October. This in fact is not the case, as during late October the farmer is starting to prepare his lands for the next crop, particularly wheat which is sown in November. Thus another water short period develops in late October and November when he must provide pre-sowing irrigation for his wheat lands and for his winter fodders.

Thus we see that the matching of water management practices and cropping systems is a complex and difficult task. Traditional systems have developed a balance which should not be taken lightly or discarded without careful study. On the other hand, production is low and water is being inefficiently used so we must not discard any innovation as impractical without thorough examination.

While the problem of water for pre-irrigation appears to be of major importance in determining cropping patterns in Pakistan, another important question is the optimum distribution of water when available land exceeds the available water supply. Is it better for the farmer to reduce crop area until the full water requirement of the crop can be met, or to use less than optimum water and accept some yield decrease in order to increase planted area? In general the marginal product per unit of water input decreases as we approach the full optimum water requirement of the plant. On this basis we would suspect that increased acreage grown under moderate stress should be preferred. However, this principle in isolation is not sufficient as a basis for a decision because it does not take into account the total mix of costs involved. Johnson (1977c) investigated this question using linear programming techniques. Using various literature sources, relative yields from different irrigation schedules were estimated for a number of common crops. The inputs are total acreage, a variety of irrigation schedules resulting in different stress levels and their associated yields, production costs of each crop under the various stress levels, price received for each crop and available water supply. The program then optimizes the acreage of each crop and stress level to achieve a maximum income over the watercourse command area. Certain constraints are included such as requiring sufficient forage production to meet the needs of farm animals and maintenance of a constant citrus acreage which was not stressed due to the high value and long term nature of that crop. The results show plainly that an increase in area of moderate to severely stressed crops generally results in higher total income than does reduced acreages of crop that receive sufficient water for maximum production. The most severe stresses simulated in these cases were generally those resulting in 50 to 60% of optimum yields. Increased water supplies were optimally used by increasing acreage of stressed crops until all available land was in use. Only then were further increases in water supply optimally utilized by growing non-stressed crops.

One of the most useful outputs of this type of research is the shadow values[5] of supplemental water available at various time periods and with different amounts of supplemental water. In order to determine the economic feasibility of watercourse improvement programs and to select the most appropriate method for improvements from among several alternatives of different cost, knowledge of the value of each increment of water saved is an essential factor.

Shadow values are shown in Table 1. The zero supplemental water column refers to the common system in which 1 cusec is allotted per 333 acres assuming a 50% overall system efficiency. This will result in about 1.1 inches (2.8 cm) per month delivered to the root zone.

Note that the first increment of supplemental water has a high value in eight months of the year. The average value of an increment of supplemental water is Rs. 248 (10 rupees equal approximately 1 U.S. dollar). The highest value of supplemental water is Rs. 532/acre ft. (1 acre ft. = $1233m^3$) in December. If 1.2 acre inches (3.05cm) per month are available, the average value of an additional increment drops to Rs. 122, although it has a positive value 9 months of the year and is worth Rs. 406/acre ft. in November. If 2.4 inches (6.1 cm) per month is available an additional increment has a positive value only 7 months of the year and the average value is only Rs. 40/acre ft.

This implies that on watercourses where water is short, water saved through watercourse improvement programs or improved use on the farm will have a high value. If the watercourse has a supply of 1 cusec per 333 acres and a 50% overall efficiency it will deliver an average of 1/2 cusec/ per 333 acres. By improving the watercourse to a 75% efficiency we can save about 720 extra acre ft. per year. At this supply level the extra water is worth in excess of Rs. 200/acre ft. or Rs. 140,000. This value for only one year's water saving is about 2 to 3 times the cost of compacted earth reconstruction with brick and concrete.

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[5] Shadow value as used here is defined as the unit worth of an additional increment of water.

TABLE 1. Shadow values of supplemental water at the root zone (Johnson, 1977c)

	Shadow Value (Rs/acre ft.[1])				
Supplemental Water[2]	0 in.	0.6 in.	1.2 in.	1.8 in.	2.4 in.
January	0	36	0	0	0
February	404	456	60	60	0
March	404	138	60	60	0
April	404	60	60	60	0
May	204	118	133	182	231
June	416	348	302	193	36
July	0	0	36	36	36
August	0	0	0	0	0
September	0	37	34	36	36
October	212	201	180	164	36
November	404	538	406	404	60
December	532	490	188	60	48
Mean	248	202	122	105	40

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[1] 1 acre ft. = 1233m^3

[2] acre in/acre per month

While this analysis is still in progress and the values must be considered as preliminary, this type of analysis confirms our conclusion above that there are critical water short periods associated with our cropping systems, and that water saved through improved water management has a very high value during those periods.

SUMMARY

Size of operational units and field size significantly affect the amount of watercourse channels required to deliver water to the field. In Pakistan total delivery channels generally exceed 200 ft/acre (150 meters/hectare). Due to the flat topography and poor condition this extensive distribution system typically operates at between 50 and 60% efficiency. If field size could be increased to 2.8 acres (1.3 hectares) at least half of this system could be eliminated.

Improved water management will require better watercourse maintenance and more effective organization to achieve this at the village or watercourse level. Research and extension programs designed to determine the most effective organization and to promote awareness to the need for better organization and maintenance should be a high priority item.

Even though cropping systems have evolved and adapted over a long time we still find that cropping intensities and production are limited by water availability at critical periods. Water saved through good management is extremely valuable at these times.

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8. Johnson, S. H., C. M. Hussain, Z. S. Khan and C. B. Ali. *The Economics of Precision Land Leveling in Pakistan*. *Mona Reclamation Experimental Project Report (WAPDA)*, Bhalwal 1977b, in press.

9. Trout, Tom. "Operational Conveyance Losses on Two Punjab Watercourse Systems". Paper to be presented at the ESSO Seminar on Water Management for Agriculture, November 4-10, 1977. Lahore.

10. Trout, T., S. A. Bowers, M. Wahla, H. U. Khan, M. Yasin and M. Iqbal. *Operational Conveyance Losses on Tubewell 81-R Watercourse*. Colorado State University Water Management Field Report No. 7. Fort Collins, 1977.

APPENDIX 25

PROPOSED APPLIED RESEARCH FOR THE ON-FARM WATER MANAGEMENT PROJECT IN PUNJAB PROVINCE

by
Colorado State University Field Party

In the establishment of the On-Farm Water Management Project for Punjab Province, as described in the recent PC-I, provision was made for research and training in areas related to water management. Such research and training will be conducted at two training centers: one to be established with the Agricultural University at Faisalabad and the other at the training demonstration farm near Lahore.

The training center near Lahore will be established on a yet to be selected farm of 50-70 acres. This farm will have, in addition to training personnel and trainees, an established labor force and equipment to satisfy the needs of both applied research and training. The applied research and training at Faisalabad will be in cooperation with farmers from various nearby villages and watercourses, such as research at Shadab has been conducted in the past.

The ultimate purpose of the applied research component is to develop and introduce on a large scale the most appropriate water management techniques for the province. Included would be problem identification, development, and implementation stages of research. While previous research efforts primarily concerned watercourse improvement the forthcoming program will in addition include agronomic, soils, irrigation, and land leveling and other subjects relating to water management. As both training centers will conduct both phases of the proposed research, the Lahore center will be heavily oriented towards precision land leveling, while the proposed Faisalabad work will emphasize all aspects of the program in an integrated format.

Applied research can also serve as a good demonstration, and in this respect all research will be organized to gain maximum demonstration benefit. In general the research will be classified under the eight general categories from the PC-I. The following is a list of research proposals from numerous individuals with practical and research experience in the Punjab. This list is tentative only and future proposals will also be considered.

I. ALTERNATE TECHNIQUES FOR WATERCOURSE IMPROVEMENT

Recent disclosures on the magnitude of water loss from watercourses identify this as a serious problem. Clyma estimates that for a 750 acre tubewell supplemented watercourse delivery over an average distance of 6000 ft. is only 36% - 40% for initial flow rates averaging 3 - 5 cusecs. Such excessive loss not only deprives the farmer of water but actually damages crops and land adjacent to the main channels. Proposed loss reduction research is as follows:

A. Research on Low Cost Watercourse Linings and Channel Improvement

1. Pucca Lining: Some of the following materials need to be evaluated for their loss reduction potential and their benefit-cost ratio, as soil cement blocks with various cement ratios, both plastered and unplastered, and polyethylene buried liners for channel bottoms and banks. This would be a continuous protecting film for the entire channel and laid down in the cross-sectional shape of a "U" and covered with soil for protection. Various film thicknesses should be tested. Where bottoms are considered adequately sealed polyethylene liners should be inserted in the banks to a 2-3 ft. depth. Where animals can be excluded from the channel cement plaster varying from 1/4 to 3/4 inch should be applied to a compacted channel. Reenforcement of plaster should also be tested. Linings of cement plastered katcha brick should also be considered.

2. Katcha Linings and Improvement: Present available data indicates that katcha channel improvement results in the greatest benefit-cost ratios. While simple maintenance should also be considered in such katcha improvement some suggested liners and sealers to be tested and cost effectiveness to be determined are as follows:

a. Bank and channel compaction at various controlled moisture contents,

b. Chemical seals, sections ponded and sodium carbonate, sodium silicate, etc., added at various concentration and allowed to infiltrate into the channel,

c. Suspensions of clay or fine soils are added in various amounts to flowing or stagnate water to seal pores. Potentially most effective for sandy soils when natural sediment loads are negligible,

d. Katcha brick linings both plastered and unplastered with katcha plaster (mixtures of soil, straw and dung). Soil brick with and without water repellent additives should be considered.

e. Liners from field-made soil blocks should be considered as a low cost alternative. Such blocks are made from a thoroughly puddled field (using bullocks and plows). When drying surface is scraped causing cracking into rectangular blocks which can be dried in the field and set in the channel.

3. Other Techniques for Watercourse Improvement: Aside from linings, numerous other techniques are possible to effect improvement. Herein improvement means any techniques which reduced water loss.

a. Compaction of banks during construction with tools such as tractors where wheels are adjusted to bank width. Another possibility includes the use of a sheepsfoot roller using a single animal. (Previous experience has shown that the customary two bullocks cannot keep compactors on the bank.) Another possibility is compaction by walking large animals such as water buffalo on freshly prepared banks. These various methods should be compared with handtamping and no compaction.

b. Loss reduction through continuous flow: Observations from a limited number of SCARP tubewells imply that channels with continuous to near continuous flow have lower loss rates. Presumably this is related to a constant saturation which retards development of plant, insect, and rodent populations. Such populations result in porous channel banks and hence increase water losses. Further verification of this continuous flow-seepage relationship is warranted. If factual and if discharge is sufficient to irrigate average bunded units in a short period of time with divided discharges, consideration should be given to dividing the flow, where possible, among the branches so that near continuous flow is possible. The result would be that channels would have less opportunity to dry and flow rates within each channel would be smaller thus insuring a smaller percent loss.

c. Reservoir storage or draining of unused water: With a fixed warabundi system farmers have little freedom in scheduling their turns. Frequently water may not be needed or desired at a particular time. If each watercourse had a reservoir at the head farmers could temporarily store water against future need or draining if the water is not storable. Preferably, reservoirs should be independently connected to the watercourse branches or branch drains so that withdrawals could be made outside of the warabundi turn or excess water dumped to an integrated drainage system.

d. Relation on height of water level in respect to surrounding land to water loss: Preliminary observations indicate that water loss is a function of the water surface height above the surrounding land. Certainly from the standpoint of the greater potential energies, higher water levels tend towards greater loss. Depending on the topography and the resulting extent (width) of the watercourse bank a feasibility study should be made on maintaining water levels close to ground levels, retaining sufficient head to serve surrounding lands. (This would probably be most applicable where the gradient is steep and the soil type is resistant to high water velocities.)

II. APPROPRIATE TECHNIQUES FOR THE MAINTENANCE OF WATERCOURSES

Simple cleaning is the usual watercourse maintenance procedures. The frequency of cleaning obviously differs among the various watercourses; there is no criteria or recommended method. Proposed research on maintenance is as follows:

1. Frequency of Cleaning: Do loss rates increase following sediment removal? If so, does too frequent cleaning maintain loss rates at a high level? While it is known that too infrequent cleaning causes elevated water levels and losses by overtopping and seepage through the upper porous bank, the optimum cleaning frèquency to minimize seepage is not known. Similarly, it should be determined how the optimum cleaning frequency varies with the season.

2. Sediment Traps: To reduce cleaning frequency sediment traps have been installed at the head of various watercourses. Where head considerations allow, sediment traps could be placed within the watercourse to provide a source of soil for checking. These traps would be placed at strategic locations near soil barrow points. The effectiveness of such placement in reducing soil borrowing for checking should be tested.

3. Development of Mechanical and Chemical Procedures for Weed Cleaning: Growth of seeds in the watercourse is one of the main factors contributing to an excessive loss. Through its restriction of flow water levels are increased inducing overtopping and seepage through the upper bank portions. Presently weeds are removed with a kussi which requires considerable labor. Consideration should be given to use of alternative removal methods such as burning with torch when channels are dry, development of a simple drag cutting tool which when pulled in the channel removes the weeds. Similarly the use of chemicals to control channel and bank grasses and aquatic weeds should be tested.

4. Influence of Cleaning Frequency and Procedure on Channel Cross Section. Channel cross sections, even in the absence of animals, tend to evolve from an original trapezoidal to elliptical, semicircular, or worse. Of concern is whether or not the frequency of cleaning influences the rate of cross section degradation. Similarly, the influence of the kussi on cross section degradation, because of its angular placed blade, should be determined.

5. Evaluation of Seepage Losses from Various Types of Cross Sections. For a given flow rate the wetted perimeter varies with the type of cross section design. Since seepage is a function of the wetted area it seems logical that cross section design may influence loss. In addition, the cross section designed may influence the wetted area adequately sealed by sedimentation and thus influence seepage reduction.

6. Methods of Inducing Channel Cleaning When Required: Generally channels are cleaned too infrequently; methods of inducing cleaning at the right time should be tested to determine the most successful procedure. One such scheme would be to readjust the warabundi based on current loss determination. When losses reach some predetermined level, the warabundi could be changed so that all subscribers share equally in the loss. One way would be to guarantee each farmer a certain nakka flow x time per acre throughout the watercourse and warabundi. Thus farmers at the head should have a greater inducement to share in watercourse maintenance and improvement.

Other methods previously suggested include setting check structures slightly below bank level so that water discharges down channel. Such discharge should clearly signal the need for cleaning. In such cases, the tops of check structures should be constructed so that further checking of mud, soil, debris, etc., is possible.

III. FORMULATION, TESTING AND INTRODUCTION OF OPERATIONAL RULES AND REGULATIONS FOR PROPER MAINTENANCE OF WATERCOURSES PROCEDURES FOR DETERMINING THE NEED, FREQUENCY, ENERGY REQUIREMENTS AND COSTS OF TOUCHUP LAND LEVELING ON FARMERS' FIELDS. Alternative organizational structures need to be tested with respect to the homogeneity vs. stratification in the village social structure, the degree of water adequacy (mogha plus tubewell supply per unit of land cultivated) and to the types of physical problems encountered on the watercourses, levelness, land too high to be irrigated, occurrence of salinity, depth to water table, etc.

IV. DETERMINATION OF EFFICIENT WATER USE FOR DIFFERENT CROPS IN DIFFERENT SOIL AND CLIMATIC CONDITIONS

A. Water Requirement Determinations for the Major Crops of Pakistan

Allocation of water, design of irrigation systems, maximum crop production, etc., require a factual knowledge or the total crop water requirement and its seasonal distribution. Since such requirements vary with the soils and climate of Pakistan these determinations should be conducted throughout the country. While under PL-480 sponsorship limited consumptive use determinations are underway, additional information is required particularly on crops such as sugarcane and citrus which receive extra water allowance on the watercourses. Such information, mostly obtained from areas of similar climatic factors and growing seasons, would allow adjusted extra water allowance according to the changing requirements with age of garden and the requirement with time of season (seasonal distribution of required water).

B. Determination of Fertilizer, Water Yield Relationship

The relationship between yield, water and fertilizer is not linear. Frequently less than optimum moisture or fertilizer amounts or both result in only small yield reductions. Where water is short one may stress a crop and accept a small yield reduction in order that more acreage may be brought into production or more water given to other crops. Research needs to be initiated on developing these yield, fertilizer, water response curves for major Pakistani crops on farmers' fields, not on experiment stations, in order that intelligent decisions can be made on stress and acceptable yield reduction in order to use one's water more profitably.

V. TO DEVELOP AND TEST TECHNIQUES OF IMPROVED CROP PRODUCTION UNDER DIFFERENT WATER MANAGEMENT PRACTICES

A. Influence of Precision Land Leveling on Application Efficiencies on Nitrate Leaching

Previous research indicates that a uniform irrigation and optimum application efficiencies are not feasible with unleveled fields. High spots receive too little and frequently no water while low areas receive too much. The result is potty stands, areas of salt accumulation, differential maturation, etc. However, little is known concerning nitrate leaching. The excessive water application to certain areas could result in excessive nitrate leaching and thus uneven fertilizer distribution. Further assessment is required of the influence of leveling on crop stand, yields, application efficiencies and nitrate leaching; although assessment of benefit-cost ratio attributable to precision land leveling is needed, especially with respect to duration of benefits, frequency of touchup leveling, etc.

B. Emergence Improvement

With silt loam soils, rains and basin irrigation frequently form crusts which retard or prevent emergence. This effect is particularly severe with dicotyleden crops such as cotton, soybeans, field beans, etc. Below are selected research topics for increasing seedling emergence.

1. Varietal selection. Varietal differences may exist in their ability to emerge.

2. Multiple seeds in each hill with appropriate adjustment in plant spacing. Emergence pressure may be increased which ruptures crusts more easily.

3. Planting of presoaked seed to hasten emergence prior to drying and strengthening of crust.

4. Temporary use of mulches (rice hulls, straw, etc.) to retard crust drying rate.

5. Planting weak and strong emerging crops in hills as, for example, cotton (weak) and mung bean (strong).

6. Planting weak emergence seed in hills filled with mulch such as burned rice hulls.

7. Use of certified seed of high germination rate.

8. Bed planting and furrow irrigation where beds are wet, under tension thus minimizing crust formation.

C. Influence of Precision Planting on Crop Stands

A frequent cause of poor crop stands is improper planting depth. Seed planted too close to the surface may find temperatures too hot and too little water, when planted too deep emergence may prove impossible. Since precision planting is more feasible on precisely leveled fields a comparison should be made of conventional planting versus precision planting on precision leveled and unleveled fields.

D. Influence of Bed and Ridge Shape on Stand Establishment on Highly Saline Soils

For crops sensitive to high salt concentrations germination is difficult on highly saline soils. This is a common occurrence in Pakistan. Research elsewhere indicates that planting position on beds and ridges of particular shapes may influence germination. Particular shapes permit salts carried in the wetting front to accumulate at a site above the seed and thus minimize salt damage to germinating seeds and seedling. Such ridge and bed shaping should be tested under Pakistan field conditions.

E. Investigation of Yield, Water and Fertility Relationships with Ratooned Crops

Due to its large number of draft and dairy animals Pakistan has greater demand for forages. The sorghum hybrid Sudan Sarghums, etc., all have ratooning capabilities; that is up to three harvests can be taken from one crop. After the first harvest the following harvest can be cut at a shorter interval. Since crop establishment is required but once, the net result should be greater yields for smaller labor, fertilizer, water and land inputs. Research needs to be initiated on water fertilizer requirements for the duration of the ratooned crop.

F. Influence of Double Cropping on Salinity Control

"Underirrigation" contributes to increased salinity. Because of limited water supplies farmers apply less than the optimum amount required for crop production and leaching. Frequently, because of timing problems in harvest and seedbed preparation, many farmers crop one portion of their land in the kharif season and another portion during the rabi season; thus only one crop is grown on an acre of land per year. Where water supplies are inadequate for cropping all of a farmer's lands, research should be initiated on doubling cropping one portion and planting the remaining part in tree crops. Double cropping should thus help reduce salinity buildup. Crop and variety selection and research on planting date may be required in order to adjust the time of harvest and seedbed preparation.

VI. IRRIGATION METHODS AND WATER USE EFFICIENCY

A. Increasing Rice Yields through Improved Irrigation Practices

Pakistan, despite its excellent climate and soils, has among the world's lowest rice yields. Present high yielding varieties require more precise water control, particularly for weed control. Modern rice irrigation systems, with provision for water supply, water level control and drainage to each paddy are required. Comparison should be made of yields with modern rice irrigation systems versus yields with conventional irrigation.

B. Irrigation of Orchard Crops

The conventional method for orchard irrigation is through flooding. On mature orchards, where intercropping is of lesser importance, comparison should be made on other systems such as irrigating interlinked small basins around each tree, and for intercropped orchards. The intercropped area could be irrigated as a separate border according to the needs of the crop.

C. Influence of Irrigation Systems on Cotton and Maize

For many of the reasons sited above cotton and maize stands and yields are inadequate on many conventional planted and irrigated fields. Comparison should be made between yields on fields with furrow irrigation, border irrigation on leveled and unleveled fields for borders of varying width.

VII. MANAGEMENT OF SALINE OR SODIC SOILS AND IRRIGATION WATERS OF POOR QUALITY

Problem soils and waters as actually encountered on farmers' lands should be managed according to current soil and water quality standards in vogue and against standards made more conservative to account for the unique soil organic matter and soil structural properties encountered in the Punjab.

VIII. FABRICATION DEVELOPMENT AND TESTING OF EQUIPMENT, STRUCTURES, ETC.

A. Nakka Development

Additional design work is required for precast nakka and check structures. Present structures tend to chip at "seal" points thus allowing leakage. Research needs to continue on development durable leak-free seals. Similarly, present nakka lids are difficult to remove when submerged. Investigation into angle of repose, and mechanical aids for removing and setting lids is warranted. Investigation into other types of nakkas and check structures should continue, especially low cost extruded rigid plastics.

Low cost locally fabricated lift purps are needed in many areas to raise water less than 3 feet to replace traditional jhallars which cost the additional 2 acres of fodder that an extra pair of bullocks require plus the man hours to drive them. Several designs for low-lift pumps have been identified and machine shops which can duplicate these need to be engaged to produce several prototypes for field testing.

IX. DEVELOPMENT OF OPTIMAL CROPPING ROTATIONS UNDER PUNJAB FIELD CONDITIONS

Given the soils and climate of the Punjab with proper sequencing and intercropping the farmers, especially where supplemental irrigation water is available, should be able to support a cropping intensity greater than 250%. Research is needed to develop cropping rotations that optimally utilize the resources and maximize the return from the cropped acreage.

APPENDIX 26

FIRST TRAINING COURSE FOR WATER MANAGEMENT EXTENSION OFFICERS AT UNIVERSITY OF AGRICULTURE, FAISALABAD

by
Qurban Ali Awan, Norman S. Illsley, W. Doral Kemper,
Dwayne G. Westfall and Gaylord V. Skogerboe[1]

INTRODUCTION

Under the On-Farm Water Management Pilot Project, Colorado State University has the responsibility to serve as advisors for the training of Water Management Extension Officers (WMEO). The Pilot Project is called the On-Farm Water Management Development Project in each of the four provinces. Under the provincial programs, each Field Team consists of a team leader called the Water Management Specialist, two Watercourse Development Officers (WDO), five Land Development Officers (LDO), and one Water Management Extension Officer (Agricultural Officer.)

The University of Agriculture, Lyallpur (UAL), which became the University of Agriculture, Faisalabad (UAF) in September 1977, was assigned the responsibility for training the WMEO's. Mr. Qurban Ali Awan of the Department of Irrigation and Drainage was named to be course coordinator to be assisted by seven other trainers representing six academic departments in the University. Dr. Alan C. Early and Dr. Max K. Lowdermilk, in cooperation with UAF faculty, developed the administrate structure shown in Figure 1 for this course, as well as the course content.

Upon the departure of Dr. Early in May 1977, Dr. Kemper took responsibility for CSU in assisting the trainers in getting this first course underway. Mr. Norman S. Illsley went to Pakistan on TDY from April-September 1977 to assist in this training course. Because of political unrest in Pakistan, the University was closed and the initiation of the course was delayed until June 10, 1977. Prof. Skogerboe was stationed in Faisalabad during September and October to serve as advisor until completion of the course. Graduation ceremonies were held October 20, 1977. Sixteen persons graduated from the first training course. They represented all four provinces in Pakistan, with two from the North West Frontier, two from Baluchistan, four from the Sind, and eight from the Punjab.

1/Course Coordinator and Asst. Prof. of Irrigation and Drainage, Univ. of Agriculture, Faisalabad; Research Associate and Professor, Dept. of Agricultural and Chemical Engineering; Associate Professor, Dept. of Agronomy, and Professor, Dept. of Agricultural and Chemical Engineering, Colorado State University, respectively.

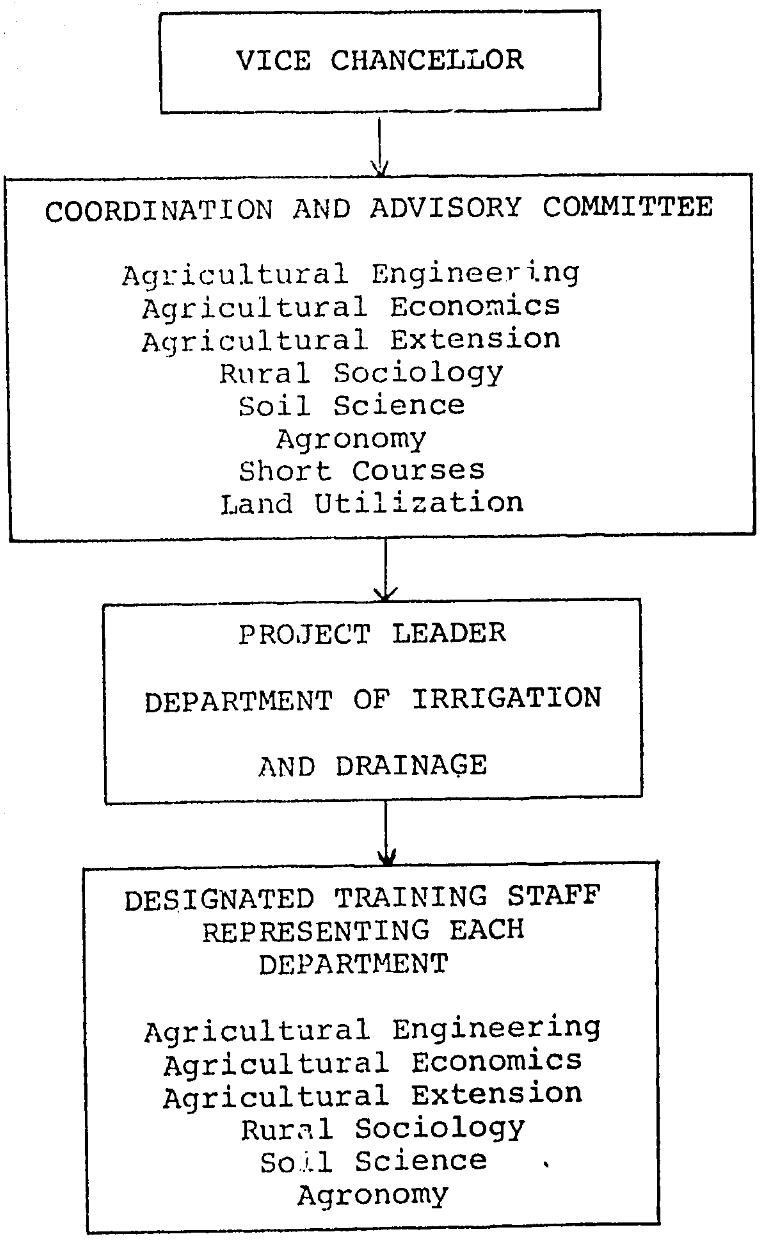

Figure 1. Communication lines for training Water Management Extension Officers (Agriculture Officers).

During the time period November 1977 through March 1978 considerable effort was made on campus to revise the course curriculum and develop appropriate training materials. The faculty trainers at UAF had developed many ideas for improving the course. Since Dr. Dwayne G. Westfall was to have primary advisory responsibility for the second training course, which was to begin in March 1978 (actually this second course got underway in April 1978), he spent most of his time prior to departure for Pakistan in late February in developing a revised curriculum and reviewing training materials.

TRAINERS FOR FIRST TRAINING COURSE

University of Agriculture, Faisalabad
Dr. Amir Mohammad Khan, Vice Chancellor

Faculty	Department	Trainer
Agricultural Engineering and Technology	Irrigation and Drainage	Qurban Ali Awan Arshad Ali M. Rafique
	Farm Power and Machinery	Jehangir K. Sial
Agriculture	Agronomy	Dr. Fateh Muhammad
	Soil Science	
Agricultural Economics and Rural Sociology	Farm Management	M. Ahktar Bajwa
	Rural Sociology	Ashfaque Mirza
Agricultural Education and Extension	Agricultural Extension	M. Akram Zia

AGRICULTURAL OFFICER (ON-FARM WATER MANAGEMENT DEVELOPMENT PROJECT)

Introduction

This position is to provide followup assistance to the farmers through demonstrations and maintenance techniques where precision land leveling and watercourse improvement have already been completed. This position is responsible to coordinate the various disciplines of On-Farm Water Management during the operation phase to secure the maximum impact of the program. Special training in precision land leveling, operation and maintenance and water management extension is required before field assignment.

Duties

1. Responsible for operation, maintenance and cleaning of the improved watercourses.
2. Assist Water Management Specialist in organizing registration and effective working of water users associations to achieve effective followup and maintenance program.
3. Provides direct assistance to the training and research staff in collection of data, and in conducting field trials.
4. Conducts demonstrations for improved irrigation and yield potentials on precisely leveled fields in cooperation with Land Development Officer.
5. To assist the Field Team in finding out maximum areas for precision land leveling in watercourse command areas.
6. To assist the Watercourse Development Officer during construction of the watercourse for better quality.
6. Perform other duties as assigned.

Scope and Effect

Precision land leveling and watercourse improvement are the first steps to raise irrigation efficiencies and reduce water losses. The full benefit of improved varieties, fertilizer, pesticides and improved cultural practices cannot be realized unless irrigation water is applied efficiently in accordance with the moisture holding capacity of the soils and the needs of the crops.

In a modern agriculture proper design of fields for optimum field application efficiencies takes into consideration the soil type and its intake rate, climate, amount and quality of water supply, crops to be grown, methods of cropping, drainage requirements, and available farm machinery. The farmers must, therefore, have guidance from training technicians to level their lands and apply water efficiently.

It is estimated that each trained graduate and helper can help prepare one watercourse plan per year and assist 20-30 farmers level 200-300 acres and guide these same farmers in water application. The team would also supervise and assist with construction of watercourse improvements on the watercourse(s) planned.

Supervision and Guidance

Incumbent is under the supervision of the Field Team Leader.

CURRICULUM FOR FIRST TRAINING COURSE

Economic Skills

Introduction: Definition, scope and goals of farm planning type and sources of data.

Farm Business Survey: Type of data required for planning, sources of data, selection of area and period, interview schedules, interviewing farmers.

Farm Business Analysis: Compution of farm cost, working out unit cost of production of various farm enterprizes, causes of cost variation on similar farms.

Guiding Principles: Law of comparative advantage, enterprize and resource combination.

Developing Farm Plans: Analysis of existing agricultural conditions at farm level, locating merits and demerits, application of partial budgeting technique, planning land labor and water use, developing optimum cropping patterns, economic comparison of old and new farm plans, need and procedure to revise plans over time.

Practicals. Developing a contact with the farmer. Explaining farm planning objectives and motivating farmers to participate.

Preliminary survey regarding agricultural conditions at the farm level.

Collection of basic data for application of a partial budgeting technique. Pretesting of the farm survey schedule.

Collection of detailed information on survey schedule for the preparation of improved farm plans.

W. Y. Yang. 1968. Method of Farm Management Investigations: Revised edition. F.A.O. Rome.

Castle and Becher. 1962. Farm Business Arrangement: Million Company, New York, London.

Bajwa Muhammad Akhtar. 1977. Farm Planning in the Short Run. A Positive Approach. Unpublished. University of Agriculture, Faisalabad.

Agronomic Skills

Definition of Agriculture and Agronomy, functions and duties of an Agronomist, crop rotations. reasons for crop rotations, essentials of a good rotation, planning a rotation, rotations followed at present in canal and well irrigated areas, the water requirements of plants, how much water is needed, irrigation needs of special crops, irrigation methods, choice of the best methods, improved varieties of various crops along with recommended agronomic practices, cropping pattern and intensities.

Consumptive use: How the rotation and cropping pattern will change depending upon different factors, water requirements of various crops, efficient use of water in relation with fertilization (practical examples from the research results to be given), influences of levels of fertility and soil moisture and nutrient absorption, effects of plant nutrients on water requirements.

Practicals. To learn the position of the farmers of the area in regard with the agronomic recommendation viz. variety, methods, inputs, plant protection measures, etc. What improvements we can suggest to help increase the production (suggestions and improvements to the farmer). How the farmer can go ahead with the mix and intercropping, depending upon the availability of water, etc. The above practicals would be carried out in case of major crops of the area.

Soil Science

Soil sampling, objectives of soil sampling, types of soil sampling tools, soil sampling for fertility evaluation, salinity/sodicity, and moisture determination.

Terminology frequently applied in soil science procedure of soil analysis and agencies analyzing soil samples, criteria for soil evaluation.

Saline, saline sodic, and sodic soils, management of saline/alkali soils, reclamation of saline sodic soils (biochemically and chemically), salt tolerant crops.

Plant food elements, importance, source and their deficiency symptoms, recommended doses of fertilizers.

Fertilizer application and efficient use of irrigation water, soils texture, textural classification of soils. Determination of texture of soil in the field by feel method.

Quality of irrigation water, criteria for quality of irrigation water, water sampling and agencies analyzing water samples.

Practicals. Soil sampling in the field for fertility evaluation and appraisal of salinity and sodicity. Determination of soil pH, and calcareousness in the field.

Analysis of soil samples in the lab, preparation of saturated soil paste, pH determination, analysis of soil saturation extract for T.S.S., EC and gypsum requirement, moisture percentage determination.

Determination of soil texture by feel method in the field, diagnosis of deficiency symptoms of plant nutrients in the field.

Water sampling and analysis of irrigation water for T.S.S., CO_3, HCO_3, $Ca^{++} + Mg^{++}$ and Na^+, writing report on quality of irrigation waters, use of soil testing kit in the field.

Field trips to witness the experiments and achievement of various agencies working on various aspects of soils.

Extension Skills

Identification of actual water management problems, creation of awareness and interest in water management through mass media, mobilization of local resources for the solution of water management problems, principles of arranging demonstrations and tours, evaluation and reporting.

Practicals. Use of audio visual aids for the demonstration of water management skills, arranging visits of community leaders to the areas where recommended water management practices have been adopted, preparation of workable water management plans.

Kelsey, L. D. and C. C. Hearne. 1963. Cooperative Extension Work. Comstock Publishing Associates, Ithaca, New York.

Sander, H. D. et al. 1966. The Cooperative Extension Service. Prentice Hall Inc., Englewood Cliffs, New York.

Sociological Skills

Structural attributes of village organization, social, economic and numerical significance of different caste, biradari and other solidary groups in the village.

The characteristics of caste endogamy and patrilineal and patrilocal family organization, extent and bases of factionalism, family dispute social and economic dominance of one social group over the other, factional tendencies as impediments in the way of developmental activities, ways to resolve these conflicts.

Characteristics of village leadership, caste dominance, age, education, honesty, land ownership, etc.

Legal authority viz. personal influence in mobilizing collective efforts.

The process of collective decision making with special reference to cleaning and maintenance of common watercourses.

An assessment of the felt need for more water. The significance of getting more water through improving the watercourse.

Any alternative solutions available and their evaluation. The procedure for getting people to agree to the improvement of the watercourse. Preparation of the plan of work and its implementation.

Assessment of the satisfaction with the total operation.

Interviewing vs. participant observation as techniques of gathering sociological data.

Interviewing helps in reporting on values, beliefs, motivations and future plans. Participant observation highlights the problems of actual implementation of a plan.

Practicals. Preparation of an intensive interviewing schedule and involvement as participant observer for studying village attributes and the patterns of collective decision making.

Studying the relevant leadership characteristics so as to influence decisions to clean watercourses. Organizing a watercourse committee. Participation of trainees in actual decisions on the part of farmers to improve their watercourses.

Lowdermilk, Max K., Wayne Clyma and Alan C. Early. Physical and Socio-Economic Dynamics of a Watercourse in Pakistan's Punjab: System Constraints and Farmers' Responses. Colorado State University, 1975. Water Management Technical Report No. 42.

Mirza, Ashfaq Hussain. Village Organizational Factors Affecting Water Management Decision Making in Pakistan. Colorado State University, March, 1975. Water Management Technical Report No. 44.

Irrigation and Drainage Techniques

Surveying techniques: taping and pacing, use of engineer's level, differential leveling, drawing profile of watercourse and surveying for watercourse design.

Elements of watercourse design: assumptions, field data required, general procedures, starting point, backward interaction, treatment of culverts, treatment of tokes and model problems with solutions.

Water measurement by Cutthroat flume: introduction, installation, reading, observation and maintenance.

Water measurement by other means: principles for head measurement, float method and weirs, etc.

Soil moisture measurement by sun drying method and touch and feel method to determine soil moisture determination (SMD) concepts and equations, computations, examples and explanations for farmers.

Delivery losses and efficiencies: concepts, equations, computations, examples and explanations for farmers.

Application losses and efficiencies: concepts, equations, computations, examples and explanations for farmers.

Identification of land leveling needs and potential costs: field measurements/observations, justifications, estimating costs and predicted benefits.

Improved methods of irrigation: border irrigation, factors affecting and recommended size of borders. Furrow irrigation, length, spacing and depth of furrow. Construction equipment.

Determining irrigation requirements: elements, equations used, use of charts, calculations and depth to be applied.

Determining irrigation capability: available supplies, how much to supply, adjustments with available time and model problems.

Irrigation and crop scheduling on seasonal basis: basic information, computations and time table of irrigation.

Determining leaching requirements: basic information, leaching requirements, expected benefits and alternate measures. Removal of excess water affects remedial measures and predicted benefits.

Maintenance of land and watercourse: maintenance of land leveling, maintenance of watercourse and cost evaluation.

The following practicals will be done:

- -Water measurement by: i. float method; ii. weirs; iii. Cutthroat flume.
- -Determination of conveyance and application efficiencies.
- -Measurement of distances.
- -Use of engineer's level.
- -Watercourse profile survey.
- -Topographic survey and preparation of topographic maps.
- -Field training in layout and construction of improved watercourse.

-Determining the potential effect of cleaning and maintenance of a watercourse on conveyance efficiency, and effect upon mogha discharge.
-Evaluation of irrigation practices to determine land leveling needs.
-Comparison of various methods of irrigation.
-Use of pan evaporation for scheduling irrigation.
-Determination of leaching requirements of saline soils.

Isreelson, O. W., V. E. Hansen. 1962. Irrigation Principles and Practices. John Wiley & Sons, New York City.

Iqbal Ali. 1975. Irrigation Engineering. Oxford University Press, London, U.K.

Reference and Training Manual by On-Farm Water Management, Punjab, 1976.

Colorado State University, Mona and University of Agriculture, Faisalabad, Research Publications.

TIME SCHEDULE FOR FIRST TRAINING COURSE

Date	0700-0800	0800-0900	0900-1000	1030-1130	1130-1230
10.6.77	EC	EX	AG	ID	-
11.6.77	Field trip,EC and AG trainers will accompany.				
13.6.77	Field trip,EX and ID trainers will accompany.				
14.6.77	EC	RS	ID	SS	ID
15.6.77	Field trip,RS and SS trainers will accompany				
16.6.77	Field trip, ID trainers will accompany.				
17.6.77	EX	ID	AG	ID	-
18.6.77	Field trip, EC and AG trainers will accompany.				
20.6.77	Field trip to Mona Reclamation Project.				
21.6.77	RS	SS	ID	FMP	ID
22.6.77	Field trip, RS and SS trainers will accompany.				
23.6.77	Field trip, ID trainers will accompany.				
24.6.77	EX	ID	RS	AG	
25.6.77	Field trip,EC and AG trainers will accompany.				
27.6.77	Field trip,EX and IG trainers will accompany.				
28.6.77	ID	RS	ID	SS	FMP
29.6.77	Field trip,RS and SS trainers will accompany.				
30.6.77	Field trip, ID trainers will accompany.				
2.7.77	SS	RS	ID	AG	
3.7.77	Field trip,RS and ID trainers will accompany.				

Date	0700-0800	0800-0900	0900-1000	1030-1130	1130-1230
4.7.77	Field trip,AG and SS trainers will accompany.				
5.7.77	EC	EX	ID	SS	ID
6.7.77	Field trip,EC and SS trainers will accompany.				
7.7.77	Field trip, EX and FMP trainers will accompany.				
9.7.77	Field trip, ID trainers will accompany.				
10.7.77	RS	EC	SS	ID	AG
11.7.77	Field trip,RS and SS trainers will accompany.				
12.7.77	Field trip,EC and AG trainers will accompany.				
13.7.77	Field trip to PARI Lyallpur.				
14.7.77	Field trip to Agri.Engg. Workshop and Private Agri. Engg. workshop.				
17.7.77	ID	EC	EX	ID	FMP
18.7.77	Field trip, EX and FMP trainers will accompany.				
19.7.77	Field trip, ID trainers will accompany.				
20.7.77	Field trip, EC and ID trainers will accompany.				
21.7.77	EX	ID	AG	FMP	ID
23.7.77	Field trip,EX and FMP trainers will accompany.				
24.7.77	Field trip,ID trainers will accompany.				
25.7.77	Field trip,AG and ID trainers will accompany.				
26.7.77	RS	EX	ID	ID	-
27.7.77	Field trip,RS and ID trainers will accompany.				
28.7.77	Field trip, EX and ID trainers will accompany.				
1.8.77 to 31.8.77	First field case study of water management.				
1.9.77 to 15.9.77	Writing of case study report for various skills.				
16.9.77 to 23.9.77	Test and report evaluation.				
24.9.77 to 15.10.77	Second case study on water management. Questionnaires: Economics Extension Sociology Agronomy				
16.10.77 to 22.10.77	Final evaluation of trainees and trainers.				
24.10.77	Distribution of certificate.				

SS-Soil Science, RS-Rural Sociology, EC-Economics, EX-Extension, ID-Irrigation and Drainage, AG-Agronomy.

Note: In field trip total group will be divided in two groups and the trainers accompanying will look after first group in the first half and the second group in the second half of the day. Field trip will mean the practical and preferably the application of principle discussed in the preceding lecture.

TRAINEES FOR FIRST TRAINING COURSE

Office	Home
Punjab Province	
1. Ch. Farzand Ali Akhtar, Agricultural Officer, Directorate of On Farm Water Management Development Project, 69-Abu Bakar Block, New Garden Town, Lahore	Ch. Farzand Ali Akhtar, S/O Ch. Hashmat Ali, Vill. Dinpur Khurd, P.O.& Tehsil, Shakargarh, Distt: Sialkot.
2. Mr. Muhammad Azam Virk, Agricultural Officer, On Farm Water Management Development Project, Samundri, Distt: Faisal Abad.	Mr. Muhammad Azam Virk, S/O Ch. Muhammad Alam, Vill. Dhool Khurd, P.O. Tehsil & Distt: Gujrat.
3. Mr. Muhammad Siddique Akhtar, Agricultural Officer, On Farm Water Management Development Project, Chicha-Watni, Distt: Sahiwal.	Mr. Muhammad Siddique Akhtar, S/O Rashid Ahmad C/O Itfaq Book Depote Kot: Samaba, Distt: Rahim-Yar Khan.
4. Ch. Mohd Sharif(M.Sc Hons Agri) Agricultural Officer, On Farm Water Management Development Project, 275-Tariq Abad, Khanewal, Distt: Multan.	Sh. Mohd Sharif(M.Sc Hons Agri) Chak No. 296/G.B. Putwarian-wala, Teh. Toba Tek Singh, Distt: Faisal Abad.
5. Syed Mohammad Naseem, Agricultural Officer, On Farm Water Management Development Project, Jaranwala, Distt: Faisal Abad.	Syed Mohammad Naseem, House No. P-412 Block No. 3 Arya Samaj Street, Gojra, Distt: Faisal Abad.
6. Mr. Shams-ud-Din Malik, Agricultural Officer, On Farm Water Management Development Project, Toba Tek Singh, Distt: Faisal Abad.	Mr. Shams-ud-Din Malik, Chak No. 201/J.B. P.O. Chak No. 200/J.B. Tehsil Chiniot, Distt: Jhang.
7. Mr. Ishfaq Ahmad, Agricultural Officer, On Farm Water Management Development Project, 851 D/Farid Town, Sahiwal.	Mr. Ashfaq Ahmad, C/O Modern Beauty Centre, 7-Anar Kali, Faisal Abad.
8. Mr. Munir Ahmad Khan, Agricultural Officer, On Farm Water Management Development Project, Chiniot, Distt: Jhang.	Mr. Munir Ahmad Khan, S/O Ali Muhammad Khan, House No. 819-P Street No.13 Afghan Abad No. 1, Faisal Abad.

Office	Home
Baluchistan Province	
1. Mr. Mazher-ul-Haq, Soil Fertility Section, Agricultural Research Institute, Quetta	Mr. Mazher-ul-Haq, S/O Manzoor-ul-Haq, Old Water Supply Shahra-e- Stadium, Quetta Cantt.
2. Mr. Ahmad Saeed Agricultural Assistant (Publicity) Agriculture Directorate, Quetta.	Mr. Ahmad Saeed, 4-24/12 Liaqat Road, Quetta.
Sind Province	
1. Mr. Muhammad Yousaf Shakil, Land Development Officer, Office of the Asstt: Water Management Specialist,O.F.W.M. Project HALA, Distt: Hyderabad.	Mr. Muhammad Yousif Shakil, Chak No. 3 P.O. Same, Teh:& Distt: Sanghar.
2. Mr. Abdullah, Land Development Officer, C/O Water Management Specialist, O.F.W.M. Project, Qazi Abad Road, Nawab Shah.	Mr. Abdullah, C/O Haji Abdul Majid, Medical Store Rehmani Nagar, Distt: Dadu.
3. Mr. Muhammad Rafiq Arain, Assistant Agronomist, Directorate of On Farm Water Management Project, 13-B, Block "C" Unit No. 2, Latifabad, Hyderabad.	Mr. Muhammad Rafique Arain, P.O. Gupna Via Kunri Pak, Distt: Tharparker.
4. Syed Ashiq Hussain Shah, Land Development Officer, C/O Asstt: Water Management Specialist O.F.W.M. Agricultural Engg: Workshop, Tando-Jam, Distt: Hyderabad.	Syed Ashiq Hussain Shah, Bukhari Manzil, Gharib-Abad, Mirpur Khas, Distt: Tharparker.
N.W.F. Province	
1. Mr. Bashir Ahmad, Agri: Extension Officer, On Farm Water Management Project, Peshawar Agri: Training Institute, Peshawar.	Mr. Bashir Ahmad, Village & P.O. Charshadha, Kandi Masud Khel Distt: Peshawar.
2. Mr. Inam-Ullah Khan, Agri: Extension Officer, On Farm Water Management Project, Training Institute, Peshawar.	Mr. Inam-Ullah Khan, Village & P.O. Amba Dher, Teh: Charsadha, Distt: Peshawar, Via. Shahqadar Fort.

LESSONS FROM FIRST TRAINING COURSE

The ideas herein are based on observations of the first training program. These observations have led to questions, some of which have led to suggestions for future programs.

The first training program got underway during a period of national political unrest. Because of this unrest many problems had to be dealt with that would not have occurred during normal times. However, these conditions did serve to point up problems that could occur even in normal times.

The questions and suggestions are not those of one person, but rather are ideas gleamed from discussing the program with several people, both at CSU and in Pakistan.

Length of Training

How long should a training program such as this run? This depends in part on what we are trying to teach, which will be discussed later. It has been suggested that the program be shortened to a six weeks course to be followed by a series of one week speciality programs spread out through the year. The rationale for this is that it is easier to present an intensive training program for a short time period and maintain a high level of activity. The longer the program, the more the tendency to run out of "steam" towards the end. The followup one week programs could serve to regenerate the intensity of activity even after the advisors are at their assigned posts.

There are several disadvantages to this arrangement. The trainees are not at the University long enough to follow through with some of the agricultural programs that are included in the training program. They cannot prepare ground, plant a test plot, and observe the results in a six-week period. With the frequency with which Pakistanis are shifted from post to post, it could be difficult to reassemble the group several times over the space of a year following the initial program. The discontinuity in the training could require considerable time being wasted in reviewing before new information is covered. There would also be time lost in the group members readjusting to each other. Finally, there would be additional travel expense each time the group assembled.

The 4½ month program does give adequate time to cover the basic information. There is no reason why the 4½ month program cannot be followed by semi-annual weekend or week-long workshops for the participants. This will be discussed more fully under "followup."

Administrative Structure

From time to time problems will arise that have not been anticipated and there must be an established authority for making immediate responsible decisions. Problems that did occur during the first program involved transportation, money for supplies, sickness, class schedule changes, having class notes typed, classrooms not being unlocked in the morning and availability of housing for the trainees. All of these problems were resolved, but perhaps not as smoothly as they should have been. It may be possible to assign each of the trainers a certain area of administrative responsibility over and above his academic responsibility. This would relieve the Director of some of his routine load and allow him to be more effective with the more serious problems and in dealing with other offices, such as the Vice Chancellor, USAID and the provincial On-Farm Water Management Development Projects. However, this should not relieve the Director from the responsibility of being available at all times or having some other responsible person available. The University will make demands on the trainers which will conflict with the training program. If the administration of the training program is more obviously structured, the persons making these demands will probably be more considerate with the training personnel. Hopefully, the trainers themselves will assume a greater degree of dedication and responsibility to the program.

Management

There is a need for better communication in the program. The roles of the various people, trainers, trainees, clerical staff, drivers and advisors must be clearly understood by all concerned. These roles can be modified as the needs of the program dictate, but they must be understood by everybody. This can best be done by regular staff meetings at which problems, accomplishments, suggestions and adjustments to the program are discussed. These meetings should improve the interaction of the trainers and let them each know what the other person is covering to make sure all things are covered without duplication.

An instructor may request a particular topic be covered in a different discipline as background for something the instructor plans to cover. This could exist between economics and sociology, or between soil and farm mechanization. There should be discussion among the trainers of what they are presenting to the trainees. Staff meetings should also be the place where various areas of responsibility are assigned to the trainers.

Upon occasion trainees should be invited to staff meetings, partly to hear their suggestions of how the program can be most effectively conducted and partly to assure them that the program is really conceived with their best interest in mind. This would also serve as a controlled structure through which they could air their grievances. A different trainee could be invited or assigned to every other staff meeting, maintaining some confidentiality to meetings, yet making trainee participation a regular activity. If any particular discipline appears to be lacking in quality of course content, these staff meetings should be the first avenue of correction.

Course Content

The Water Management Extension Officers (WMEO) must be skillful in working with farmers. This ability to work with farmers has been cited by several people. The two basic elements of this ability are communication and credibility. Communication principles can be taught by Extension trainers, but must be practiced in the field to develop skill. To establish credibility with farmers, the WMEO must have skills or knowledge that are immediately recognizable to the farmer as being of value to him. Ideally this should be immediately related to water management. Increasing water flow by cleaning a watercourse, or increasing stands of corn and cotton by using beds rather than flooding would be examples.

The WMEO should be skillful at working with groups of farmers as well as individuals. The larger the group he can handle the greater the potential effectiveness of his input. Sometimes a one-on-one activity can have a much wider impact than just the individual being helped. Locating the farmer on a watercourse whose irrigation system is very inefficient and helping him make a radical improvement will certainly be noticed by surrounding farmers.

To work on the macro basis, the WMEO must be able to gather and evaluate information from the entire area commanded by the watercourse. This will involve conducting local meetings of farmers, showing film or slide programs, giving talks, developing and administering questionnaires, as well as working with individual farmers.

Photographs that contain subject matter that the local people recognize generate far more interest than the same subject in a strange location. Therefore it may be of value for the WMEO to have some skill and a small camera to document his work and for producing his own promotional photographs. This should be covered in the Audio Visual portion of Extension.

The WMEO should be skillful at evaluating crop, soil and irrigation conditions as he is walking through farmers' fields. He should be able to visually tell good stands from bad, and to a degree, why the difference. He should be able to feel the texture and moisture content of soils. He should be able to estimate the quantity of water being applied and how uniformly the field is being irrigated. He should also have some ideas about what to do to correct obvious problems. The WMEO should have a good knowledge of the irrigation requirements of the more common crops. He should also know their growing seasons, and possible rotation patterns. This information should be taught in Agronomy and Soils.

The WMEO should be familiar with and capable of operating and adjusting the various machines that have been found suitable for agriculture in his area. These would be hand operated (kussi), animal drawn, and powered equipment. This area should be covered in Farm Machinery, while surveying should be covered in Irrigation and Drainage.

The WMEO should be able to make accurate estimates of labor, time, and costs of the various practices he might be recommending to the farmers. Insecticides and fertilizers would be covered in Agronomy, while structures and machinery would be covered in Irrigation or Agricultural Machinery. Sociology or Extension would cover the inputs for organizing community groups such as water users associations, or machinery cooperatives. After proving himself with some of the more immediate problems, the WMEO will probably have the opportunity to advise farmers on what crops, and how much, to plant. Much of this will be covered under farm management.

The WMEO must be thoroughly familiar with irrigation water control and use. He must be skillful at estimating and able to measure the amount of water being delivered to a field, determine the condition of the watercourse and whether it needs maintenance, determine the condition of the mogha and whether it is submerged, measure the infiltration rate of a field to estimate the required time for irrigation, and evaluate the degree of levelness of fields being irrigated. He should be familiar with the various methods of irrigation, flood, bed, furrow and corrugations, and under what conditions it is advisable to use each.

The WMEO will probably want to operate demonstration plots both to increase his own knowledge of crop response to various treatments, as well as to show local farmers the effects of some new treatment. He must be able to run these in a manner that will give valid, convincing results.

In order to accomplish this training more effectively than was done during the first program, the following ideas are suggested. To begin with, a pre-training exam should be given. This should be a serious, comprehensive written and/or oral examination with three purposes. It establishes the bench mark from which each trainee's future progress may be measured. It informs the trainers what the trainees already know, and what areas of information must be covered in order to give the trainee the block of knowledge it is felt they must have. Finally, it gives the trainee foreknowledge of what is expected to be covered in the course, thus setting his attention more precisely on the direction of the course. (It will also require that the trainers think through seriously their entire subject matter before the program begins.)

Daily five minute quizzes covering the previous class subject matter can also serve the functions of giving the trainer feedback of what concepts were not well covered, and also reinforce the main ideas of the course to the trainees. These could be given to the trainees as they enter the classroom and they can fill them out while settling down. It should take no more time than calling roll.

The structure of the lecturing could be improved upon. The classrooms had inadequate lighting and poor blackboards. The rooms could not be darkened enough to show slides or movies well. Several times the lectures in Extension were held outside in a less "classroomish" environment, and these meetings produced much more discussion participation by the trainees. If the classes could be held in a seminar type room that was physically more comfortable and had better facilities for AV equipment, the transfer of knowledge and participation of the trainees should be far better. Such rooms do exist in the library, and should fit the requirements of the small group of trainees anticipated. There may be some objection that we are "pampering" or giving special consideration to these "students," but when they are finished, we are expecting some very special "performance" out of them. They are NOT mere undergraduate students.

English has been used as a medium of instruction. However, both trainees and trainers have felt free to slip into Urdu on occasion. Probably English is still the best medium partly because much of the training literature and technical terms are in English, and partly that if a local language such as Punjabi is used, it very quickly sets one element in the group in a position of superiority to the others. Many of the lectures were written out word-for-word. This may have been due to lack of ease in lecturing in English. It should be easier and better if only an outline of the lecture were prepared prior to the class meeting. If such an outline were handed out at the beginning of each meeting, more or less like an agenda, with topics and pertinent figures listed, the class meeting could be conducted more on a discussion basis. This method could be reinforced if the trainees were assigned pertinent reading to review prior to the class discussion.

In conjunction with outside reading, and the thought of a seminar room, the literature that has been published by CSU and WAPDA should be placed in a comfortable room where the trainees can have access during their free time. This should be accompanied by other literature pertinent to the program. A record should be kept of what publications they read and how they evaluate them so that gradually we can give priorities to certain documents. As supplies permit, the trainees should be encouraged to build up a library of material they feel is of real value, and not just shelf stuffing.

Housing and Food

The seminar room concept leads directly into the idea of a lounge where the trainees can come in the evenings to read, talk or study. Much of the material that they will be learning is not factual like mathematics, but rather attitudinal. By discussing what are the alternatives in certain situations, the trainees will develop insights that will help them solve real problems later on. Several people have suggested that this "informal" learning may well be the most valuable training we can give them. Ideally, the seminar room should be used for quiet activity outside of class time. Therefore, an additional lounge room should be available for vocal activity.

To give some direction and added value to these free time facilities, the trainers should take turns being available in the lounge in the evenings. They may just play cards or karoms and drink tea, or they may have some really searching discussions on some lecture topic. The results will be valuable for the program even if they only result in rapport between trainee and trainer.

To make this kind of facility work, it must be easily available to the trainees and comfortably furnished, without a TV! Therefore, it is recommended that the trainees be housed in one location. Their rooms should provide enough privacy for study and comfortable rest. The trainees should not be intermingled with undergraduate students. This would dilute the intensity of the dedication that we are trying to instill through the program. It would also influence the trainees to achieve at the undergraduate level which they are well beyond.

Communication will be greatly facilitated if the trainees are all in the same location. Early morning field trips will start more smoothly if the trainees are all picked up at their quarters. Changes in plans can be communicated if the message has to go to only one location. Provincial culture frictions should diminish if the men are living together in equal quarters.

Food and drinking water should be of a quality that there is no sickness related to it and that the trainees have sufficient energy for a rigorous program. If this means special equipment for water purifying and supervision of food purchasing and preparation, then these things must be done. To have recurring dysentery that lasts over a week not only hinders the affected trainee, but also degrades the entire program.

If the University can demonstrate competence in arranging for the special needs we feel this group requires, this same ability to accommodate should attract other special training interest groups. The need exists in Pakistan.

Observation of the Program

The morale and commitment of the trainers to the program was probably highest during the return trip from the first field trip to Mona. There was a second strictly pleasure trip to a mango ranch toward the end of the program which again brought the faculty into close harmony. This type of activity should be done monthly to maintain the vitality and enthusiasm of the trainers. There will be issues of friction arising between personnel and this type of relaxing recreation will help reestablish understanding and tolerance among the group.

In a similar manner, the trainees should have an occasional weekend away from the routine and pressure of the program, as well as sports activity available at the University. Volleyball is available and if the swimming pool is to be used we should be sure of its purity.

The luncheons held for the trainees were good, however, the effects of two hours over a meal lasted only about as long as the food! The occasion must be over a longer period of time.

Lectures must be covered by outlines prepared in advance and distributed to the trainees. These outlines may also serve to inform the other trainers what is being presented outside their specific field. With an outline, the trainee needs only to take additional notes on points that are not clear to him. Daily quizzes can be drawn from points in the outline. The outline can serve as a source of subject matter for periodic examinations. Finally, the outlines will constitute a permanent resource handbook for the trainee.

Field work should have previous preparation whether it be a watercourse survey or an interview with a farmers committee. To accomplish this, there must be available transportation for the trainers to get to the field to make arrangements. This cannot be done reliably by trying to accompany the trainees on a field trip and hopefully catch something nearby that will fit in for the next day. Field supervision must be sufficient so that the trainees are busy with meaningful activity.

Adequate supplies of safe drinking water should always be available in the field. If field work is going to concentrate in one area, such as Thikriwala, a small building would facilitate communication, drinking water, storage of tools, maps, small group meetings, working on maps, and even staying overnight to get an early morning start. The USAID house trailer at the PARI Agricultural Engineering workshop would serve this purpose very well, if it could be made available. Otherwise, an office such as IRDP uses would help, but would neither be as adequate or mobile.

At the University, the equipment that is being used for demonstration or practice must be in working order. If it means that a pump must be repaired so that flumes have water running through them, then this should be done well in advance rather than at the last minute. This gives the feeling that things are normally running, not broken down.

Similarly arrangements and assurances must be made well in advance for irrigation water (so that irrigation doesn't have to be done with a garden hose from a faucet), the use of tractors and bullocks along with their equipment, and land to work with.

Test plots that the trainees will operate must be planned and all materials available so that their first experience is a professional operation. Transportation must be available for both personnel and machinery. Probably the largest piece of equipment to require moving will be an MF 135 tractor or disc harrow. A tilt bed trailer such as SCS uses in Peshawar, which can be pulled with a pickup, would be ideal. This trailer could be shared with the OFWMDP in Lyallpur who are frequently moving scrapers and tractors.

For personnel, two vehicles are necessary for the typical field work because usually the class splits into two groups, such as one working in the village on sociology, while the other is surveying a watercourse.

The foreign advisors should be responsible for preparing and presenting one of the subjects being taught. This can either be done solo, or by teaming up with one of the other trainers. This must be done in such a way that it does not imply superiority on the part of the advisor, yet it must serve to demonstrate the level of presentation that is expected of all trainers.

Advisors and local government officers should be invited to present programs on specific topics. Consideration should be given to using the video tape equipment for recording occasional lectures or field presentations to save for future class use, or to use as a coaching aid to help trainers polish their presentation skills.

Follow Up

Upon completion of the program, the trainees are embarking on what hopefully will be several years of working with farmers helping them improve their use of irrigation water. They will have unique experiences, some good and some bad. Pakistan's agriculture is changing rapidly. New machines are being developed and new varieties of crops are being tested. Finally, the magnitude of the task, which the conscientious WMEO will be struggling with all suggest that an annual refresher workshop for one week duration will promote the success of the total program. Valuable experiences can be exchanged. New equipment can be introduced. Accomplishments in the various provinces can be compared. Most important, all of the WMEO can return to their communities knowing they are not alone at the task.

REEVALUATION OF COURSE CONTENT

I. Background

The On-Farm Water Management Program is designed to give the farmers the help which they need to level their land, improve and maintain their watercourses and to make good use of this water when it reaches the farms in terms of optimizing their crop production and economic return.

The techniques for land leveling and improving watercourses are reasonably well known and consequently it was decided to have the implementing agencies teach these techniques to "Land Development Officers" and "Watercourse Development Officers," respectively.

The techniques for helping the farmer optimize his crop production cover a somewhat broader spectrum and are not as well defined as those for watercourse improvement and land leveling. However, it is generally recognized that the payoff, to the farmer and the nation, of this On-Farm Water Management Program will be realized primarily in terms of increased crop production. To help define the technology to improve these aspects of water management and crop production, and to provide a sound and expanding basis for training water management extension officers to help and motivate the farmers to adopt these improved water management techniques which are related to crop production, a coordinated research program has been developed at the University of Agriculture, Faisalabad.

The On-Farm Water Management teams, which are organized and administrated by the Agricultural Departments of the respective provinces, are composed of five Land Development Officers whose primary activities will be helping farmers level their land: two Watercourse Development Officers whose primary responsibility will be to help the farmers improve their watercourses; and one Water Management Extension Officer who will help the farmers improve their water management and associated cultural techniques which will increase crop production. Each of these teams will also have a leader called a Water Management Specialist, who will assist as needed in the supervision of these activities and in contacting and organizing the farmers for the watercourse improvement and cleaning activities where cooperative efforts will be necessary to achieve these goals.

The specific goals of the water management research and training program at the University of Agriculture, Faisalabad, are to provide the base information needed, the training program, and the specific training of the Water Management Extension Officers who are to play such a key role in determining the success of the provincial On-Farm Water Management Development Projects. Their job is a big one and their training should be carefully focused to help them do this job well. For instance, since there will be five members on the team trained in land leveling and two members of the team trained in watercourse improvement, the Water Management Extension Officer should not be given training in land leveling and watercourse improvement other than to acquaint him with the general objectives of those programs and to help him understand how those programs are designed to help the farmers attain their water management-crop production improvement objectives. The specific organization of the teams will be the responsibility of the respective provincial governments with direct advice and counsel provided by the Soil Conservation Service. The Colorado State University Water Management Research Team has agreed to act in a general secondary advisory capacity on the On-Farm Water Management Pilot Project. CSU has specific assignments to contribute to the development of training materials and to determine the types of organization and policies which will be most effective in helping the farmers accomplish their cooperative activities, such as improvement and maintenance of their watercourses and ownership of equipment which will facilitate water management. Such cooperation can help the smaller farmers participate, along with the larger operations, in the improved technologies.

II. Responsibilities of the Water Management Extension Officer and Training Needed to Provide Him With the Essential Skills

The specific job to be done by the Water Management Extension Officers may evolve in slightly different directions in the different provinces. Consequently, it will be essential for the university to maintain close contact with the leaders of the respective provincial On-Farm Water Management Development Projects to make certain that the training program is preparing these WMEO's for the job that they will be doing in the field with their teams. At the present time, it appears that the job description of these WMEO's should read as follows:

A. To help farmers on improved and unimproved watercourses to develop maintenance and cleaning programs which will increase and maintain the delivery of water to their respective farms.

B. To help farmers determine the proper frequency and amount of irrigation to be applied.

C. To help farmers improve their irrigation efficiency and surface drainage.

D. To help the farmers improve their crop stands and yields.

E. To help farmers plan their cropping schedules to optimize use of their water, land, labor and power resources in maximizing their economic return.

The background for each of these job components and approaches that could be used to help the trainee gain the requisite information, motivation and skills are detailed below.

A. To help farmers on improved and unimproved watercourses to develop maintenance and cleaning programs which will increase and maintain the delivery of water to their respective farms. In this specific responsibility it should be recognized that on the improved watercourses the Watercourse Development Officers and probably the team leader (Water Management Specialist) will have already worked with these farmers to help them organize for the improvement. They will have gained a promise from the farmers to participate in the maintenance program as a prerequisite to being considered for the improvement program. Consequently there will need to be close coordination between the Water Management Specialist, the Watercourse Development Officers and the Water Management Extension Officer on the cleaning and maintenance of improved Sarkari Khal.

However, the Water Management Extension Officer will have responsibility for helping the farmers manage their water from the Sarkari Khal to the fields along the farmers' individual watercourses. In most cases, this is an individual responsibility of the farmer served by that branch. The USAID funded Water Management Research Program of the university has a specific responsibility to help identify, develop and provide the Water Management Extension Officer with the techniques and training to help the farmer do this job.

As the benefits of improving the watercourses are demonstrated to the farmers, it is anticipated that the demand for this service will exceed the rate at which the watercourse improvement teams can help the farmers bring about the formal improvements. If this happens, the fact should be recognized that a regular program of cleaning and maintenance, which keeps operating water levels reasonably low within the watercourse and plugs observable leaks, can bring about an immediate and continuing improvement in the delivery efficiency of most unimproved watercourses. If the demand for watercourse improvement is exceeding the rate at which the improvements can be implemented, participation of the farmers in a well organized cleaning and maintenance program could be used as a prerequisite for selection in the improvement program.

To properly train the Water Management Extension Officer for his role in helping farmers in the cleaning and maintenance programs, he should be provided with existing information on the inputs necessary and the benefits to be derived from a cleaning and maintenance program, and on the activities which have been most effective. The visual aids developed to inform and train him in this regard should at least partially be developed in a form which he can use to carry this message to the farmers. An offset printed book on cleaning and maintenance, which includes drawings and pictures, should be developed for this purpose.

However, the primary factor which will help this Water Management Extension Officer be most effective in convincing the farmers to develop a good cleaning and maintenance program will be participation in a good cleaning and maintenance program and seeing and measuring the benefits provided. Mr. Mumtaz Awan of the Punjab On-Farm Water Management Development Project, who has participated in the watercourse cleaning and maintenance research at Mona, should be called in to help the University trainers train the trainees in this program. Having measured the benefits and seen the methods used by the trainers to convince the farmers to participate in such a program, the trainees should then be given the opportunity to work with farmers on a watercourse and help them develop a cleaning and maintenance program. The University trainers and Mr. Awan would give general guidance to the trainees and help them analyze their successes and failures. Ideally, it would be best if each of these trainees could work individually with the farmers on a watercourse as they will be doing after they join their field teams. However, since the farmers speak primarily Punjabi and about half the trainees are not fluent in Punjabi, it is proposed that two-man teams, composed of at least one man fluent in Punjabi, should go to the farmers on different watercourses. The team should determine the existing cleaning and maintenance effort, evaluate the benefits that could be derived from an improved cleaning and maintenance program, discuss these with the farmers, and convince the farmers on at least one watercourse to develop such a program. Incentives for the farmers to participate in such an improvement program would be primarily the imcreased water supply, but could also include low cost markers which could help them gauge the operating levels of their watercourse and use this to determine the required frequency for their cleaning and maintenance activities. A specific instruction manual should be developed which would help the trainees teach the farmers methods by which they can reduce losses in their individual sub-branches of the watercourse, and improve their ability to control and measure the amount of water which they are applying to their fields.

B. To Help the Farmers Determine the Proper Frequency and Amount of Irrigation to be Applied

Some farmers have a fairly good sense of timing for their irrigations, but many farmers, especially the ones with smaller holdings, need and accept advice on this matter (communications with Mr. Saeed, Mona Reclamation Experimental Project). Results obtained by Mr. Mushtaq Gill (1977) indicate that under the conditions existing in Pakistan, measurements of pan evaporation and rainfall coupled with estimates of crop coefficients give the best basis for irrigation. Evaporation pans and rain gauges should be provided to each team to enable them to provide crop and water scheduling information to the farmers who wish to use it. To help the trainees develop the ability to deliver this service to the farmers, they should be instructed in the general water requirements of crops and provided with the coefficients needed to obtain water use requirements from the potential evaporation estimates made from the evaporation pan techniques. Adequate precautions for preventing losses of water, other than evaporational losses, from the evaporation pan should be stressed including the use of a screen over the pan. A correction coefficient relating the screened pan evaporation to the open pan evaporation could be developed by having two evaporation pans side-by-side at the University, one with and one without a screen. The trainees would take turns (of about one week duration) taking evaporation measurements from both the covered and uncovered pans during the time of their training and would compare the coefficients which they had developed for the different weeks.

If for some reason it is impossible to provide the field teams with evaporation pans, the trainees should be instructed in the use of some of the equations which estimate potential evapotranspiration from climatic factors which can be obtained from nearby weather stations. However, this should be recognized as a second best alternative and the valuable time of the trainees should not be used in this effort unless circumstances prevent them from using this simpler and more direct (Gill 1977) pan evaporation procedures.

It should be emphasized that for farmers to use this information in providing the proper amount of water to their fields, that they must have a reasonably accurate estimate of the rate at which the water is delivered to their fields by their watercourse and this will generally require calibrated measurement structures which will allow illiterate farmers to estimate their water flow.

C. To Help Farmers Improve Their Irrigation Efficiency and Surface Drainage

Generally, the Water Management Extension Officer will need to coordinate with the Land Development Officers to optimize their effectiveness on this job. Level land is a prerequisite for the most efficient irrigation system. The Water Management Extension Officer, as he makes measurements and discusses water use efficiency with individual farmers, will have many opportunities to encourage the farmer to level his land by discussing the benefits of leveling with the farmer.

One approach to the farmers which has been used effectively to help them estimate their water losses is to meet with a large group of the water users from a watercourse and discuss with them the amount of time required to irrigate their fields. Since the farmers generally know the area of these fields and their distance from the mogha, the time required for irrigating a unit area can be plotted against the distance from the mogha, as in Figure 1, and a general relationship established indicating decreasing irrigation efficiency as a function of the distance from the mogha.

In general, those farmers who require more time to irrigate a unit area than is indicated by the average line drawn through these points have some specific problems which merit the attention of the WMEO and perhaps of the Land Development Officers. The most common reasons for exceptionally long times required to irrigate fields include:

1. The field being at a high elevation which requires the farmer to raise the elevation of water in the watercourse, thus spending part of his water filling the watercourse (Trout et al. 1977), and causing him to lose more water by leakage because the leakage is an exponential function of the elevation of the water surface in the watercourse (Akram and Kemper 1978);
2. High spots in the field which require that the farmer push more water into the bunded unit in order to cover the high spots (Clyma et al. 1975);
3. Coarse textured soils with high rates of infiltration;
4. Overestimation by the farmer of the amount of water needed.

The trainees should observe and take notes while the trainers meet with most of the farmers on a watercourse, discuss the time required by the farmers to irrigate their fields, identify fields with the greatest potential for water management improvement and make appointments with the individual farmers who own those problem fields to diagnose the problem when water is flowing into those fields. Then they should go to the field with the trainer and listen and observe while the trainer takes the relevant measurements of elevation, flow and head loss, discusses the problems with the farmer and then identifies solutions. Some of the solutions will be:

1. Cleaning and enlarging the farmer's branch watercourse to reduce the head loss to his field and thereby avoid backing his water up in the main watercourse and reducing losses through the banks.

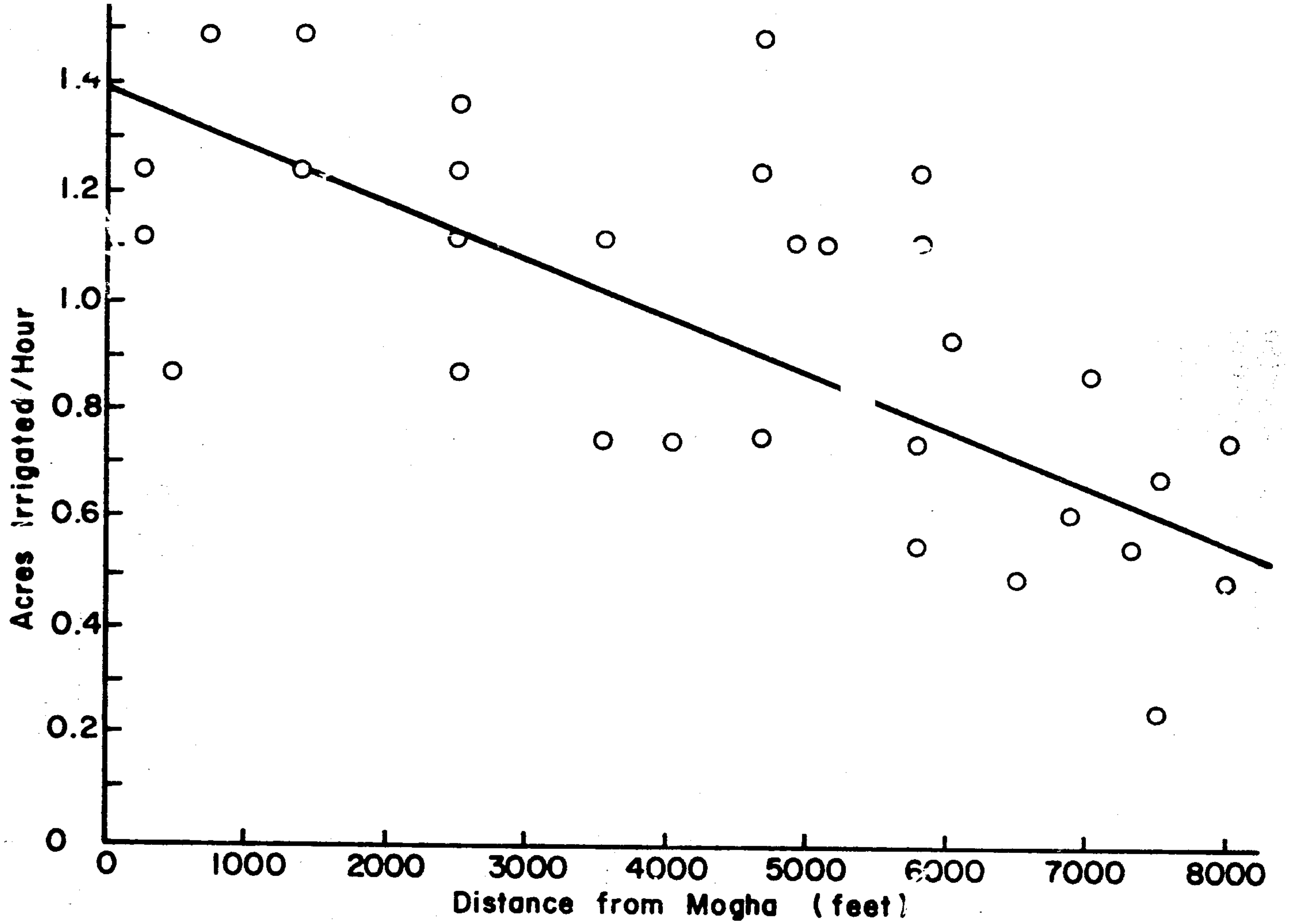

Figure 1. Acres irrigated per hour by farmers as a function of distance of their fields from the mogha.

2. Leveling his land to remove the high spots and reduce the amount of water that must be applied to cover the field.

3. Irrigating in furrows instead of flood irrigation to reduce the elevation to which he has to bring the water in his field to accomplish the irrigation

4. Irrigating in compacted furrows to increase the rate at which water can be pushed across coarse textured soils (Baksh 1978, Akram and Kemper 1978).

5. Decreasing the leakage through his banks by plugging the rat holes or installing compacted soil cores in the center of the banks.

6. Decreasing the amount of water applied so it does not exceed the water holding capacity of the soil.

The trainees should be exposed to the range of these problems responsible for poor irrigation efficiencies. Under the direction of the trainers, they should participate in the solutions and measure the benefits in terms of decreased time (or water) required to irrigate the field following the improvement.

The trainees should then be assigned into pairs in which at least one of the trainees is fluent in Punjabi and the pair should be sent out to obtain an appointment with farmers on a watercourse command area for a group meeting in which irrigation efficiencies of fields are discussed in this analytical manner. They should then work with at least four farmers to help these farmers identify and solve their problems. The trainees should make written and verbal reports of the meeting with the group of farmers and of the problems encountered and solutions developed for the specific farmers, including measurements of irrigation efficiencies before and after the solutions were implemented.

When the solution of the farmer's problem appears to be a need for land leveling, the trainees will report this need to the trainer who will contact the leader of the local On-Farm Water Management team in the area and will request that one of the five Land Development Officers be assigned to help the trainee discuss the leveling program with the farmer. The trainee would then take the Land Development Officer to meet with the farmer and discuss the costs involved in the land leveling. The trainee should participate in this discussion, helping the Land Development Officer explain the benefits of the land leveling to the farmer. If the farmer is convinced and goes ahead with the land leveling program, it would then become a part of the local On-Farm Water Management team's regular land leveling program, with the trainees measuring the amount of water needed before and after leveling. If the farmer has a crop on the field, and the leveling cannot be accomplished until after the trainees have completed their training period, the trainee should take measurements of the water used prior to the leveling and the field should be identified so that the succeeding group of trainees (or the Land Development Officer) can measure the amount of water required by the field after the first irrigation following land leveling, make the relevant comparison and report the results to the trainer and the trainees who began working with the farmer.

If the training period encompasses the planting season for kharif crops, such as maize and cotton, the trainees should plan a meeting with the farmers in which they discuss the yields of these crops which the farmers are obtaining and tell the farmers that one factor which can appreciably reduce the yield of these crops is having water stand on the surface of the soil for an appreciable length of time thereby sealing the surface and keeping the needed air from the root systems. They should then inform the farmers that surface drainage has resulted in substantial increases in crop yields at the Mona Project area and that this drainage was accomplished by planting the cotton and maize on beds between furrows, connecting the furrows to the watercourse and carrying the excess water from cotton and maize fields down through the watercourse to rice fields which were at a lower elevation and could use the water without appreciable damage to the crops. The trainees could then offer to bring the equipment which would make the beds and furrows and show the farmer how to use it if the farmer wishes to try this technology to increase the yields on part of his field(s). If farmers do use this technology, its effects on stands and yields should be monitored.

If the training period does not coincide with the monsoon season, the trainees should be given the available data on benefits derived from surface drainage, recognizing that this will be a factor affecting yields in those portions of the country where monsoon season rainfall is heavy (e.g. >12").

D. To Help the Farmers Improve Their Crop Stands and Yields

In addition to the water management factors discussed above, the yields can generally be increased by proper seedbed preparation, proper placement and spacing of seed, proper placement, timing and amount of fertilizer, and proper weed control and surface mulching to reduce unnecessary transpiration and evaporation. Most of these factors are related to or affected by water management. For instance, proper seedbed and placement of the seed involves either arranging the soil and placement of the seeds so that the seed is in contact with adequate water to bring about its germination and emergence, or so that the irrigation water can move to the seed by capillary action following planting.

Proper placement and timing of the fertilizer involves getting it down into the soil where the fertilizer can either diffuse through the water to the plant roots or be convected by the water moving to the plant roots. Maximizing the benefits derived from fertilizer also involves placement of the fertilizer, timing and amount of the irrigation (or surface drainage of excess rain water) in a manner so as to minimize leaching of this fertilizer out of the root zone, or denitrification of this fertilizer as a result of anaerobic conditions that rapidly develop in a soil when the surface of the soil is sealed by water. Avoiding loss of water by transpiration from weeds and excess evaporation from unmulched soils becomes particularly important when the farmer has a limited water and nutrient supply.

The trainee should receive basic classroom instruction on the effect of these various factors on crop stands and yields. Specific recommendations should be drawn from research in Pakistan and countries with similar climatic and soil conditions of the stands needed for each specie (and as needed, for varieties within the species), amount of fertilizer needed to achieve certain production levels, recommended amounts and methods of planting the seed (including methods of determining percentage germination of the seed), and amounts, placement, and timing of fertilizer. Wherever the data are available, the functional relationships between amounts of fertilizer and water and the yield should be provided to the trainee (recognizing that these are dependent on timing and placement).

The trainees should be made aware of the fact that most of the small farmers in Pakistan suffer from the general constraint of inadequate equipment to provide proper shaping of the soil surface, placement of the seeds, weed control and soil surface mulching. Consequently, if the recommendations to achieve these cultural conditions which facilitate increased crop production are to be implemented, it will be essential that the farmers gain access to improved equipment. This equipment should include furrow and bed shapers, wheat seeders, seeders for maize, cotton and other summer crops (attached to bed shapers and independent of bed shapers), and cultivation equipment which will achieve weed control and surface mulching. About 80% of Pakistan's farming is still done with bullocks; however, tractor farming is increasing and consequently both bullock and tractor drawn sets of equipment should be available for demonstration to the farmers. However, the farmer who has a tractor is generally much more advanced on the path toward improving his crop yields, his holdings are larger and he can afford independent purchase of the needed equipment. It is probable that bringing a piece of equipment to his farm which can be used on his tractor and demonstrated in soil preparation, seeding or cultivation of his land for a few hours will result in his acceptance of the equipment if his stands or yields are improved.

Successful introduction of bullock drawn equipment is a more complicated process. The bullocks have a wide range in power, have tendencies to not follow a straight path, and tendencies to be suspicious of new pieces of equipment to which they are attached. Bullock drawn equipment does not have any automatic controls and often requires hand guidance and judgment by the farmers, which is an art that requires considerable practice to perfect. This becomes immediately apparent when a government officer (or a foreign advisor) tries to move earth with a pair of bullocks and a karah or tries to plow with a native plow! Fortunately, farmers generally know the idiosyncracies of their bullocks and will learn how to use a new piece of equipment drawn by their bullocks more rapidly than government officers or foreign advisors. However, it is necessary to deliver this technology to the farmers via the government officers. Since the farmers are generally illiterate, it is practically impossible to deliver this type of technology to them through the written word. Unless they have a successful demonstration of the new equipment by a government officer, it is improbable that they will learn to use the equipment to the best advantage during the short time which they can invest in this activity. Consequently, there appears to be no alternative to having the government officers learn to use improved bullock drawn equipment. This will require considerable time, availability of the improved bullock drawn equipment and of bullocks to pull this equipment and of farmers or other persons who are trained in the handling of bullocks and can help these Water Management Extension Officers to understand and work effectively with bullocks. Ideally, trainers would be available who had used this equipment in the field and know how to use it effectively. However, it is probable that the trainers themselves at first will not have had extensive experience in the use of such equipment and it will be necessary that they also get out in the field and practice. This should be coordinated closely with the equipment development component of the Water Management Research Program funded by USAID at the University of Agriculture at Faisalabad. The principal investigators of that project should be involved as trainers in this activity. A practice area should be provided in which the trainers and trainees could learn to handle the respective pieces of equipment. In addition, a test plot area should be provided on the University farm where the trainees would actually shape the soils, prepare the seedbeds, plant the seeds, irrigate and control the weeds on the crop(s) which are normally planted during the season in which their training course takes place. Since the investment in the seed, fertilizer, and time and effort is appreciable, it is proposed that these crops be properly irrigated, grown to maturity and harvested and that the proceeds would be used to buy seed and fertilizer for future crops. The trainees should be evaluated in terms of measureable characteristics of the soil and crop system which they have developed. These could include uniformity of width and height of beds, crop stands, adequacy and efficiency of irrigation and so forth.

These practice and training exercises on the university farm should precede the farmer's normal planting season by at least a couple of weeks so that the trainees can demonstrate this skill and technology to the farmers prior to the normal planting date. Since communication with the farmers will again be a critical factor in motivating the farmers to adopt the techniques, it will be essential that each person who does not speak Punjabi have a Punjabi speaking partner. Each team should be required to motivate at least four farmers to try the new technology. The trainers should be taught that participation of the farmer in the operation of the equipment, to the point where the farmers develop a feel for the equipment, is an essential part of this process. Comparison of this improved technique with the more common management methods should be encouraged. When the improved technique shows definite advantages in terms of stands or yields, and the farmers wish to adopt it, the trainees will discuss with the farmer (or the farmers) the apparent benefits and costs involved and the various options which the farmer(s) might use in gaining the use of this equipment. These options might include:

1. Cooperative ownership.
2. Rental from a blacksmith who would keep the equipment in repair and rent it out to those who desire to use it.
3. Ownership of the equipment by an individual farmer who would do some custom work for his neighbors to defray his cost.
4. Ownership by a landless laborer who has a team of bullocks, who would build a business of doing custom work for small farmers using improved equipment for a share in the crop.

Specific types of equipment to be used would be decided upon by a committee with representatives from the Provincial Agriculture Departments' On-Farm Water Management Development Project, the University of Agriculture at Faisalabad, and the CSU Water Management Field Party. The agreed upon field equipment would be available to the trainees during their training period and would also be made available to them when they joined their teams in the On-Farm Water Management Development Project. Means for funding the availability of this equipment would be developed by the committee and their respective organizations.

E. To Help Farmers Plan Their Cropping Schedules to Optimize Use of Their Water, Plan Labor and Power Resources in Maximizing their Economic Return

As the Farm Planning Research Study funded by USAID at the University of Agriculture at Faisalabad gains information on the existing cropping schedules and their economic potential compared to other cropping schedules, if there is a substantial basis for improving the farmers' economic return, the trainees will be given the information base needed for helping the farmers make the most economically rational decisions in planning their crop schedules in terms of the water, land, and power resources. However, the trainees should not be trained or encouraged to spend an appreciable part of their time in this activity until the research has determined that there is a substantial potential for improvement of the farmers' economic return in changing his cropping patterns. The potential effect of such changes on a national scale in providing national needs for food and foreign exchange should be evaluated, along with the potential economic return to the individual farmer, in determining the cropping patterns that will be recommended.

PROPOSED OUTLINE FOR SECOND TRAINING COURSE

Training Course Coordinator - Qurban Ali Awan
USAID/CSU Advisor - Dwayne G. Westfall

SUBJECT	LECTURES (hours)	FIELD (days)	TRAINER
March 6, 1978			
Watercourse Improvement			
Introduction	1		Qurban Awan
Slide Show	1		John Reuss
Examination			
Preliminary Evaluation of Knowledge Level of Trainees	2		Westfall
Rural Sociology			
Structural Attitudes of Village Organizations	1		Ashfaq Mirza
Characteristics of Castes	1		Ashfaq Mirza
March 7			
Extension Methods			
a	1		Akram Zia
b	1		Akram Zia
Watercourse Improvement			
Flow Measuring Devices	2		Qurban & Arshad
Rural Sociology			
Legal Authority and Personal Influence	1		Ashfaq Mirza
Process of Collective Decision-Making	1		Ashfaq Mirza

SUBJECT	LECTURES (hours)	FIELD (days)	TRAINER
March 8			
Agricultural Extension			
Introduction to Cleaning and Maintenance	2		Mumtaz Awan
Watercourse Improvement			
Cutthroat Flumes	2		Qurban & Arshad
Rural Sociology			
Assessment of Felt Need for More Water	1		Ashfaq Mirza
Alternative Solution and Their Evaluation	1		Ashfaq Mirza
March 9			
Watercourse Improvement			
Field Trip to Mona		1	Mumtaz Awan & OFWMDP staff
March 10			
Free			
March 11			
Agricultural Extension			
a	1		Akram Zia
b	1		Akram Zia
Rural Sociology			
Assessment of Satisfaction	1		Ashfaq Mirza
Interview vs. Participant Observation			Ashfaq Mirza
Watercourse Improvement			
Use of Levels		1/3	Qurban & Arshad
March 12			
Watercourse Improvement			
Cutthroat Flumes UAF		1	Qurban & Arshad
March 13			
Watercourse Improvement			
Cutthroat Flumes at UAF WC. Thikriwala		1	Qurban & Arshad
March 14			
Rural Sociology			
Preparation of Intensive Interviewing Schedule	2		Ashfaq Mirza
Agricultural Extension			
a	1		Akram Zia
b	1		Akram Zia
Soil Science			
Soil Science Terminology and Soils of Pakistan	2		M'd Iqbal Bajwa

SUBJECT	LECTURES (hours)	FIELD (days)	TRAINER
March 15			
Agricultural Extension			
Field Trip to Thikriwala		1	Zia & OFWMDP Staff
March 16			
Soil Science			
Soils of Pakistan	2		M'd Iqbal Bajwa
Agricultural Extension			
a	1		Akram Zia
b	1		Akram Zia
Examination over Agricultural Extension, Flumes and Levels	2		Zia and Arshad
March 17			
Free			
March 18-21			
Rural Sociology			
Studying Relevant Leadership Characteristics (Initial farmer contact)		4	Ashfaq Mirza
March 22-23 & 25			
Irrigation and Drainage			
Cutthroat Flumes and Seepage Losses (2 WC's)		2	Qurban & Arshad
Data Reduction	6		Qurban & Arshad
March 24			
Free - Pakistan Day			
March 26-30 & April 1			
Rural Sociology			
Organizing a Watercourse Committee	6		Ashfaq Mirza
(Evening programs on watercourse cleaning and maintenance to be presented to farmers by trainees.)			
Examination over Rural Sociology	2		Ashfaq Mirza
March 31			
Free			

SUBJECT	LECTURES (hours)	FIELD (days)	TRAINER
April 2-13			
Agricultural Extension			
Trainees separate into teams of 2 or 4 each and clean an unimproved watercourse. (Evening programs on water course cleaning and maintenance to be presented by trainees.)		11	Akram Zia
April 7 & 14			
Free			
April 15			
Agricultural Equipment			
Machinery for Agriculture and their purpose	2	2/3	Sial & Illsley
April 16-April 30			
Agricultural Equipment		13	Sial & Illsley
Trainee to become skilled in the use of hand and bullock drawn equipment. Tractor drawn equipment orientation. Trainees will become skilled in its operation			
April 21 & 28, & May 1			
Free			
May 2			
Agronomy & Agricultural Machinery			
Cotton Production Guideline	4		Fateh M'd
Determining Irrigation Requirement			
Consumptive Use	2		CSU
Pan Evaporation	1		Qurban & Arshad
Irrigation Scheduling	2		Qurban & Arshad
May 3, 4, 6			
Plant Cotton at UAF		3	Staff
May 5			
Free			
May 7-11			
Plant Cotton Demonstration Plots in Farmers Fields		6	Staff
May 12			
Free			

SUBJECT	LECTURES (hours)	FIELD (days)	TRAINER
May 13			
Evaluation and Improvement of Irrigation Practices			
Methods of Irrigation	3		CSU
Evaluation of Basin Irrigation at UAF	2		Qurban & Arshad
Examination over Agricultural Equipment	1		Sial & Illsley
May 14-16			
Evaluation and Improvement of Irrigation Practices			
Evaluation of Time Farmers Require to Irrigate Fields	2	2/3	Qurban & Arshad
Evaluation of Farmers Irrigation Basin		2	Qurban & Arshad
May 17-18			
Evaluation and Improvement of Irrigation Practices			
Water Management Aspects of Precision Land Leveling	2		SCS
Pan Evaporation Measurements		1-2/3	Qurban & Arshad
May 19			
Free			
May 20-22			
Agronomy			
Rice Production Guidelines	4		Fateh Moh'd
Plant rice nursery at UAF & Prepare Field for Planting		2-1/3	Fateh Moh'd
May 23-24			
Field Trip to Cotton Research Station at Multan		2	Fateh Moh'd
May 25			
Take Notes on Cotton Demonstration Plots in Farmer's Fields & UAF		1	Staff
May 26			
Free			
May 27			
Agronomy			
Wheat Production Guidelines	2		Fateh Moh'd
Farm Management			
Farm Planning	2		Moh'd Akhtar Bajwa

SUBJECT	LECTURES (hours)	FIELD (days)	TRAINER
Soil Science			
Essential Nutrients, Functions and Symptoms	2		Moh'd Iqbal Bajwa
May 28			
Agronomy			
Wheat Production Guidelines	2		Guest
Farm Management			
Farm Business Survey	2		Moh'd Akhtar Bajwa
May 29			
Soil Science			
Nutrient Mobility in Soils	2		Moh'd Iqbal Bajwa
Farm Management			
Farm Business Analyses	3		Moh'd Akhtar Bajwa
Soil Science			
Fertilizer Materials, Availability, Soil Reaction, & Production Responses	3		Moh'd Iqbal Bajwa
May 30			
Soil Science			
Making Fertilizer Recommendations	2		Moh'd Iqbal Bajwa
Review, Questions & Answers	2		Staff
Examination over Soil Science & Agronomy	2		Bajwa & Fateh Moh'd
May 31			
Agronomy			
Field trip to Pari at Faisalabad	1		Fateh Moh'd
June 1			
Take Notes on Cotton Demonstration Plots in Farmer's Field & UAF		1	Staff
June 2			
Free			
June 3			
Farm Management			
Developing Farm Plans	2		Moh'd Akhtar Bajwa
Agronomy			
Sugarcane Production Guide	3		Guest
Questions & Answers	1		Staff
June 4			
Soil Science			
Soil Salinity - SAR & ESP	2		Moh'd Iqbal Bajwa
Transplant Rice at UAF		2/3	Fateh Moh'd

SUBJECT	LECTURES (hours)	FIELD (days)	TRAINER
June 5			
Agronomy			
Orchard Production Guideline	2		Guest
Transplant Rice at UAF		2/3	Fateh Moh'd
June 6			
Agronomy			
Fodder Crop (Summer) Production Guidelines			
Divert Seed Rice at UAF		2/3	Fateh Moh'd
June 7-8			
Farm Management			
Develop Farmer Contacts and Perform Preliminary Survey of Farm Conditions (Take field notes on Rice & Cotton Plots)		2	Moh'd Akhtar Bajwa
Agronomy			
Cover Fodder Crop (winter) Production Guideline	2		Fateh Moh'd
June 9			
Free			
June 10-15			
Agronomy			
Vegetable Crop Production Guideline	2		Guest
Pulses Crop Production Guideline	2		Guest
Examination over Crop Production Guidelines	2		Fateh Moh'd
Farm Management			
Collection of Basic Data for Farm Budgeting - Pretesting		1-1/2	Moh'd Akhtar Bajwa
Collection of Detailed Data for Developing Improved Farm Plans		1-1/2	Moh'd Akhtar Bajwa
Data Analyses (campus)		2	Moh'd Akhtar Bajwa
June 16			
Free			
June 17-19			
Transplant Rice and Set Up Demonstration Plots in Farmer's Fields. (Take field notes on cotton plots.)		3	Fateh Moh'd

SUBJECT	LECTURES (hours)	FIELD (days)	TRAINER
June 20-22			
Agricultural Extension			
Perform maintenance on previously cleaned watercourse		3	Akram Zia
June 23			
Free			
June 24-27			
Agronomy			
Cover Maize Production Guideline	4		Fateh Moh'd
Plant Maize at UAF		3-1/2	
June 28-29			
Agronomy			
Field trip to Maize Research Center at Yausafivala		2	Staff
June 30			
Free			
July 1-5			
Plant Maize and Fodder at UAF		5	Fateh Moh'd
July 6-13			
Establish Maize and Fodder Demonstration Plots in Farmer's Fields		7	Fateh Moh'd
July 14			
Free			
July 15-16			
Review, Critique & Prepare to Depart for New Job Assignment as Water Management Extension Officer		2	Staff

WATER MANAGEMENT EXTENSION OFFICER
TRAINING COURSE OUTLINE
UNIVERSITY OF AGRICULTURE, FAISALABAD

DATE	LENGTH OF TIME	SUBJECT	TIME (%)		LOCATION	ACTIVITIES IN FIELD
			FIELD	CLASS		
6 Mar - 13 April	34 days	Integrated rural sociology, agricultural extension, cleaning and maintenance program together (including proper use of flumes and levels). Initial contacts with farmers to identify areas where cotton, rice, maize and fodder demonstration plots will be located will be made. Field trip to Mona (1 day) and PARI (½ da).	90	10	UAF classroom and farmer's field	Two phase approach 1. Trainers demonstrate in villages methods of making farmer contacts, explaining importance of cleaning watercourse and clean one watercourse. Trainee will document changes in flow, etc., before and after cleaning. (10 days) 2. Separate in teams of 2 or 4/ team, contact farmers and clean watercourse. (12 days)
15 Apr - 6 May	19 days	Agricultural Equipment (Teach use of hand, bullock and tractor drawn equipment.) Plant cotton at UAF. Cotton production guideline to be covered prior to cotton planting. (Use irrigation scheduling to project watering schedule.)	70	30	UAF classroom and UAF Research Farm	Trainees will become skilled in the use of the following equipment: 1. Corn, cotton and small grain seeders, manual and bullock drawn 2. Bed and furrow shapers, manual and bullock drawn 3. Fertilizer spreaders, manual and bullock drawn 4. Plows and cultivators, manual and bullock drawn 5. Levels 6. Operation of irrigation siphon. Tractor drawn equipment will be demonstrated by Jehangir Sial. Trainees will be skilled in operation of tractor drawn equipment.

DATE	LENGTH OF TIME	SUBJECT	TIME (%)		LOCATION	ACTIVITIES IN FIELD
			FIELD	CLASS		
						Cotton will be seeded using various methods on hills on pre and post irrigated fields. Fertilization, irrigation, etc., will be performed.
7 May - 11 May	5 days	Plant cotton demonstration plots in farmers' fields.	100		Farmer's field	Use techniques learned at UAF in planting farmer's cotton on beds. Evaluate, stands with bed and farmer's method of planting
13 May - 18 May	6 days	Irrigation efficiency and uniformity evaluation	80	20	UAF classroom and farmer's field	Steps to accomplish objective: 1. Evaluate basin irrigation system 2. Level land (have Land Development Officer make all measurements). 3. Explain benefit and method of bedding and shaping. This is to help promote land leveling.
20 May - 22 May	3 days	Plant rice nursery at UAF (Cover Rice Production Guideline)	80	20	UAF classroom and field	Appropriate equipment will be used to level, cultivate, fertilize and irrigate nursery.
23 May - 25 May	3 days	Field trip to cotton research station (2 days). Take field notes on UAF and farmer's cotton demonstration plots (1 day).	100		Multan Farmer's field	Evaluate stand, plant growth and irrigation scheduling, weed and other operations as required.
27 May - 19 June	21 days	Cover Soil Science subject matter (1 day). Cover Farm Management subject matter (8½ days) Cover Crop Production Guideline subject matter (3½ days)	20 20	80 80	UAF classroom and field UAF classroom and field	

DATE	LENGTH OF TIME	SUBJECT	TIME (%)		LOCATION	ACTIVITIES IN FIELD
			FIELD	CLASS		
		Transplant rice to plot area at UAF and direct seed test area (3 days).	100		UAF research farm	Rice transplanting to include seed-bed preparation, fertilization, irrigation and other operations as required.
		Transplant rice demonstration plots in farmer's fields (3 days).	100		Farmer's field	Use techniques learned at UAF to improve production.
		Field trip to Rice Research Center (1 day).	100		Kala-Shah-Kaku	
		Field trip to PARI (in addition to previous visit (1 da).	100		Faisalabad	
		Take field notes on UAF and farmer's cotton & rice demonstration plots on a weekly basis (4 days). (Above activities will be coordinated together to avoid heat of day when possible, i.e. morning in field and afternoon in class.)	100		UAF & farmer's field	Perform necessary weed control and other operations as required.
20 June-22 June	3 days	Perform maintenance of previously cleaned watercourse	100		Farmer's field	
24 June-5 July	11 days	Plant maize and fodder at UAF (Field trip to Maize Center at Yousafivala should come just before this time.)	80	20	UAF	Bedding and furrowing, fertilization, planting, irrigation and other operations as required will be performed.
6 July - 13 July	7 days	Plant maize and fodder demonstration plots in farmer's fields.	100		Farmer's field	Improved techniques learned should be used to increase production.
15 July - 16 July	2 days	Review, critique and prepare to depart for home assignment.			UAF	

TOTAL 4½ months

APPENDIX 27

ORGANIZING FARMERS TO IMPROVE IRRIGATION WATER DELIVERY--THE PROBLEM AND PROSPECTS FOR SOLUTIONS IN PAKISTAN

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and Ashfaq H. Mirza[1]

ABSTRACT

Data from ten districts in the Punjab and Sind reveal that about half of the irrigation water entering poorly constructed and maintained sample watercourses is lost before reaching farmers' fields. This water is not only lost to crop production, but also contributes to waterlogging and salinity. One of the most important things which can be done to increase water supplies to farmers' fields, reduce waterlogging and salinity, and increase the productivity of fertilizer, pesticides, and improved seed varieties, is to undertake a program of watercourse reconstruction and maintenance. This article presents data revealing the extent and significance of water losses, discusses options for organizing farmers to undertake and maintain the watercourse improvements, and suggests guidelines for evaluation of organizing efforts.

I. The Problem

The kinds of organizations which people create and maintain for the social control of irrigation water intimately affect the productivity of its use. Attempting to comprehend physical and agronomic problems of irrigation without probing into underlying social organization for irrigation is like attempting to understand deficiencies in plant growth without reference to conditions of climate. When water moves efficiently from rivers, through a network of canals and associated watercourses to plant root zones, it is because people have effectively organized a decision system capable of enforcing technically sound rules for pursuing the collective interest. Defects in the delivery systems of irrigation water are typically associated with deficiencies in organizational relationships, or the lack of organizations.

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Pakistan has one of the most extensive integrated irrigation water distribution systems in the world. However, Pakistani farmers are not adequately organized to obtain and apply irrigation water to meet the demands of a modernizing agriculture. Organizing farmers to improve on-farm deliveries of irrigation water represents a most significant problem as evidenced by the following facts:

1. World Bank (1976) estimates suggest that, if the provisions for watercourse cleaning and maintenance stated in the Canal and Drainage Act (1973) were fulfilled, farmers on 78,000 watercourses in Pakistan would "save" approximately five million acre feet of water by 1978 without capital inputs. If farmers were to engage in cleaning and maintenance of watercourses until 1982, about 10 MAF could be saved annually at no cost to government. This amount, valued at Rs. 360 ($36) per acre foot, would result in annual savings to Pakistan of approximately $360,000,000. Farmers <u>do not</u> provide minimum levels of watercourse cleaning and maintenance because they do not know the magnitude of their water losses, they do not know how to do the most effective job of cleaning and maintenance, and they are not <u>organized</u> to do the job.

2. Watercourse delivery efficiencies are low--overall approximately forty to sixty percent of the water entering at the outlet mogha will be lost before reaching farmers' fields. Application field losses range up to about 75 percent and losses per 1000 feet go as high as 66 percent (see Table 1). Farmers need to organize to improve their watercourses; a few farmers working independently in an unorganized fashion cannot accomplish the necessary improvements.

3. One percent of water saved at all watercourse outlets would roughly equal a "savings" of about one million acre feet of water across the country. Each acre-inch of water saved has an approximate economic value to the farmer of about Rs. 30 (Eckert, et al., 1975: 8-16). Organizing farmers to improve watercourses produces immediate and tangible benefits for both the farm and the nation.

4. The water "lost" through seepage and spills in poorly constructed and maintained watercourses also directly increases problems of waterlogging and salinity. While there is insufficient data to estimate how much on-farm delivery losses and overirrigation during the year contribute to waterlogging and salinity, it is estimated to be substantial. Though return flow reuse is possible by tubewells, more tubewells alone do not provide a solution. Increasing costs of fossil fuels make it problematic to recirculate groundwater through tubewell pumping and in time, water quality is degraded.

Table 1. Mean delivery efficiency and percentage loss rate summary by watercourses and nutrient.

District location	No. cases	Weighted mean percentage delivery efficiency	Percentage loss rate/ 1000 ft.	District means weighted by No. of cases in sample E_d
Muzaffargarh				47
WC 1	11	37	32	
WC 2	24	51	24	
Bahawalpur				66
WC 1	13	82	36	
WC 2	19	65	63	
WC 3	11	59	35	
WC 4	11	58	37	
Dadu				60
WC 1	12	44	21	
WC 2	11	65	17	
WC 3	21	66	8	
Thar Parker				54
WC 1	17	59	10	
WC 2	16	63	22	
WC 3	14	40	63	
Thatta				30
WC 1	9	31	47	
WC 2	9	26	24	
WC 3	3	28	35	
WC 4	4	36	107	
Faisalabad				69
WC 1&2	63	69	8	
Multan				58
WC 1	7	64	14	
WC 2-4	70	57	15	
Lahore				62
WC 1	10	62	20	
Sargodha				55
WC 1	5	49	18	
WC 2	7	47	18	
WC 3	7	56	13	
WC 4	13	60	10	
Gujranwala				58
WC 1-2	19	58	11	
Total Cases	406			

Mean Delivery Efficiency (E_d) = 52.1
Mean percent loss/1000 feet = 28.3

II. An Example

Some of the most significant evidence to support what farmers can do, given incentives, extension education, and engineering assistance, comes from a research program which has culminated in improvements of watercourses by farmers under the direction of the Mona Reclamation Experimental Project and the Colorado State University Water Management Research Project in Pakistan.[2] Farmers rebuilt over 33,000 feet of watercourse in 44 days. Later they individually improved over 10,000 feet of their private subbranches. Overall this improvement was accomplished at a cost of about Rs. 2.0 per foot.[3]

This experience, and others, indicates clearly that farmers can be motivated to improve their watercourses at low cost. These are many indications that a well conceived program can result in a "watercourse improvement revolution" in the 78,000 watercourse commands in the Indus Basin. However, this will require government incentives and minimum assistance.

What are some of the factors which can be expected to affect the ability of farmers to organize to provide themselves with improved watercourses? Selected factors, pulled from studies to date (Mirza, 1975; Lowdermilk et al., 1975; 1978), can be presented in hypothesis form. Some are:

1. Leadership for collective action can more easily emerge in single agricultural caste villages where caste boundaries need not be crossed, or in multi-caste villages where no single caste group can successfully dominate and several groups must bargain in order to make trade-offs with each other.

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[2] The Colorado State University Water Management Research Field Team in Pakistan is involved in testing various approaches to the problem of improving watercourses with farmer cooperation. These field experiments are expected to provide guidelines which can be incorporated in larger scale improvement programs.

[3] See: Colorado State University Field Party and Mona Reclamation and Experiment Project, "Helping Farmers Identify and Achieve Their Potential for Watercourse Improvement." Mimeographed report available at CSU Water Management Research Office, Islamabad, 1976. (The estimated cost includes farmers' labor, permanent structures, engineers' and extension workers' time plus about Rs. 10,000 in experiments by CSU. Therefore, the actual cost should be less than Rs. 2.0 per foot by improved watercourses.)

Single or multiple agricultural caste villages, as contrasted with double agricultural caste villages, will reveal a greater propensity to generate organized action and effective leadership in collective watercourse reconstruction, cleaning and maintenance.

2. The greater the number of households sharing a watercourse command area, the greater the difficulty in mobilizing collective action to improve water management.

3. Farmers at the tail of the watercourse reveal a greater propensity to mobilize for action to reconstruct, clean and maintain the watercourse than farmers whose land is located near the head of the watercourse.

4. The greater the number of large landlords toward the mogha (head of watercourse), the poorer the quality of collective watercourse activities.

5. The presence of public tubewells, providing supplemental water, on a watercourse leads to reduced efforts of farmers for reconstruction, cleaning and maintenance.

Such hypotheses can be further tested in evaluations of farmers water user associations.

III. Options for Organizing Farmers

The watercourse (sarkari khal), being owned by no farmers must be collectively reconstructed and maintained. Investigations reveal no particular legal or structural obstacles to the formation of farmer water user associations for such purposes (Radosevich and Stickley, 1976). Pakistan Islamic water law also provides sample precedent--for example it grants importance to equitable water allocation. All waters are deemed to be the common entitlement of the community and are subject to public administration. Furthermore, the Canal and Drainage Act provides for collective action in the construction and maintenance of watercourses.

In order to reconstruct and maintain improved watercourses, local farmer water users' associations would function to:

1. Organize construction of improved watercourse.

2. Provide for watercourse operation and maintenance including, silt and vegetation removal and the hiring of a khal chowkidar;

3. Manage conflict pertaining to the watercourse and water allocation.

Typically, a farmer's water association would serve a watercourse command area of about 400 acres and would be composed of about 40 farmers. Possible membership requirements would be attendance at meetings, contributions to interest bearing savings account organized by the association, and purchase of shares in the association. Voting power might be allocated in a manner proportionate to water rights. Sanctions for violating association rules might include utilization of a portion of the offender's share of water for one week for public purposes (extra filling of village ponds, etc.) or other fines. Farmers will probably devise many other specific forms of sanctions. There will be need for a procedure to grant recourse to an accused offender--one such rule could be to require a 2/3 vote of all members to sustain a sanction if challenged.

The question is, how might water user's associations be established in Pakistan? There appear to be three primary legal alternatives in the absence of specific legislation providing the purpose and guidelines for formation of such organizations.

Alternative 1 - Informal Water User Associations

The informal approach is conceived as a minimum solution. It may be preparatory for becoming a formal organization when the membership has gained sufficient experience and maturity.

Farmers would be allowed to work out their own organization procedures fitting their particular situation. No attempt would be made to pressure farmers to adopt any particular scheme foreign to their understanding. A variety of approaches will most likely evolve and all should be carefully evaluated.

Alternative 2 - Organizing Farmers Formally Under the Companies Act (1913)

A "company" is defined by its common usage as "an association of a number of individuals formed for some common purpose" (Radosevich and Kirkwood, 1975;92-93). Section 4(2) of the Companies Act provides that no company, association, or partnership consisting of more than twenty persons shall be formed for the purpose of carrying on any function (except banking) that has as its object the acquisition of gain unless it is registered as a company under the Companies Act or other act or charter. This provision does enable the voluntary formation of water user associations, since entities are not created for gain or profit, but rather to help the users in optimizing their total resource capabilities.

An association which has organized under the Act may issue shares representing ownership interest. The ownership interest can be represented by irrigated acreage within the canal delivery area, capital contributions, or other selected criteria. These shares are transferable and become, in effect, "movable property."

Shares in the association can be appurtenant to the land, transfer may be made from owner to purchaser upon sale of land or from landlord to tenant, or tenant to tenant upon change of working parties, but should not permanently be transferred from the parcel of land. This protects lands from being taken out of production due to the sale of water rights. Reallocations of water in agrarian Pakistan from irrigated use to industrial or other uses through the private sector could defeat national efforts to achieve increase food production.

There are both advantages and disadvantages of incorporating. When dealing with companies, the property of the company belongs to the company (Radosevich and Kirkwood, 1975: 92-93). This loss of control of ownership may be offensive to a people whose primary wealth is the land. However, creditors can proceed against only the company and not the individuals. Farmers will want to be informed of the implications, so a conscious decision can be made on what properties, if any, will become company properties.

Alternative 3 - Organizing Farmers Formally Under the Cooperative Societies Act (1925)

The Cooperative Societies Act, 1925 (Radosevich and Kirkwood, 1975: 94-96), was enacted to facilitate the formation and working of cooperative societies for the promotion of thrift, self-help, and mutual aid among agriculturists and other persons with common economic needs so as to bring about better living, better business, and better methods of production. It was made applicable to the whole of Pakistan, except in Tribal Areas, by the Sind Cooperative Societies (West Pakistan Amendment) Ordinance, 1965.

Only societies registered as cooperatives may use the word "cooperative" in their titles. The Provincial Government may, by special order, exempt any society from registration requirements in an effort to save trouble. Provisions of the Companies Act do not apply to societies registered under the Cooperatives Societies Act; this simplifies administration.[4]

IV. Establishing Organizationed Boundaries

One important feature which distinguishes the formation of water user associations is the boundary of the organization.

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[4] Legal experts should study Radosevich's work carefully. The Registered Societies Act and its provisions for formation of nonprofit associations should be examined as to its potential applicability for farmers organizations.

Association boundaries must have a logical relationship to the water delivery, use and drainage area. Thus, they can be organized around a watercourse, one or more villages receiving water from a common canal, or some other configuration having a common source of supply (See Figure 1 for illustration).

Quite often water users within an irrigation system find it not only beneficial to organize at the association level, but also to create a federation of associations along the minor and/or major canals (Radosevich, 1975: 16-22). Figure 2 illustrates one possible arrangement.

V. Evaluating Proposed Alternatives

Systematic evaluation should be undertaken to obtain empirical data regarding the problems and successes of organizations operating under these three alternative conditions. Selected principles for conducting the evaluative research might be as follows:

1. Research should not evaluate specific administrators or village leaders--it should be primarily designed to evaluate the outcomes of alternative policies and organizational frameworks:

2. Researchers and associated administrators should emphasize the importance of the problem--obtaining and developing effective farmer water users associations--rather than emphasizing any specific method of obtaining effective farmer organizations. It is important not to advocate any specific organizational model at the outset, but to advocate the importance of the problem of developing farmer organizations by one method or another. Should any single model fail, it is essential to be in a position to shift to alternative models.

3. Affected administrators and villagers should be involved in the program evaluations as much as possible while still protecting the integrity of the assessment and evaluation:

4. Given that field conditions prohibit full implementation of tight experimental design in which all potentially confounding variables can be controlled, quasi-experimental designs are suggested. Lack of control over all potentially confounding variables is not cause for despair or paralysis, but researchers must generate, as many plausible rival hypotheses as possible and do supplementary research which will determine whether the rival hypothesis can explain program "successes" or "failures".

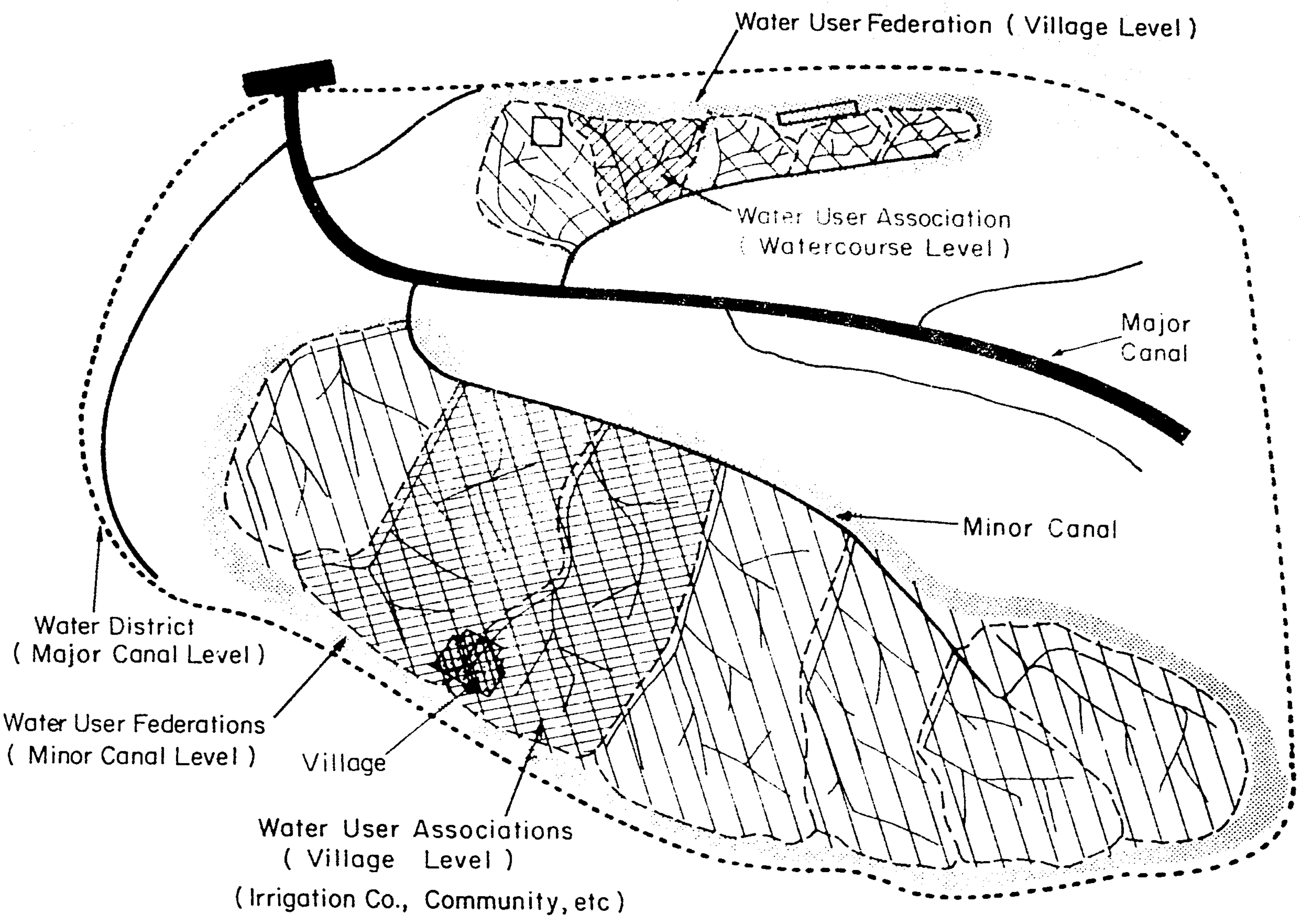

Figure 1. Water User Organizations for Pakistan: Development Scheme.

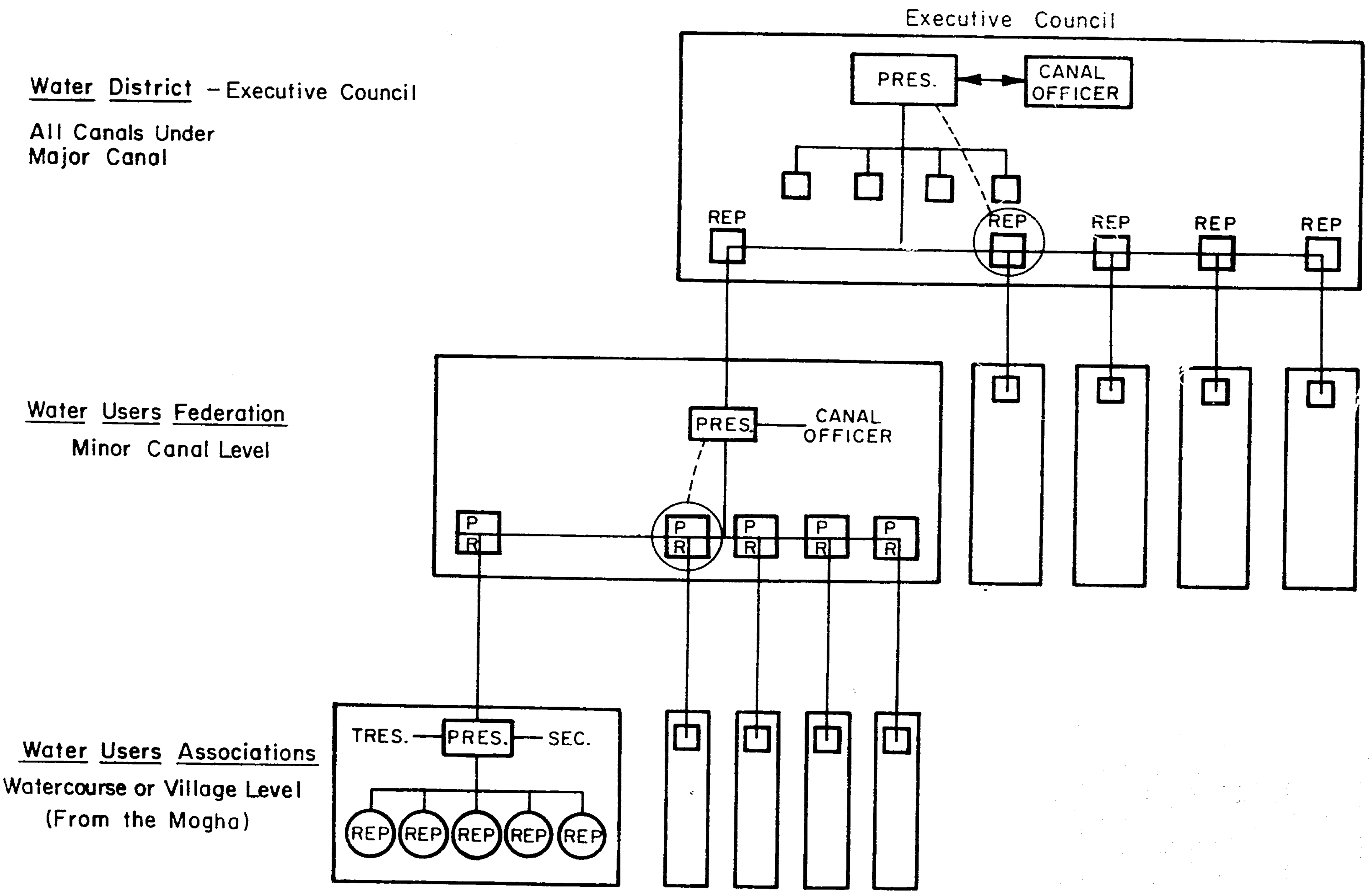

Figure 2. Water User Organization for Pakistan: Organization Scheme

VI. Summary and Conclusions

This paper has made a case that water losses of major magnitude are occurring due to poorly constructed watercourses, that such losses can be reduced in major ways at great savings to the national economy, and that to accomplish the objective of improving watercourses, farmers must be organized to effectively provide themselves with an important collective good--a well-designed, well constructed watercourse which will reduce seepage damage at the head of the channel, and which will increase needed water supplies at the tail.

At present, three organizational alternatives are available for establishing the necessary water users associations--the informal, the authority of the Companies Act, and the authority of the Cooperatives Act. Farmers may elect to organize in any of the three ways, but it is essential to carefully evaluate the outcomes of their efforts before major policy commitments are made.

One of the most important constraints to increasing agricultural production is the limited water supply. The productivity of improved seeds and fertilizers which have constituted much of the "green revolution" is centrally dependent upon adequate supplies of irrigation water. Given an inadequate supply of irrigation water, the farmer must reduce the level of all of his "modern," and relatively costly, inputs. Farmers must accept reduced output and profits in order to decrease chances of loss. Fertilizer is relatively costly and return from its application depends on the delivery of water in adequate amounts and at the proper time. The rational farmer with inadequate irrigation water supplies will apply fertilizer at low levels in order to insure that his marginal costs do not exceed his marginal returns--a most rational response, but one which sacrifices productivity. One of the most important things that can be done to increase water supplies, as well as to reduce water logging and salinity, is to reconstruct poor watercourses which, overall, lose over fifty percent of the water between the mogha and the field outlet. But to reconstruct watercourses and to maintain the improvements, farmers must be organized. This paper has addressed some of the major considerations relevant to that organizing effort.

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APPENDIX 28

FARMER ORGANIZATION TO IMPROVE AND MAINTAIN WATERCOURSES[1]

W. D. Kemper[2]

Basic Ingredients Required in a Development Program

The three basic ingredients for success of a development program are:

1. The program is physically sound and has potential for returning high benefits compared to costs.
2. That the farmers be given what they cannot provide (information, technical services, capital, etc.) and no more.
3. That the farmers understand from the beginning that the development program is theirs - and that while there are limits and regulations governing the extent of government participation, within those limits the farmers are in charge and the success or failure of the program is their responsibility.

Successful development of the third ingredient requires considerable thought and planning on the part of the government employees working with the farmers, so that they are guiding rather than pushing the farmers. We must let the farmers know that we respect their wisdom and judgement in all matters and are available, at their request, to give them technical guidance on their watercourse improvement program.

Need for and Responsibilities of an Executive Committee Chosen by the Farmers

Since there are commonly from 30 to 100 farmers on a watercourse it is impossible to give detailed guidance to each farmer. Moreover, they need an executive committee which they will support and which can make the many decisions necessary in initiating, carrying out, and maintaining the benefits of a development program. Consequently, one of the first responsibilities of the water management team is to help the farmers understand the need for, and responsibilities of, such a committee.

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[1] Presented to On-Farm Water Management Project trainees at Lahore and Hyderabad.

[2] CSU Chief of Party.

The farmers know the capacities of their neighbors for decision making and leadership. When they understand the functions which the executive committee members must perform, the farmers themselves are best able to select the men for this job. Experience at Mona indicates that three strong and active committee members are sufficient to provide the necessary supervision on the construction, plan the program and carry out the other committee assignments. If the farmers feel that acceptance of the program requires appointment of an influential person to the committee, whom they know will not be active, they should expand the committee so there are always at least three active members.

Responsibilities of the committee should include the following:

1. To assist in gathering and controlling laborers for watercourse construction.
2. To resolve land disputes caused by proposed watercourse realignment.
3. To help in site selection for installation of nakkas, check structures, culverts, buffalo baths, etc.
4. To supervise the labor and provide them the necessary equipment.
5. To make decisions concerning where the water normally used by the branch under construction would be used.
6. To censure workers who were late, absent, or whose work was substandard and develop in them a more positive work attitude.
7. To propose essential modifications of the warabundi to the proper authorities.
8. To determine the working hours and schedule for the watercourse improvement program.
9. To determine the labor assessment per holding.
10. To establish a watercourse maintenance program.

Information Needed by the Farmers

The specific approach to be used in helping the farmers organize for an improvement program will depend on the degree to which the farmers are already informed and motivated, on the cooperativeness of the group, and the leadership available.

However, in general, the farmers should first be informed of the program, including:

1. Its potential benefits (in terms of extra water delivered to fields and reduced seepage damage to crops);
2. its costs (in terms of inputs required from the farmers and from the government);
3. the fraction of the farmers that must want, and commit themselves to, the program;
4. the responsibilities (discussed above) which the farmers "executive committee" will need to assume to successfully complete the program;
5. the general physical changes which will occur in their watercourse and limitations in terms of take outs and check structures which the program allows; and
6. the steps that need to be taken on their part if they want to initiate this improvement program.

Prerequisities of this first meeting should include:

a. An invitation from the farmers to come and explain the program to them (this invitation can result from general publicity of the program, personal contacts of team members with the farmers, etc.). However, we should not force our presence upon them but should go only when the farmers have taken the initiative to invite us.

b. Measurements of watercourse losses from their watercourses - preferably including measurements taken with full supply toward the end of the week when the water is in the lower reaches of the watercourse. Estimates of the extent to which high levels of water in their watercourse may be reducing flow from their mogha should be obtained.

c. An outline map of the area commanded by their watercourse, including the extent of the authorized sarkari khal, should be drawn - preferably on a large scale with a felt tip marker so a group can see it.

d. A description of the program including items 1 through 6 above should be printed at the conclusion of this meeting and it should be left with one of their leaders who can read, so they can review and discuss the details among themselves.

When this "information meeting" is closed we should make clear that whether they accept the program or not is their decision and that we can help them if they want to achieve this benefit for themselves, but we will come again only if invited.

We should not press them to accept the program. We should be ready to accept the fact that many groups of users are not ready to enter into such programs. Until there is one improved watercourse to serve as a demonstration, few groups of farmers may have the faith in us to invest their time and resources. The extra time spent in finding a group with good leadership which really wants the improvement will be worthwhile. We should not be discouraged if some of the groups do not invite us back. We should accept this as a natural screening procedure which helps us select the best group for the first program.

If we are invited back, at the time the invitation is made we should ask the farmers to choose their executive committee members prior to or at the meeting.

We must do all we can to ensure that the farmers appointed executive committee continues to feel responsible for the program; that the farmers understand that it is their program. Our role as government employees is to support the executive committee by giving technical advice and informing them of the program regulations.

This "advisory role" rather than the "officious officer role", will require a great deal of personal tact and self-control. If we are able to achieve it, the farmers will accept the direct responsibility and the watercourse improvement program will succeed.

APPENDIX 29

FARM WATER MANAGEMENT: PAST, PRESENT AND FUTURE IN PAKISTAN

W. D. Kemper[1]

A. FOREWORD

Our achievements commonly fall short of our objectives. We often, consciously or unconsciously, hide this shortfall to build our ego and our image in the eyes of our co-workers and administrators. This course of action is not only dishonest, but it is dangerous. When we delude ourselves and our co-workers into believing that our objectives have been totally achieved, when they have not, we halt our progress because we believe that further improvement is not possible and we cease to try. Rediscovery and continual recognition of this potential for improvement, like repentance in our personal lives, opens the way to progress.

It has been my pleasure to work with a team of water management specialists from CSU here in Pakistan during the past few years. It has been our privilege to cooperate with many Pakistani engineers, scientists and administrators in the rediscovery of Pakistan's potential for improvement in water management. As I leave your country and have been asked to write this paper, the temptation arises to dwell on the successes of the programs on which we have worked together, and to imply that we have done the hard work, accomplished all the important objectives, set a good example and that progress will be easy from now on. Such a paper could give us a temporary feeling of accomplishment and goodwill toward each other, but would be basically untruthful and would tend to lull us into the sense of complacency and inaction that has characterized farm water management in the past.

Consequently, this paper will emphasize our potentials for improvement more than past successes. It will imply that we as individuals, and the organizational systems within which we work, have a potential for improvement. Water management in Pakistan will improve as we strive to achieve these personal and organizational potentials.

B. "THE GREAT INDUS FOOD MACHINE"

The Indus Basin contains over 33 million acres of irrigable land, receives about 140 million acre feet of good quality river water each year, and has a climate which allows year-round production of crops. One of the world's biggest and best

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[1] Chief of the CSU Water Management Field Party.

canal systems delivers this water to the potentially rich agricultural areas. The basin is underlain by a permeable sandy aquifer which allows storage of water for pumping as needed for irrigation. This tremendous storage reservoir is commonly within 50 feet of the plants which need the water. Extensive public and private tubewells have been constructed to make this water available to the crops. A manpower resource, involving over 50 million people, is available with common labor costing less than Rs. 1 per hour.

In spite of the availability of the components for one of the world's greatest food machines, in the average season only about 15 million acres of this land is producing and the average yields are low with wheat at about 20 maunds per acre, maize at 13 maunds per acre and rice at 20 maunds per acre. Yields from other countries with similar climates and on Research Stations in Pakistan indicate that these three crops should have yields up around 60, 80 and 80 maunds per acre respectively.

This low productivity is a result of several factors including small farm size and inability of most farmers to afford the implements and power requirement to do a first class job of farming. The farmers are commonly illiterate which makes most of them inaccessible to new technology via the printed word. The extension program is under-financed, poorly equipped and the extension training program does not provide field experiences which give the trainee the ability to develop credibility with the farmers. Many of the farmers, and particularly the smaller farmers, are poor managers, partially because they do not know or are not able to afford a large portion of the management alternatives.

Poor water management is probably the primary constraint on crop production in the Indus Basin. The designers of the irrigation system recognized that there was more land available than could be irrigated with the available water supply. Consequently, they designed the irrigation system to supply about 1 cusec per 300 acres and hoped that the farmers would develop optimum management techniques which would maximize the economic return from the water available. The majority of the farmers have not developed this water management ability and, in the past years, no Government Agency has been assigned to help them do so.

C. EVIDENCE OF POOR WATER MANAGEMENT

A walk along a watercourse, preferably on Saturday or Sunday when the water is being delivered near the tail end, will generally show where a large part of the water available to the farmers through their mogha is being lost. Normally between 30 and 40% of the water coming through the mogha and from the tubewells is reaching the fields at the ends of the watercourse. Measured delivery efficiencies at the ends of watercourses have ranged from 0 to 60%.

Average delivery efficiencies to the farmers' fields on the watercourse are about 55%. These figures for average operational delivery efficiencies are based on measurements on over 600 fields in 46 watercourse command areas in the Punjab and Sind portions of the Indus Basin (Early et al. 1976, Clyma et al. 1975 and Trout et al. 1977).

Another evidence of poor water management is that water levels in the watercourses are commonly so high that they reduce the flow from the distributary to that watercourse below the amount which is actually allocated to the farmers. A survey of moghas in the Mona Project area indicated that over 75% of them were "submerged" in this manner. This problem was especially acute toward the tail end of the distributaries where the supply level of water in the distributary was commonly below the designed supply level. In several cases, when the tubewell was pumping water into the watercourse, water was actually flowing from the watercourse into the distributary. In most cases this high level of water in the watercourse is not a necessary condition but is a result of inadequate cleaning and maintenance by the farmers.

Another indication of poor water management is the extremely poor stands of cotton and maize grown during the kharif season. In a few cases, these poor stands may be attributed to poor seed. However, good stands of these kharif crops can be obtained (Sabir 1976) by planting the seed in the "shoulders" of beds formed between furrows and irrigating with a small amount of water in the furrows if the seeds need more water to germinate, if the seedling needs a lower soil temperature or if a crust has formed and the seedling requires that the crust be softened before the seedling can emerge.

Another evidence of inadequate water management is the high and low spots obvious in a field following irrigation or a heavy rainfall. Farmers normally apply water to a field until the highest spot is covered. This often results in water standing in the low areas for several hours and sometimes for two or three days. Data collected by Wahla and Reuss (1976) show that cotton yields in the low areas are only about half of the yields in the higher areas in the Mona project area. Similar data has been obtained by Rehmat Ali and Bashir Sabir (1975 and 1976) on maize. Bashir Sabir found that, during the high rainfall season of the 1976 monsoon, maize yields were doubled where the maize had been planted on beds between furrows rather than in flat basins. Maize planted on beds between furrows where the furrows were allowed to drain back into the watercourse and thence downgrade to a rice paddy had yields three times those obtained in a flat, enclosed basin where runoff and runon were prevented.

Technology to obtain better yields is available, but farmers are not generally aware of it and some of them do not have the resources to implement these methods even if they knew of them.

D. WHY IS WATER MANAGEMENT POOR WHEN WATER IS SUCH A VALUABLE RESOURCE?

The average watercourse in the Mona Project area receives between 4 and 5 cusecs of water from the mogha and the tubewell. On days when water is running toward the lower end of the watercourse, observable leaks through rat and insect holes and through improperly closed nakkas commonly amount to 10% of the flow at the head, or about 0.5 cusecs of water. Closure of these leaks could generally be attained with the expenditure of less than one day's labor which would save more than one acre foot of water a day. However, this is seldom done in SCARP areas where water pumped from tubewells is costing Rs. 50 per acre foot at the well. Since less than half of this pumped water normally reaches the fields, the actual cost of the tubewell water at the fields is over Rs. 100 per acre foot of water, while the salary of a laborer who could close the leaks in one day would be less than Rs. 10. Since farmers at the tail ends of these watercourses are only receiving about 35% of the water from the mogha and the tubewell, they have a real and recognized need for this water. Reasons proposed to explain their failure to take this action are: (1) That the Abiana charges collected from the farmers for this water are in the range of Rs. 10 to 20 per acre/foot and, consequently, he believes this to be the value of the water, and (2) That the farmer recognizes that by closing these leaks he will be helping his fellow farmers and he has such strong feelings against doing more than his share that he foregoes the benefits to himself.

Cleaning and maintenance becomes more difficult to organize as the number of participants is larger. Assembling between 30 and 150 farmers and assuring that each one does his share is a major problem, particularly when there are long-standing disputes among the participants.

There is generally no legally organized association that organizes the cleaning and maintenance. However, some of these informal groups have well-defined sanctions which are imposed upon those who do not do their part. For instance, on some watercourses where the leadership is very strong, the forthcoming water turn is taken away from the farmer who does not do his part, and is given to another farmer who was willing to do this extra share of work to obtain the extra water. However, this reallocation of the water and most of the other sanctions used are actually not legal. Consequently, most of these watercourse users groups have little legal power to force freeloaders to do their share. This leads to demoralization of the group as a whole and contributes to the inadequacy of the cleaning and maintenance programs.

Most of the farmers do not understand the magnitude of the water losses from the watercourses. Several farmers in the watercourse command areas, where improved watercourses have been constructed, were asked to define the most important contribution of the technical staff to their welfare. Most of them replied that the measurements which showed them how much water they were losing convinced them that they should do something to prevent those losses. They were asked why they had not been able to estimate these losses for themselves by comparing the relative times required for irrigation of acres near the head of the watercourse as compared with those near the tail of the watercourse. Many of these farmers indicated that they had suspected that losses were larger, but that they had heard from other farmers or Irrigation Department personnel that only about 10% of the water was lost from watercourses, and they therefore did not feel that much would be gained from a watercourse improvement program.

Consequently, it appears that part of the inaction of the farmers toward improving their watercourses can be attributed to scientists and engineers who provided them with a gross underestimate of their operational losses. The data on which this estimate was based were from ponding losses observed on 11 sections of watercourses which were carefully selected to avoid leaking nakkas and irregular banks so measurements of the unavoidable losses could be obtained. This data was misinterpreted by successive groups of national and international water management experts to be an estimate of the operational losses occurring in Pakistan's watercourses. This figure of 10% loss became so firmly engraved in the literature that no one put forth the effort to go out and measure the losses that were occurring on operating watercourses. The irony of this deficiency of data is that during the same period (that is, 1967 through 1974), it was extremely difficult for graduate Agricultural Engineers to obtain employment in Pakistan. The academic qualities of these engineers was good as evidenced by the successful participation of many of them in graduate programs at overseas institutions. Unfortunately, however, lack of equipment and transportation at the University had limited their field experience, and they had no tested ability to measure operational losses in the fields. Evidence that at least some members of the faculty recognized the need for developing this relevance to the field problems was the cooperation of Arshad Ali with Wayne Clyma in taking some of the first measurements of operational losses in Pakistan. This cooperation required that Arshad travel 8 to 10 hours by bus or train each time he came up to the Mona Reclamation Experimental Project to participate in these measurements of watercourse loss and irrigation application efficiencies.

Another factor which has played a major role in the poor water management is the lack of equipment to efficiently manage the water and shape the soil surface to direct the water to its proper destination. The common tools available to the farmer are the native plough and the kassi. A farmer who can force a 5 cusec stream of water from a lower branch to a higher branch using only a kassi has my profound respect. However, considerable soil is carried downstream from the bund as he builds it, new soil has to be borrowed to build the bund each week and the result is an extensive borrow pit and eventually a weakening of the watercourse banks at that junction.

When it is suggested to the farmers that they adopt furrow and ridge or furrow and bed type of irrigation and planting, their reply is often that it would be too expensive because it would take them from 5 to 10 days per acre to build the desired furrows using their kassies. The possibilities of adopting furrow and bed type of cultivation using a bullock-drawn lister to make the furrows does not occur to them because most of them have never even seen a bullock-drawn lister in operation.

When asked how much water he applies to his crop per irrigation, the farmer can only guess based on the amount of water standing in the fields when he closes his nakka. He not only does not understand the relations between rate of flow, time of flow, irrigated area and depth of irrigation, but he has no means of measuring or estimating the flow of water in the watercourse at the point where it is delivered to his fields.

In summary, the reasons for poor water management in Pakistan include lack of cooperation among farmers, lack of knowledge about losses which leads to lack of motivation to improve their watercourses, misinformation from Government sources which led them to believe that they were losing only about 10% of their water from their watercourses, inadequate equipment to manage water, and a deficiency of field training in the curriculum of the Agriculture Engineers which prevented them from performing their proper function in analyzing the water management system, identifying its deficiencies and defining its potential for improvement.

E. CURRENT PROGRAMS FOR THE IMPROVEMENT OF WATER MANAGEMENT

Arshad Ali's investment of time and bus tickets which allowed him to cooperate with Wayne Clyma in the measurement of watercourse losses and irrigation application efficiencies paid some rich dividends. They published data (Clyma et al. 1975) indicating that some watercourses were losing an average of almost 50% of their water rather than the 10% which had been previously estimated. This means that the average farmer on those watercourses could increase the amount of water delivered to his fields by almost 100% if he could stop all the loss. A large number of Government personnel who had built the 90% delivery efficiency into their hydrologic models and planning schemes for almost a decade, were not willing to believe that delivery efficiencies were only 50 or 60 percent. They argued that the Mona Project area was probably not characteristic of all the watercourses in the Punjab and did not appear to recognize that a large part of the measurements presented by Clyma et al. (1975) were measurements that had been taken by Waryam Mohsin, Siddique Shafiq, Mohammad Afzal and Iqbal Pervez in the Lyallpur, Multan and Lahore areas. The arguments of these unbelievers were helpful because they generated support for a wider survey to determine whether these high watercourse losses occurred in other parts of the Punjab and Sind. Alan Early et al. (1976) organized this survey to measure watercourse losses, irrigation application efficiencies and related factors influencing water management and it was conducted by the Survey and Research Section of the Master Planning Division of WAPDA and CSU. This survey showed that water delivery efficiencies through watercourses averaged about 53% in the Punjab and the Sind which was similar to the earlier data taken in the Mona-Lyallpur-Lahore-Multan areas. But it also showed that the irrigation efficiencies measured in these provinces were up in the range from 50 to 80% during the seasons of measurement compared to the irrigation efficiencies down around 20 to 30% which were measured by Clyma et al. during 1973 and 1974 in seasons, which were much wetter than the average and primarily in SCARP areas. While the CSU-Mona reports had never actually said that this low application efficiency data (20 to 30%) was characteristic of the Indus Basin in all seasons, we did not adequately disclaim this possibility. Many readers of our early reports assumed that we were assuming application efficiencies averaging only 20% in the whole Indus Basin. One designer of ground water models commented that, "If delivery efficiency was only 50% and application efficiency only 20%, the water table would have risen to 20 feet over our heads by now!" If the WAPDA-CSU data taking had stopped in 1974 and we had allowed the planners to use and overgeneralize the limited data obtained on application efficiencies, we would have contributed to an inaccuracy in estimating average application efficiency of the same magnitude as the previously discussed inaccuracy in estimating the average operational delivery efficiencies.

Before the USAID sponsored survey was under way, it was recognized that this survey would obtain data from specific watercourses at only one point in time, and that following the water losses, irrigation efficiencies and other water management practices throughout a whole year would give additional information that would be helpful in determining the potential for improvement of water management in Pakistan.

Consequently, the 15 or 20 Agricultural Engineers recruited by Alan Early for the USAID funded survey were given assurance that they would have continued employment through the course of the follow-up survey which would be funded by the World Bank under the direction of WAPDA Master Planning Division, Survey and Research Section. These surveys employed the largest contingent of Agricultural Engineers in a single project to date in Pakistan. The data which they are obtaining will give Pakistan one of the most complete sets of information regarding farm water management systems that is available anywhere in the world. This information set will provide the basis for determining the direction and magnitude of farm water management improvement projects to be funded by the World Bank in Pakistan.

Meanwhile, USAID and the Pakistan Government were sufficiently convinced of the potential for improvement in water management that they developed the "On-Farm Water Management Program" which includes land leveling, watercourse improvement and improvement of water use efficiency as its three primary components. The land leveling component was designed on the basis of cost feasibility for land leveling evaluated in a previous precision land leveling program carried out by the Agriculture Departments, advised by a team from the U.S. Soil Conservation Service and funded by USAID. The other two components were based largely on the water management and pilot watercourse improvement programs which had been part of a joint Mona Reclamation Experiment Project-CSU research effort in 1973 through 1976. Both of these projects were staffed to a large extent by Agricultural Engineers.

At present these On-Farm Water Management Projects have been initiated in the Punjab and the Sind Provinces where teams involving one Team Leader, four Land Leveling Officers, two Watercourse Improvement Officers and one Water Management Officer are being stationed at selected locations within the province. Five of these teams have been placed in the Punjab and three in the Sind. The NWFP is scheduled to begin their program next year. In the process of selecting personnel for these teams, the end of the supply of Agricultural Engineers was reached and a large portion of these team members will have to be Agricultural Graduates who have received short course training in land leveling and watercourse improvement. Agricultural Engineers will have preference for positions on these teams, and, if they perform adequately, will probably be selected for leadership positions. However, with the planned recruitment and activation of about 80 of these teams planned in Pakistan over the next 4 or 5 years, it is apparent that the Agricultural Engineering Departments will not be able to produce sufficient engineers to fill even a majority of the positions.

These teams are expected to improve about 1,500 watercourses and level about one million acres of land. If their efforts in cooperation with the farmers produce the benefits/costs ratios which have been indicated by the pilot studies at Mona and in the Precision Land Leveling Program, the World Bank has indicated an interest in expanding this program to include the rest of the 88,000 watercourses in Pakistan. World Bank experts are already studying the problems of where adequate supplies of Agricultural Engineers could be obtained, and what types of other personnel such as sub-engineers and field assistants, could be recruited and trained to do the more routine aspects of these land leveling and watercourse improvement jobs under the direction of qualified and field-trained Agricultural Engineers.

In the past there has been considerable reluctance on the part of some of our Agricultural Engineers to train sub-engineers and field assistants to operate levels so the field assistants could independently obtain the elevation data for all bunded areas that are necessary for the proper design of a watercourse, or for land leveling of farmers' fields. Probably as a result of memories of the past when jobs were not available to Agricultural Engineers, there was a feeling that if these sub-professionals were trained to do these jobs, they might take away jobs from the Agricultural Engineers. That danger is past. From now on, any Engineer who is willing to work will have more jobs in Pakistan than he can handle because he will be asked not only to level land, improve watercourses and develop and demonstrate water management and cultivation and seeding equipment, but he will be increasingly called upon to play leadership and training roles in the development of the army of personnel that will be required to help the farmers improve their water management.

In addition to the many positions available in these survey and implementation programs, there is a continuing and expanding need for Agricultural Engineers in research programs such as those at the Mona Reclamation Experimental Project, the Agricultural Research Council, the Irrigation Drainage and Flood Control Research Council, the IRRI-PAK Machinery Development Program and several other organizations in Pakistan. These research institutions will provide the continuing flow of solutions to farmers' problems which will bring about the evolution of the water management implementation programs to their most efficient form.

In planning the development of the On-Farm Water Management implementation teams, it was recognized that the farmer needs help in using the water after he gets his land leveled and gets the water to his land. He needs help to improve his methods and timing of irrigation, to clean and maintain his watercourses, to form furrows and beds and place the seed properly, to design and maintain his private-owned sub-branches, to properly deliver the water to his fields, to organize and cooperate to efficiently manage his water distribution system, to cooperatively own water management and crop production equipment which can increase his crop yields, to properly manage, recharge and recover water from his underlying and sometimes saline aquifer and to plan his cropping schedule to optimize the use of his water, land, labor and power resources to maximize his economic return. The breadth of training required here can only be obtained at a university and the University of Agriculture at Lyallpur was selected as the institution which should train one person on each team to do these jobs. While the teachers in the various concerned disciplines were available, and were academically qualified, they have not generally had the opportunity for field experience which would allow them to prescribe with confidence the solutions to the farmers' problems and to predict the farmer's reactions to those prescriptions. Gaining this field experience will require considerable investment of their time, facilities to travel to the field and funding to conduct relevant studies when they get there.

A group of proposals are being submitted from the University to USAID which, if funded, will provide several Research Assistantships on which persons in the Agricultural Engineering and other faculties can pursue advanced degrees with various aspects of water management research and training as the subject of their theses. This combination of field research and field training is essential to the development of a training program in water management which will fill the real needs of the farmers, remain relevant to the farmers' problems and improve with time.

F. WATER MANAGEMENT TECHNOLOGY FOR THE FUTURE

1. Irrigated Lands

There appear to be opportunities for redesigning of watercourses which would save an appreciable portion of the losses, even when the normal rodent and insect populations move back in and riddle the banks with holes. One such design would be to lower the normal operational level of the watercourse down to near the level of the soil surface. Data obtained by Kemper et al. (1975) and more recently and extensively by Moh'd Akram at Mona (personal communication) indicates that the losses of water from mature watercourses doubles for about each 2" increment that full supply level is raised above the surrounding land surface in the straight sections between junctions. Data obtained by Trout et al. (1977) indicate that losses from one main branch of the watercourse serving Tubewell 81R, which had a full supply level that was near the ground surface, were only about 1/2 of the losses which occurred when the fully supply level in the watercourse was several inches above the surrounding soil surface. The water level must be raised above the surrounding soil surface at the point of delivery and this may cause the water level to rise in the watercourse for a distance of 1,000 or more feet above the point of delivery. However, if the water is being delivered at the end of a 8,000 foot watercourse, there is normally no necessity of placing this water in a high and vulnerable position in the first 6 or 7,000 feet of its journey. All that is needed to accommodate this lowering of normal operational level is to excavate the watercourse an extra six or eight inches and to provide check structures which can raise the water to the desired levels at the delivery points. To avoid dead storage in such deep watercourses, a field will be needed somewhere in the lower reaches of the watercourse. It has been observed that this type of field is often naturally available and, when it is not, the extra water is often drained out to fill the village pond, or some farmer has sold soil to a brick factory or otherwise excavated a field so he can recover most of this water.

There is also some data which indicates that, if water is maintained at a constant level in the watercourse, erosion and insect activity is limited to the unsaturated zone where it does not increase the loss. These findings indicate that it may be feasible to split the flow in a watercourse into two or more constantly running streams which would allow farmers to take the water in smaller streams more frequently or for longer periods of time. This might be especially helpful in the large SCARP watercourses where five or six cusecs of water is often difficult to handle. Splitting the water in this manner would reduce the headlos in the watercourses and would allow building of smaller watercourses, check structures, culverts and otherwise decrease the cost and land area occupied by the watercourse.

As the benefits of furrows and beds over the flat basin planting become obvious for kharif crops, the farmer will want to try the furrow system. He will find that the furrows must be filled and water maintained at a given level until the desired amount of water has been absorbed by the field. If he allows that water level to come up over the beds, a large portion of the benefits of this system will be lost. Consequently, he needs a "controlled level" water distribution system, with extended overflow weirs which allow the water not needed on that field to pass on down the watercourse to the next field when the proper level has been achieved. Such systems are not extremely expensive, but they will require precise engineering and installation and the farmers will need the help of engineers.

Eventually the production levels should increase, value of produce will increase and the value of water will become so high that pakka lined watercourses, or underground pipe distribution systems will be good investments. These will require extensive engineering involving storage capacity, sediment traps and provisions for cleaning as well as normal design factors. The engineer, or his assistants, will also be required to give farmers guidance on precisely when to irrigate to achieve optimum benefit from his water.

2. Barani Lands

In a recent discussion paper (Kemper et al. 1977), the potential for improving water management on barani lands by forming contoured bunded benches to hold all the incident rainfall was evaluated. Using production vs available water functions obtained in the Lyallpur area, it appears that when available rainfall during the crop season is in the range from 30 to 40 cm and the normal runoff is more than 15%, formation of such leveled bunded benches can increase yields during the first wheat season sufficiently to pay for the total cost of the earth moving. Considerable engineering would be needed to build these level contoured bunded benches.

In areas with rainfall available during the cropping season in the 15 to 25 cm range, which have negligible production at present, treatment of part of the area to shed its water and leveling, bunding and cultivating of a lower area to receive this water and grow crops appears to have potential economic feasiblity. This runoff-runon type of agriculture could bring a major part of Pakistan's arid lands into production, but would require careful design of the runoff areas to minimize erosion, and of the planted areas to provide adequate water and to make provision for overflow into grassed waterways.

The research and development phases that will be necessary to determine the actual potential of improved water management for increasing crop production in barani areas and providing the guidelines for a development program will be essentially the same as the phases followed in developing the watercourse improvement program for the irrigated areas.

The first phase will involve determination of whether there is an economically feasible potential for improvement of crop production by improvement of water management on barani lands. Given the framework provided in the discussion paper (Kemper et al. 1977), it appears that this can be done by a limited survey to determine: (1) whether there are areas where water available during the crop season is in the 30 to 40 cm range where average runoff is greater than 15%, and (2) Whether it is economically feasible to treat some soils in the areas where there is 15 to 25 cm of water available during the crop season in a manner such that average runoff from them can be boosted up into the 25 to 50% range.

The second phase will involve (1) Field scale trials of the technology with farmers on their lands to adapt it to the resources of the farmers and determine actual costs, benefits and acceptability of the program and (2) Concurrently, an extensive survey should be conducted to determine the rainfall runoff and potential for managing runoff in the barani area.

The general survey and research program should follow the same basic steps that were used in the watercourse improvement case. The work done by Waryam Mohsin, Mohammad Afzal and Arshad Ali with Wayne Clyma (e.g. Clyma et al. 1975) on watercourse losses and the research on methods for reducing losses by earthen improvements (conducted by Mohammad Akram, Iqbal Pervez and Malik Iqbal with Kemper, e.g. Kemper et al. 1975 and Kemper and Akram 1975) were the equivalent first phase activities which determined that there was an economically feasible potential for improvement of watercourse.

The second phase will be comparable to the Mona-CSU pilot watercourse improvement program and the surveys conducted concurrently by the WAPDA-CSU and World Bank Teams.

There will be a need for hard working field trained engineers at every stage.

3. Opportunities in the Private Sector.

The benefits of improved water management are becoming more obvious. The increase in water supplies to fields as a result of improved watercourses, and increased application efficiencies and crop production due to land leveling and furrow irrigation are observable and measurable benefits to the farmer. We as Agricultural Engineers should be the first to measure these benefits and perform the elementary economic analyses which will show whether our input is worth our pay!

If we find that the government agency which is hiring us is paying us more than our inputs are worth to the farmers, we had better work harder, because the potential benefits are there.

If, however, we find that our inputs are providing farmers with benefits that are far greater than our pay, we should not complain about the government pay scales, but should plan opportunities to go into private consulting and development work, directly with the farmers. Our real value to society will not be firmly established until at least part of us have established private practices.

Government should only do for farmers and engineers those things which they cannot do for themselves. Our strength grows as we do all that we can for ourselves and extend our help to others.

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APPENDIX 30

IMPROVING IRRIGATION WATER MANAGEMENT IN THE INDUS BASIN

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"Water Problems in The Indus Food Machine" (Johnson et al., 1977a) details the extent of the irrigation water management problems that exist in the Indus Basin. Low delivery and application efficiencies, inadequate and under-trained extension staff, uneducated and unknowledgeable water users, economically vulnerable irrigation personnel and greedy water users all contribute to the massive water management problems. Recent interest by the World Bank, USAID, the British Government, the United Nations and other international donor agencies on water management problems has focused on the importance of reaching the end users of an extensive irrigation system. The engineering bias and large scale structural approach to solving water shortage problems is often only partially successful because the problem involves the socio-economic and institutional framework of the system itself in addition to the technical aspects.

The purpose of the "Water Problems in the Indus Food Machine" article was to analyze the practical, field level water management problems that restrict the output of agricultural products in many developing countries. The purpose of this paper is to present data from current research that documents potential benefits from implementing appropriate solutions to these problems. These recommendations are not the final and only set of actions, but they represent a set of solutions that appear to be viable under the institutional and socio-economic conditions that currently exists in the Indus Basin.

The first section provides an introduction to the irrigation system in the Indus Basin. The second section contains a rather detailed background on various aspects of the terminal watercourse system including an explanation of the watercourse layout, of the water supply schedule, and of the watercourse level organization. The third section outlines the results of recent research and presents some tentative solutions and their expected results. The fourth section re-examines the entire problem and presents a more comprehensive set of

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solutions that encompasses not only the technical manifestations of the problems, but also the socio-economic institutional framework that fosters the development and continuation of the low level of water management. The final section assesses the recommendations and draws conclusions.

INTRODUCTION

The bulk of the irrigation system that serves the Indus Basin was designed to eliminate the famines that inevitably occurred when the rainfall was light or unseasonal. The Indus Basin was visited by severe famines in 1783, 1802, 1812, 1817, 1824, 1833 and 1837. Erratic monsoons again caused serious famines in 1851-1852, 1860, 1868-1869 and 1877-1878 (Thompson, 1925). However, since 1878 famines have not reached serious proportions because of the expansion of the irrigation-canal system. Presently, the system serves over 33.5 million acres and is the largest contiguous irrigated acreage in the world.

The perennial canal system, while being designed to eliminate the possibility of famine, was not designed for maximum production on the irrigated lands. Although two or more crops can be grown per year the first irrigation system designers planned for a cropping intensity averaging one crop per year which was defined as a cropping intensity of 100 percent. However, the earliest canals were troubled with waterlogging and an intensity of about 75 was actually achieved; although, in some canal commands that were plagued by waterlogging and salinity, only about 50 percent cropping intensity was achieved (Thompson, 1925).

In order to maintain a cropping intensity of 75 percent, the canals in the Punjab were generally allocated one cubic foot per second (cusec) of water for every 333-350 acres of culturable command area (CCA). Most of the canals in the Sind were allocated one cusec per 300 acres of CCA due to higher evapotranspiration rates in the south.

The irrigation system was designed by the British to be simple in order to operate at a minimum cost of skilled managerial manpower and capital. "There was also something of an ideological belief in the virtues of non-interferency by government officials below the watercourse level, which was connected with the object of minimizing opportunities for corruption" (Paustain, 1930).

BACKGROUND

A. Watercourse Layout

The term "watercourse" is commonly used, in the Indus Basin, to mean either the total network of delivery ditches fed by one outlet from the distributary, or the land area served by that network. In order to avoid confusion, we will confine the use of the term "watercourse" to the network of ditches and will follow Eckert et al. (1975) in using the term "watercourse command area" to denote the land area served by the network of ditches served by an outlet from the distributary. At this outlet from the distributary, commonly called a "mogha," the water passes from the control of the Irrigation Department to the control of the water users.

There are over 88,000 watercourse command areas in the Indus Basin with over 78,000 watercourse command areas located in the Sind and Punjab provices of Pakistan. The average irrigated acreage on these command areas is 400 acres each with an average of 40 farmers owning land in each area. However, watercourse command areas vary widely in size and configuration and each watercourse is unique in itself. Watercourse command areas will be found where up to 150 farmers own the land, while other watercourses may serve only one or two large landowners. Land ownership is not necessarily synonymous with land operation. In a watercourse command area where, for example, 40 farmers own land, it is not unusual to find only 25 farmers actually operating the land. Often while two or three brothers may jointly own the land, only one brother will do the actual farming. Thus, the average "land holding" is smaller than the average "operational unit" found in the field.

The main channel which delivers water from the mogha (and/or tubewell) to the farmers' property is called the "sarkari khal." The provincial Irrigation Department authorizes the location and width of the right of way of the sarkari khal. This sarkari khal with its main branches is supposed to provide each farmer with legal access to the water, which cannot legally be defined by the intervening farmers who own the land through which the sarkari khal runs. The right of way generally extends a few feet beyond each bank, allowing the users as a whole to take soil from the farmers' land to build and maintain the sarkari khal (Radosevich, 1975).

The sarkari khal leads the water to an extensive system of field channels which are built, controlled and used by the farmers to irrigate their individual fields. Examination of a large number of watercourses has shown that there is an average of about one mile of delivery channel, including sarkari khal laterals and farmers ditches, for every 20 acres (Eckert et al., 1975). The percentage of the total water delivery channels that are authorized by the Irrigation Department and operated collectively by the farmers varies from 5 percent to 15 percent, with the topography, watercourse command area configuration and ownership patterns determining the percentage. For example, the 900-acre watercourse serving Tubewell 56L in the Mona Reclamation Experimental Project (MREP) area contains approximately five miles of sarkari khal and 40 miles of minor ditches. (See Figure 1.)

B. Water Supply Schedule

In a perennial canal system, the water flows constantly in the distributary as long as there is need for the water and sufficient flow in the river, unless the canal is closed for maintenance or repairs. Therefore, water flows in the distributary and, consequently, through the mogha and down the watercourse 24 hours per day for about 340 days per year. The irrigation rotation (warabundi) period is usually seven days, although two week rotations do exist in some canal command areas. On a seven day rotation, every farmer receives water allotted to his land for a specific time period during the 168 hours in a week. Assuming the watercourse command area is 333 acres and the water allocation is one cusec for 333 acres, each acre receives an allotment of approximately .5 hours per acre. Since one cusec flowing for an hour is approximately equal to an acre inch, the water authorized to the farmer is about one-half inch per acre each week. This water is not applied to each acre each week but is distributed on the cropped fields as the farmer determines the need. However, given the magnitude of the delivery and application losses in the unlined watercourses and poorly managed fields, the farmers, on the average, lose more than half of the water before it reaches the root zone of their crops (Freeman and Lowdermilk, 1976). The farmers at the tail of the system lose more than the farmers at the head and these tail-end farmers are generally less successful and affluent compared to the farmers located near the head of the watercourse. Table 1 presents a set of representative results to illustrate the effects of location on the watercourse crop yields.

C. Watercourse Level Organization

The irrigation system existing in the Indus Basin is a large-scale bureaucratically-managed system that delivers, with a minimum of human interactions, a fixed product to the eventual users. The irrigaton system is the property of the government and there has been little attempt to interact with, or to organize, the water users (Freeman and Lowdermilk, 1976). The water arrives at the mogha and then passes into the control of the farmers who have no control of the amount delivered.

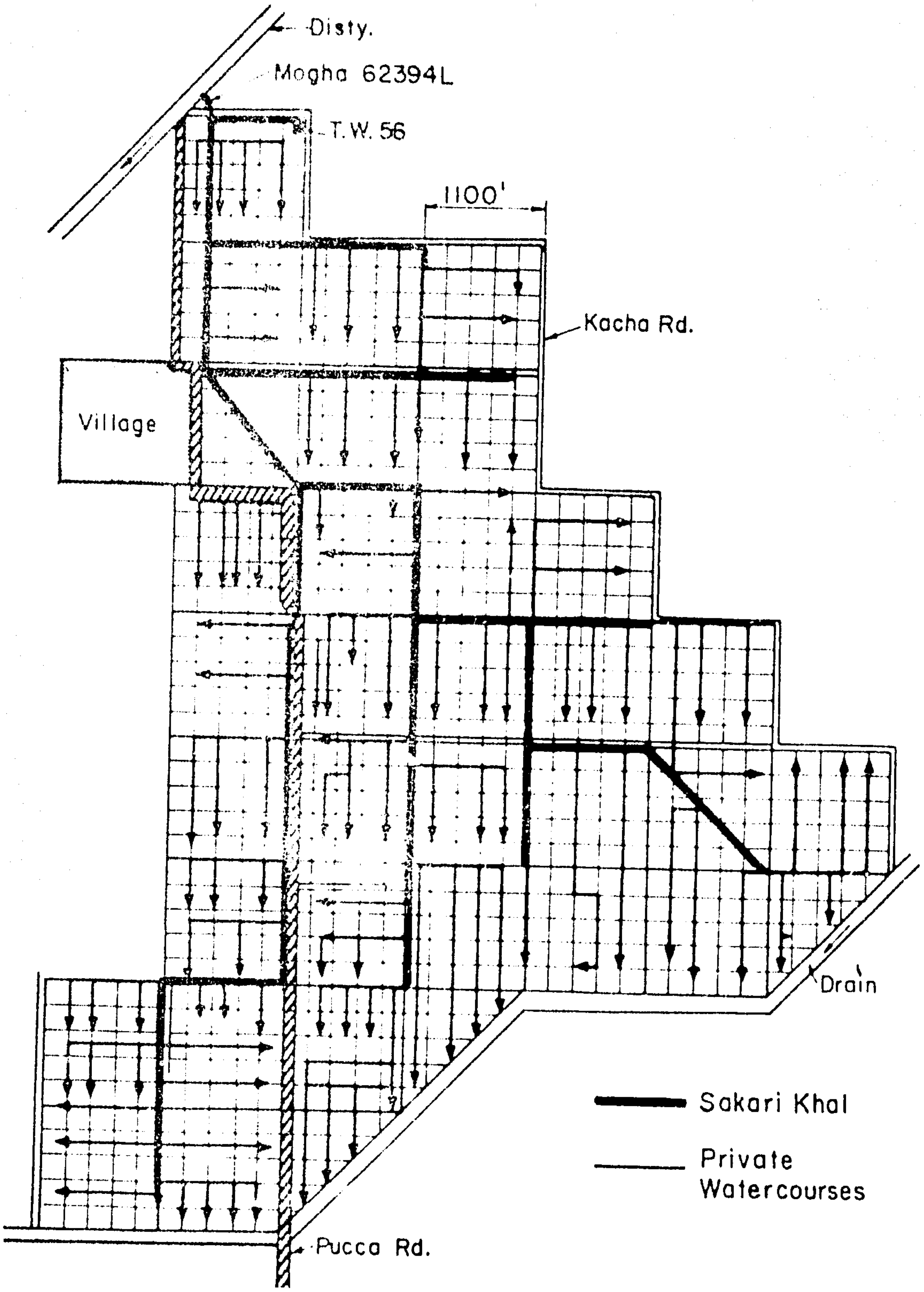

Figure 1. General plan of T.W. 56 watercourse. Lines leading to arrows are watercourses. The heavy dark lines are the authorized sarkari khal.

TABLE 1. Distribution of Average Yields Along Watercourse.[1]

Crop	Head (Tons/Ac)	Middle (Tons/Ac)	Tail (Tons/Ac)
Wheat	1.94	1.19	1.00
Rice	.84	.57	.58
Cotton	.36	.25	.21
Sugarcane	16.5	9.79	10.4

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[1] Hussain, et al. (1976).

If it rains four inches, or if it is 115°F, the system is designed to deliver the same amount of water with the same rotation schedule.

On the majority of the watercourses, while there is not a formal organization of users, there is some form of community effort to periodically clean the sarkari khal. A common method followed is for the entire group of farmers to start at the mogha working together to clean the sarkari khal. Farmers leave this work force as they reach the outlets to their respective properties, leaving those owning land further downstream to provide the majority of the labor (Mirza et al., 1975). Although they have no legal basis for doing so, the villagers often employ sanctions against noncooperators to induce them to do their share.

The lack of a community responsibility for upkeep of the entire watercourse system, combined with the reluctance of the Irrigation Department to assert its full legal authority at the watercourse level, has resulted in a "tragedy of the commons" (Hardin, 1968).

The watercourse is a common property of all the farmers, yet it belongs to no one. The benefit of watercourse improvement is distributed among so many farmers that unilateral improvement work on the system does not provide sufficient benefit to the improver to be a good investment. Without a community commitment to organize to maintain the system, and rules and sanctions to assure participation, individuals commonly attempt to maximize their net benefits from the common property by minimizing their contribution to the system's upkeep. Hence, the system maintenance is poor, and the losses of water are much higher than necessary.

REDUCING WATERCOURSE LOSSES

Extensive research and surveys by the Colorado State University Water Management Research Team in Pakistan, in conjunction with the staff of the Mona Reclamation Experimental Project (MREP), the University of Agriculture, Faisalabad (UAF), the Department of Agriculture, and the Master Planning Section of WAPDA have shown that the operational delivery losses on watercourses in Pakistan average over 40 percent (Clyma et al., 1975) of the water passing through them as compared to the 10 percent loss rates that were previously assumed (Harza, 1963). These are the losses that occur in the water channels under the control of the farmers and do not include the losses from the canals.

A. Lined Watercourse Channels

Losses can be minimized by lining the watercourse channels, and during the mid 60's and early 60's, it was the policy of the Government to encourage lining of the watercourse channels. Due to staff and resource constraints, this program was never implemented except on a few pilot watercourse channels. In the fall of 1973, two experimental brick masonry and concrete lined watercourses were constructed by a contractor for research purposes by the Mona Reclamation Experimental Project and the Colorado State University Water Mangement Research Team. The distances of the main channel and branches line was 14,225 feet and 15,778 feet, respectively. Different shapes and widths were constructed in order to evaluate the effectiveness and costs of alternative methods of construction. Table 2 contains a tabulation of the alternatives tested.

From Table 2 with an average cost of approximately Rs. 40 per linear foot and 14,225 feet and 15,778 feet, respectively, the costs for the two lined watercourses were Rs. 569,000 and Rs. 631,000. For the two watercourse command areas, this amounts to Rs. 1,039 per acre and Rs. 1,207 per acre, respectively.

Losses on the above two watercourses averaged between 5 and 10 percent of the water per 1,000 feet before improvement. Table 3 details the changes in losses after concrete lining.

From Table 3 it is apparent that the average loss rate after lining is about 47 percent of the original average loss rate. It is also interesting to note that a touch up and plastering job after completion of the improvement will reduce the losses by another 90 percent so that a proper job of watercourse channel lining can result in an overall delivery efficiency of over 94 percent when all the field outlets (nakkas) are properly closed and sealed. The annual water flow to the above lined watercourse is approximately 2,040 acre feet per year. With losses of the magnitude of the data presented in Table 3, more than 1,000 acre feet are lost from the main watercourse channels per year. With a proper, quality controlled lined channel and main branches, and careful attention to sealing of all the nakkas, the losses can be reduced to only about 122 acre feet per year, or an annual savings of 878 acre feet. If this lined channel is given a twenty year life and amortized at 12 percent, the annual capital cost is Rs. 76,140. Including a maintenance and repair cost of 1.5 percent of initial costs, the annual costs for the lined watercourses are Rs. 84,671. With a savings of 878 acre feet of water per year, the cost per acre foot saved is Rs. 96.

With the limited engineering manpower available, it is nearly impossible to design and supervise the lining of 88,000 watercourses. Farmers have viewed these lining efforts as the responsibility of the government and once the watercourse channels are lined, the farmers tend to feel that the lined channels belong to the government; therefore, the farmers

TABLE 2. Alternative Lined Watercourse Dimensions and Costs.[1]

Watercourse No.	Shape	Channel Dimensions Width (Bottom) (feet)	Depth (feet)	Wall Thickness (inches)	Material	Length (feet)	Cost/Foot[a] (Rupees)
MN-78: Main	Rect.[b]	1.75	2.5	13	masonry[e]	5000	50
MN-78: Main	Rect.	1.75	2.0	9	masonry[e]	2200	45
MN-78: Branch E	Trap.[c]	1.5	1.7	3	concrete	642	33
MN-78: Branch C	Trap.	1.5	1.7	3	concrete	789	30
MN-78: Branch F	Trap.	1.5	1.7	6	masonry	2798	50
MN-78: Branch U	Rect.	1.75	2.0	4.5	masonry[e]	1000	24
MN-78: Branch K	Trap.	1.5	1.7	3	concrete	809	27
MN-78: Branch D	Trap.	2.0	2.0	mud[d]		4000	10
MN-122: Main	Rect.	2.0	2.5	13.5	masonry	5250	50
MN-122: Branch R	Rect.	2.0	2.5	9	masonry	2188	48
MN-122: Branch E	Rect.	2.0	2.0	4.5	masonry	4040	38
MN-122: Branch I	Rect.	2.0	2.0	9	masonry	4200	45

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[1] Muhammad Akram and W. D. Kemper (1977).

[a] One dollar equals approximately 10 rupees.

[b] Rectangular.

[c] Trapezoidal with 1:1 side slope.

[d] Earthen improved by contractor labor and elevated so bottom is higher than surrounding soil surface.

[e] With cement-sand plaster on the inside surface of the walls.

TABLE 3. Before and After Losses on Lined Watercourse Channels[1]

Watercourse No.	Loss Rates in Cusecs per 1000'		
	Loss Rate Before	Loss Rate After*	Loss Rate After Replastering
MN-78: Main	.40	.008	---
MN-78: Branch C	.56	.05	---
MN-78: Branch E	.68	.38	.014
MN-78: Branch K	.74	.55	.002
MN-78: Branch F	.44	.15	.012
MN-78: Lower Main	.70	.47	.01
MN-78: Branch J	.25	.08	.038
MN-78: Branch I	.36	.003	---
MN-78: Branch I	.40	.08	.042
MN-78: Branch F	.61	.30	.04
MN-78: Branch F	.75	.76	.01
Average	0.54	.26	.023

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*Not including losses at junctions and field outlets.

[1] M. Akram and W. D. Kemper, 1977.

tend to refuse to contribute labour or capital to maintain the lined system. Finally, the low quality workmanship on some branches of the watercourses that have been lined has raised some question as to whether the potential savings will generally be realized by lining watercourse channels.

The capital costs of lining 88,000 watercourse channels and main branches is over Rs. 43 billion or $4.3 billion. Pakistan cannot presently afford such a massive investment, and lining of watercourse channels does not solve the institutional problems that lead to low agricultural production.

With the high costs for concrete and brick lining, alternative lining materials have been suggested. Extensive studies by the Punjab Irrigation Research Institute on plastic linings concluded that this alternative was also quite expensive and was subject to damage from livestock, resulting in rapid deterioration. Soil-cement blocks have been made and used for watercourse lining (Akram and Kemper, 1976). Table 4 presents loss rates on watercourse channels before and after lining with soil-cement blocks.

Comparison of the data in Table 4 with that in Table 3 indicates that the quality of construction with soil-cement blocks was generally better than the contractor-built concrete and brick lined watercourse channels. The costs of the soil-cement lined sections were about Rs. 25 per foot, so with the given annual flow of 2,040 acre feet of water, the annual losses would be about 256 acre feet. If soil-cement block lined channels are estimated to have a 15 year life and amortized at 12 percent the annual capital cost is Rs. 52,176 for the 14,238 feet of lined channel. Including a maintenance and repair cost of 1.5 percent of initial costs, the annual costs for the soil-cement block lined watercourse channels are Rs. 57,506. With a savings of 744 acre feet of water per year, the annual cost per acre foot of water saved is Rs. 77 (as compared to Rs. 96 for the fired brick masonry). However, with the recent increase in the price of cement, soil-cement block construction costs have risen and the cost differential between these two alternatives has been reduced about 50%.

The majority of the losses from watercourse channels are through the porous upper portions of the banks and through poorly sealed outlets and junctions (Kemper et al., 1975 and Kemper and Akram, 1975). Seepage through the bottom of the watercourses is a relatively minor percentage of total losses. These results suggest that it may be possible to line the sides of the watercourse, thereby leaving the bottom unlined with the sediment acting as a sealer. In order to determine the construction costs, leakage rates, and longevity of this type of watercourse, a series of lined watercourse channels were constructed with concrete and brick sides (75° from

TABLE 4. Water Loss Rates Before and After Lining with Soil-Cement Blocks in Test Section of Branch I of the Watercourse Serving Tubewell 78.[1]

Section No.	Loss Rates in Cusecs per 1000'		
	Loss Rate Before Lining	Loss Rate After Lining	Loss Rate After Replastering
1	.36		.004[2]
2	.25		.002[2]
3	.40	.082	.048[3]
4	.40	.087	.036[3]
Average	.35	.085	.023

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[1] Akram, M. and W. D. Kemper. (1976).

[2] Plastered immediately after lining was installed.

[3] Plastered one year after lining was installed.

horizontal) and earthen bottoms. The earthen bottoms quickly seal due to the deposit of silt and have loss rates comparable to the other alternatives. These "side linings" reduced the water losses by about 80%. The cost per foot of watercourse for this alternative was about Rs. 15, so with a savings of 592 acre feet per year and annual costs of Rs. 34,511 for the 4,238 ft. watercourse, the cost per acre foot of water saved is Rs. 58.

B. Unlined Watercourse Channels

Providing the channels with proper design specification (cross section, slope, etc.), replacing the permeable side banks with fresh compacted soil, and installing concrete outlets can significantly reduce the losses in most watercourse systems. This type of improvement uses relatively little capital and can utilize the labour that is available during the slack periods of the year. In the watercourse rebuilding projects conducted to date, watercourse users have elected a committee that can speak for all the water users and mobilize the labour as needed. With forty or fifty independent farmers, coming from as many as ten different brotherhood groups (biradiris), organizing farmers is no easier in the Indus Basin than it is anywhere else in the world. However, once the farmers are convinced of the value of watercourse improvement, they have shown a surprising willingness to form committees and make improvements on their watercourses. Data is presented in Table 5 for watercourses that have been improved with these techniques.

The average cost for earthen improved watercourse channels is around Rs. 2 per linear foot, although on MN-56R where a lined section was required to protect the watercourse through the village, the average cost quickly rose to over Rs. 6 per linear foot. Excluding this lined section, the improvement costs per linear foot on that watercourse were approximately Rs. 2.3.

The reductions in losses by earthen improved watercourse channels are presented in Table 6.

From Table 6 the percentage increase in the amount of water delivered to the fields is 75 for TW 56 and 36 for TW 51, which gives an average improvement of 56 percent. Similar improvements on several other earthen watercourses have resulted in savings of an average of about 50 percent of the water that was being lost. Assuming 25,000 ft. improved at a cost per foot of Rs. 2, a life of eight years and interest at 12% per year, the annual amortized capital cost is about Rs. 6,300. Annual maintenance and repair costs for earthen watercourses are much higher than for lined watercourses and are estimated at Rs. 4,500 per year for a total annual cost of Rs. 10,800. With a savings of 510 acre feet of water per year, the annual costs per acre foot of water saved is Rs. 21.

TABLE 5. Cost Data for Farmer Improved Watercourses[1]

Watercourse no. Input	MN-56L	MN-51	MN-56R
	Costs in Rupees		
Volunteer Labour[a]	8211[c]	8282[c]	5032[c]
Unskilled Labour	4275	1543	--
Skilled Labour	4023	2146	--
Supervisory	7400	3276	1360
Engineering	2484	1075	1207
Bricks	14335	5415	6095
Cement	3515	1822	3836
Sand	734	360	600
Aggregate	450	--	--
Concrete Pipe Culverts	1630	1600	--
Concrete Outlets	4750	8280	1980
Junctions	--	5000	2800
Tractor Hours	4680	--	--
Lined Section	--	--	45000[b]
Total	56488	38801	67910
Total Length (feet)	26550	23750	11000
Cost (Rs./foot)	2.13	1.63	6.17

---

[a] Volunteer labour valued at Rs. 1 per hour.

[b] 1100 foot lined section through village.

[c] Provided by the farmers

[1] Unpublished Data--Economics Section--Mona Reclamation Project, Bhalwal.

TABLE 6. Water Losses Before and After Improvement of an Earthen Watercourse[1]

TW-No. and Condition	Inflow (CSC)[a]	Loss Rate		Volume		Field Delivery
		CSC/1000'	%/1000'	Inflow AC-FT/WK[b]	Loss AC-FT/WK	AC-FT/WK
TW 56-Before	4.0	.29	6.56	55.3	27.9	27.4
TW 56-After	5.4	.21	4.03	75.0	24.8	50.2
TW 51-Before	4.7	.16	3.76	6[illegible]2	28.9	35.3
TW 51-After	5.0	.13	2.53	6[illegible].4	21.5	47.9

---

[a] CSC = cubic feet per second

[b] AC-FT/WK = acre foot/week

[c] Increased inflow was due to improved design of watercourse which lowered the full supply level near the mogha and allowed the authorized amount of water to flow from the canal to the watercourse.

[1] Trout and Munir (1977).

The last alternative studied is that of simply providing a good cleaning and maintenance program for the watercourse channels. Extensive research on various cleaning and maintenance options is currently in process and the results should be available soon. Preliminary data indicates that a good cleaning and maintenance program can save up to 30 percent of the water that is presently lost from the watercourse channels. The costs of a program of maintenance is estimated at Rs. 3,000 per year and assuming a savings of 250 acre feet per year, costs Rs. 12 per acre foot of water saved.

All of the cost of the unlined improvement alternatives charge an opportunity cost of Rs. 1 per hour for the farmer's labour. In terms of capital investment, each alternative emphasized less and less capital, with the lower extreme being the cleaning and maintenance alternative which requires no capital except for the kussies (a hoe type of shovel) used by the farmers. Of course, as less capital is invested, less water is saved, and there is a trade off between the value of the two.

C. Appropriate Solutions

Given a variety of watercourse improvement techniques that range from complete masonry lining of watercourse channels to simple maintenance and cleaning, the problem is to determine what is the best solution for a given area. Economic theory dictates that the expenditure for saving water should not exceed the value of the water saved. The farmers should be willing to invest in watercourse improvement up to the point where the cost of the last acre-foot of water saved is just equal to the value of the last acre-foot of water saved. Assuming additional irrigation water has a declining marginal value, any investment below the point of equality will return more than it costs, and any investment beyond the point of equality will cost more than it returns. In order to determine this point of equality, it is necessary to know both the costs of saving different quantities of water and the value associated with these different quantities. The previous two sections have defined the costs per acre foot of saving different quantities and, in general, these costs will be reasonable estimates in the Indus Basin. The costs of saving water were determined for specific improvements which saved different amounts of water. This series of points can be converted into a continuous function of costs vs amount of water saved for an entire watercourse by considering the most appropriate improvements for different sections of the watercourse. For instance, in the section where water flows continuously, sidewall lining may be economically appropriate, while in the major portion of the sarkari khal, earthen improvements will be appropriate; and in farmers individual channels, simple maintenance may be all that is justified. Consideration of different lengths of these types of improvements leads to a multitude of cost vs water saved curves, the minimums of which can be represented by a continuous curve of the type shown in Figure 2.

The value per acre-foot of the water is more difficult to estimate since it varies depending upon how the water is used. In areas that concentrate on higher value cash crops, the value of water is greater and the farmers can afford to pay more for improving the watercourse system. Using linear programming (LP) models, it is possible to develop the shadow values for water as the quantity available changes over time. Such models are not generalized, but must be built and analyzed for the different cropping zones in the Indus Basin. One model for the perennial irrigated areas in the Sargodha region of the Punjab has been developed and the analysis is available (Johnson, 1977a). The value of water curve developed from this model is represented in Figure 2 for water in the crop root zone, and for water at the end of the sarkari khal (where it enters the farmers individual channels assuming 80% of the water leaving the sarkari khal is delivered to and left in the root zone). From the intersection of these curves, it appears optimal to invest up to about Rs. 43 per acre foot of water saved which will save 70 percent of the water that is presently lost in the watercourse system. The current on-farm water management program is emphasizing an alternative that costs Rs. 21 per acre foot of water saved, which is less than optimal, at least for the given area, but it is not over-investing in terms of the potential benefits. If the cement utilized in the project is valued at its true foreign exchange value rather than at its government subsidized cost, the right hand side of the cost curve in Figure 2 would shift upwards 5 or 10%.

In 1975, as part of a Watercourse Survey of the Punjab, Early and Lowdermilk (1975) measured conveyance losses on watercourses serving Tubewell 78 (brick and concrete lined sarkari khal). Their measurements indicated that lining the sarkari khal of a watercourse system, even when quality work is done, does not automatically reduce losses. Losses were still near 50% and were largely caused by greatly increased losses in the farmer's branches which had not been enlarged to handle the increased flows from the lined channels. Improvement of the sarkari khal will not solve the delivery system loss problems unless the farmers also enlarge and improve their own field channels.

IMPROVING APPLICATION EFFICIENCIES

Application Scheduling

The amount of water needed in the root zone divided by the amount of water delivered to the field will be denoted in this paper as the "application efficiency" when the water delivered exceeds the water needed. In order for the farmers

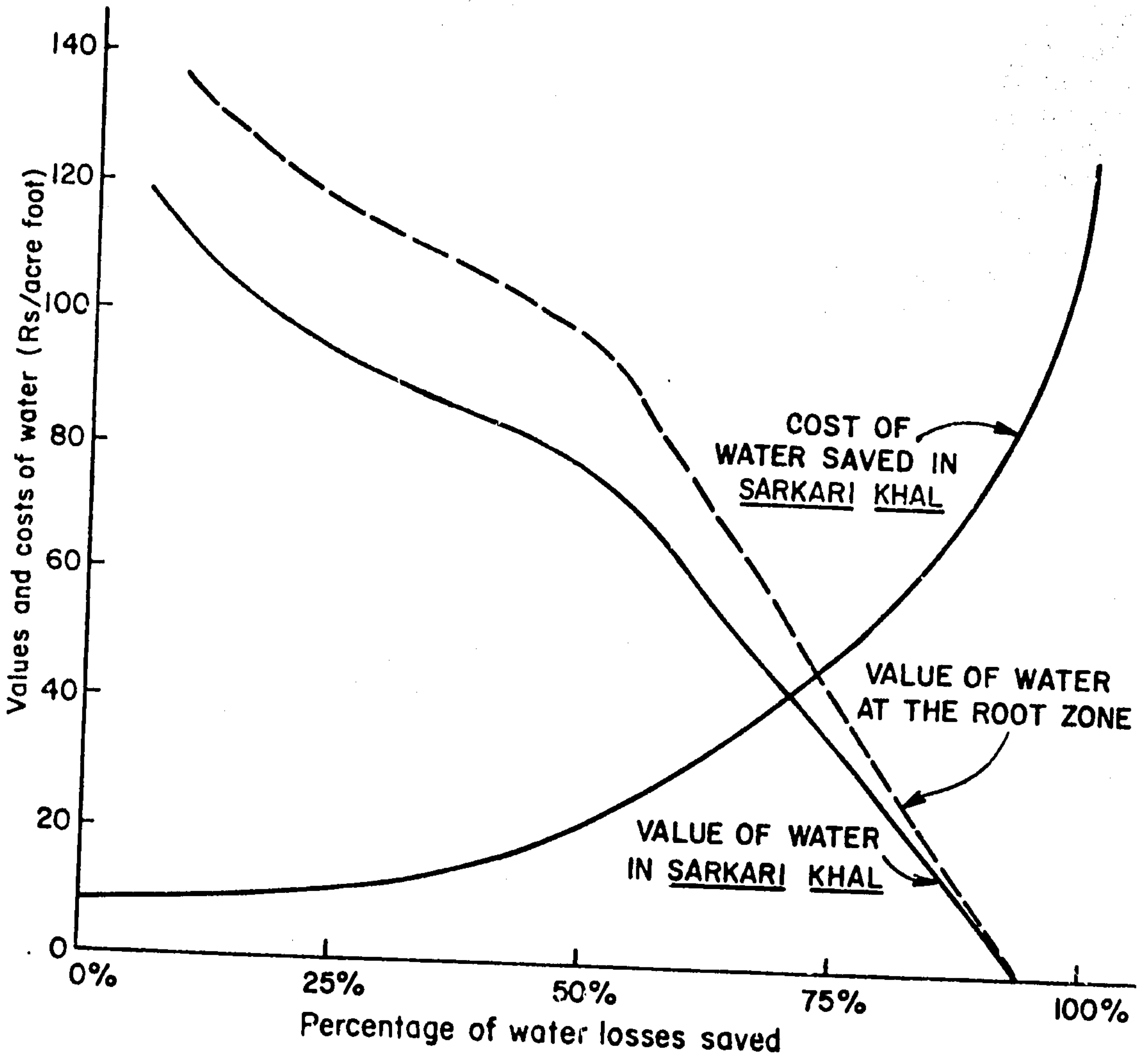

Figure 2. Costs and values for water saved by watercourse improvement and maintenance.

to increase their irrigation application efficiency they have to know the crop water requirements of the plants and need to be able to apply the amount of water required at the proper time. With a high rate of illiteracy and many farmers with small holdings, disseminating information concerning plant-soil-water relationships to all the farmers is a big job. One experimental approach to helping farmers apply the proper amount of water has been to use a computer irrigation scheduling model calculated at weekly intervals. This computer program, which is now written and operational (Early, 1975), computes the irrigation water requirements for specific crops based on standard meteorological data (including precipitation, pan evaporation, hours of bright sunshine, total wind run, mean temperature and relative humidity). The limiting factor for this type of program, both in LDC's and DC's has been the lack of a suitable delivery mechanism. The proposed mechanism for the experimental project in the Punjab is to utilize the current radio programs that are now directed to the farmers. This program would also be coordinated with the On-Farm Water Management Extension Service once it is operational. Preliminary research using this computer program for scheduling wheat during rabi season 1974-1975 in the Integrated Rural Development Areas near Lahore and Multan, indicated that irrigation application amounts can be reduced on some fields by as much as 10 inches with no reduction in yields (Early, 1975).

Simple weekly irrigation charts that predict crop water demands based on daily rainfall are also another possibility. These charts are now being field tested and seem to be practical where rapid communication and highly trained manpower is not available. The field worker can quickly be trained to read these charts and the only additional data he requires during the cropping season is the daily or weekly rainfall amounts (Reuss et al., 1976). Some combination of these techniques may be possible where the meteorological information is fed into the computer and the results distributed to the field worker who, using his charts and his knowledge of the farmer's local conditions, helps the farmers plan their irrigation schedule for the following water turn.

For the old line departments which currently deal directly with the farmers, and the newly created government corporations whose purpose is to deliver inputs to the farmer, irrigation scheduling services such as described above requires an entirely new concept of service. The service must be provided by the government employee to the farmer without remuneration or special privileges. Timeliness of the information is just as important as the information itself and mandates that all data be collected, coded and the model run on schedule in order to provide the information to the farmers when needed.

Precision Land Leveling

Another factor that contributes to the low application efficiencies is the degree of unlevelness of the farmer's fields. Table 7 presents a sample of 46 acres, giving the maximum range of elevation with a given area.

When the elevation differences within the field exceed 0.3 ft. the farmer commonly builds bunds across the field which hold the water on the high area at a level higher than the low area. These bunds often become permanent field boundaries, breaking the land into smaller units by irrigation and cultivation. In an unpublished study (by Waryam Mohsin and W. D. Kemper, 1974) conducted near Faisalabad (Lyallpur) it was found that such bunding within fields had reduced the average size of irrigation units to about 1/4 of an acre. These farmers were extremely short of water and had carefully levelled the land within these small bunded units, noting high and low areas during irrigation and using karahs (a simple wooden scraper pulled by bullocks) and "kussies" (the common hand tool used for moving soil) to move the soil. These farmers had necessarily increased the area that was devoted to ditches, but they had achieved level fields where differences between the highest and lowest points were commonly less than 0.10 foot. However, extensive data collected by Lowdermilk et al. (1978), in a survey of the Punjab and Sind provinces, indicate that there are substantial elevation differences in most of Pakistan's irrigated fields and that elevation distributions similar to those shown in Table 7 are common in Pakistan's irrigated acres. Some farmers have a flat level field lying immediately below a sloping field and built high dikes around the bottom end of the sloping field. They irrigate these two fields as a pair, filling the sloping field until the highest point is covered, holding the water in place for a reasonable intake opportunity time, and then draining the remaining water into the lower flat field. This drainage water is often sufficient to completely irrigate the second flat field.

From Table 7, only 2 percent of the area surveyed had acres which were within the presently accepted criteria (0.15 feet maximum difference) for level basins. Seventy-three percent had elevation differences of greater than 0.30 feet. Data concerning fields that were levelled with engineering assistance in the Mona project area are presented in Table 8.

In this area precision land leveling costs ranged from Rs. 1,098 per acre to Rs. 186 per acre with the average being Rs. 542 per acre. The average earth moved per acre was 180.7 cubic meters. Using indigenous bullock-powered equipment, moving this much soil is a big job. A tractor-drawn scraper can easily move this soil but, of course, the question arises; is leveling these fields a good investment for the farmers?

TABLE 7. Range of Elevation Between Maximum and Minimum for a Sample of Irrigated Fields in the Punjab

Range of Elevations (ft)	No. of Acres	Cumulative Acres	Percent of Total (%)	Cumulative Percent (%)
0.00 - 0.10	0	0	0	0
0.10 - 0.15	1	1	2	2
0.15 - 0.20	3	4	7	9
0.20 - 0.25	3	7	7	16
0.25 - 0.30	5	12	11	27
0.30 - 0.35	3	15	7	34
0.35 - 0.40	5	20	11	45
0.40 - 0.45	6	26	13	58
0.45 - 0.50	4	30	9	67
0.50 - 0.55	5	35	11	78
0.55 - 0.60	2	37	4	82
0.60 - 0.65	-	37	-	82
0.65 - 0.70	2	39	4	86
0.70 - 0.75	1	40	2	88
0.75 - 0.80	1	41	2	90
0.80 - 0.85	1	42	2	92
0.85 - 0.90	1	43	2	94
1.05 - 1.10	3	46	7	101

TABLE 8. Cost Data for Precision Leveled Fields[1]

Sr. No.	Area Leveled (acres)	Quantity of Earth Moved (m^3)	Total Cost (Rs)	Cost Acre (Rs)	Max. Cut (foot)	Max. Fill (foot)
1	2.0	230.75	692.00	346.00	0.25	0.30
2	3.0	522.00	1566.00	522.00	0.35	0.55
3	2.25	712.00	2136.00	949.00	0.80	0.50
4	3.0	900.00	2700.00	900.00	0.80	0.40
5	2.75	1007.00	3021.00	1098.00	0.95	0.70
6	2.0	124.00	372.00	186.00	0.30	0.20
7	3.5	600.00	1800.00	514.00	0.50	0.60
8	3.5	435.00	1305.00	373.00	0.40	0.75
9	2.75	633.86	1901.58	397.00	0.50	0.55
10	2.0	643.00	1929.00	964.00	0.65	0.40
11	2.25	422.00	1266.00	562.00	0.45	0.40
12	5.0	683.76	2051.10	410.00	0.30	0.25
13	4.0	910.00	2732.70	683.00	0.80	0.45
14	3.75	309.80	929.40	248.00	0.30	0.30
Average	2.98	580.94	1742.98	582.29	0.53	0.43

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[1] Karim and Ahmad (1977).

Experience with irrigating precision leveled fields as compared to traditional level fields indicates that the average precision leveled fields can be irrigated in about 60 percent of the time (i.e. requires 60% as much water) required to irrigate the traditional leveled fields (Johnson et al., 1977b). This means if the farmer now requires five inches of water to cover all the high spots, after leveling he can apply about three inches providing adequate water and avoiding leaching in low spots which wastes much of the N applied on the low spots of unleveled fields. Most farmers that have had fields precision leveled under a cost sharing agreement are now willing to level the remainder of their fields using their own resources. Work by Hanif et al. (1976) indicates an increase of three maunds (one maund equals 82.5 pounds) of wheat an acre attributable to land leveling alone. Data collected by Dempster (1976) of the Soil Conservation Service Precision Land Leveling Project in Pakistan indicates an average yield increase on wheat of 20 percent (approximately 4 maunds) from precision leveled compared to benchmark fields. Precision leveled fields can also be irrigated and cultivated in larger more convenient units, since smaller bunded units are usually developed to reduce differences in elevations within fields. However, the advantages of leveling, including simpler cultivation patterns in larger fields, must be clearly demonstrated to the farmers, or they return to their traditional small bunded units.

The On-Farm Water Management Project currently in progress in Pakistan is designed to implement these technical solutions (watercourse improvement, land leveling and water management extension) into a program which will significantly improve the water management of the farmers. Over the next five years 1,500 watercourses are to be improved and 424,500 acres to be precision leveled. This program is currently funded. The first training program for watercourse improvement officers has been completed in the Punjab and Sind Provinces and the training program for water management extension advisors began in early June (1977) at the University of Agriculture, Faisalabad (Lowdermilk et al., 1976). As of December, 1977 21 watercourses have been improved or are being improved under this scheme. Where watercourses have been improved, nearby farmers are anxious to have their watercourse improved. The program appears to be improving and gaining more interest of the government and the farmers as the results are more widely visible.

INSTITUTIONAL CHANGES THAT COULD FACILITATE IRRIGATION WATER MANAGEMENT

Much of the development effort in the Indus Basin, including the On-Farm Water Management Project, focuses on various technical elements that are considered inadequate or inefficient in the present system. It is becoming apparent that the ability of the institution to provide trained personnel to help achieve these benefits and to help farmers use their increased water supply to increase crop production will be the primary constraint on the rate at which this program can move across Pakistan's 88,000 watercourses. Improving the ability of these institutions to provide relevant field training and building their capabilities for solving problems in the field to provide the bases for such training are essential to achieve the desired implementation schedule.

From the farmers' end, they must learn the benefits of water management to give them the incentive to organize so they can cooperatively improve and maintain their delivery system. A USAID financed study is now underway, by the University of Agriculture at Faisalabad, to determine the characteristics and policies of water users' organizations which will be most effective in achieving improvement and maintenance of watercourses. Such organizations could also serve to facilitate the transfer of knowledge and information between the Irrigation Department and the water users. Types of water users' organizations which have enabled farmers in other countries to improve their ability to organize for watercourse improvement and maintenance were outlined by Radosevich and Kirkwood (1975), and those that appeared most suitable to Pakistan's culture were indicated.

Farmers' organizations are not a new phenomena in the Indus Basin as many villages have cooperative groups. However, these cooperatives have not generally been successful due to their inability to provide services that are not available elsewhere. A water users' organization would provide a service that is not available elsewhere. However, this may not be sufficient to keep a water users' organization viable and functioning.

If farmers can be convinced that there is an economic benefit to be derived from organizing and operating a water users' organization they will probably take the necessary steps. However, they are commonly in need of encouragement and instruction on how to organize and register such an organization. A first step could be a notification of the type indicated in Appendix I which could be enacted at the national level. Specific suggestions for rules, executive responsibility and authority and financial operation could be derived from the UAF study and experience in the Provincial On-Farm Water Management Projects and the Mona Reclamation Experimental Project watercourse improvement programs.

A radical step that could provide an economic incentive required by the farmers would be for the Irrigation Department to charge a fixed fee per acre served for irrigation. Water users' organizations could then be empowered to collect the irrigation revenue from the individual farmers. A fixed percentage, perhaps 20 percent, could be retained by the water users' organization for improvement and maintenance of the sarkari khal (government authorized and commonly operated portion of the watercourse), and the remainder would be deposited in the bank and credited to the government account. With an average on a perennial canal of Rs. 20 per acre annual irrigation revenue charge, a 500 acre watercourse provides Rs. 10,000 per year. Twenty percent of this rebated to the water users' organization would provide Rs. 2,000 per year for use to improve and maintain the watercourses, which could be used for the capital costs of concrete control structures, culverts, animal watering and bathing station and other structures which would protect the watercourse and facilitate control and measurement of the water. If more capital was needed, the water users' association could be authorized (based on an application documenting the need) by the Irrigation Department to raise the assessment. Where the government has installed a public tubewell on a watercourse the water users' organization could take over the operation of these wells and eliminate the exactions and poor service presently provided by the majority of public tubewell operators (Johnson et al., 1977a). Required "rest periods" for the wells to avoid use at times of peak load could be achieved by locked time clocks or voltage sensors.

Another major potential for improvement lies with the agricultural extension departments. Currently, the extension field assistants are assigned to cover an area of 5,000-10,000 acres without any transportation or housing provided. They must request housing from a rich landlord in the village, which then commits them to providing additional services to their landlord and his biradari members. There is generally little reward for an extension agent to go to the field, and most of their time is spent on paper work, or travel between villages. The agents have very little field training (Johnson et al., 1977a) and in some cases appear to avoid going to the field because they have no confidence in their ability to help the farmer. The budget available for printed material is extremely limited. More intensive field training, smaller areas of responsibility, incentive to work in the field, a higher level of motivation and more and better printed material are all elements that appear to have high investment potential in the extension services.

The training program for Water Management Extension Officers at the University of Agriculture, Faisalabad (Lyallpur), is an attempt to improve the training, motivation and field incentive of extension personnel (e.g. Lowdermilk et al., 1976). The training program places heavy emphases on developing specific field skills which the WMEO can teach his field assistants and farmers which will enable the farmers to improve their water management and crop production. During their training program the trainees will actually work with farmers to maintain their watercourse, improve their water management and increase their yields so that when they go into real field situations they will already have experience and confidence. Experience in Pakistan indicates that the farmers are willing to work with extension personnel if the "extenders" have previously helped other farmers solve their problems.

Another major change that would improve water management is for the Irrigation Department to accept responsibility for monitoring the maintenance and performance of the watercourse channels. The present laws appear to give the Irrigation Department the authority to close the watercourse if it is in poor condition. However, the Department has hesitated to enforce good maintenance practices, due to a lack of clarity of the legal documents, limited personnel and limited equipment for measurement. Clarification of the law could provide the Irrigation Department with clear closure authority to enforce proper watercourse maintenance. This type of authority would give the Irrigation Department employees tremendous power over the water which is essential to the livelihood of the farmers, and provisions would be necessary to make certain that this power is not abused. Rebuilding and redesigning farmers' watercourse channels is a substantially different activity compared to operating and maintaining canals and will require somewhat different training for the Irrigation Department engineers. But even more important are the changes in the engineers' thinking and schedules which will allow them to fill advisory roles in addition to their control and authority roles with the farmers. The major key to improving on-farm water management in the Indus Basin is developing cooperative working relationships between farmers, and between the farmers and the Irrigation and Agriculture Department staff.

APPENDIX

PROPOSED LEGAL AUTHORITY FOR WATER USERS ASSOCIATIONS

Drafted by George E. Radosevich[1]
(Could be enacted at national level)

Water User Associations

Section 1. Authority to Organize--

The goal of this notification is to encourage and expedite the most efficient and effective use of provinical waters. To facilitate this goal, water users in a common geographic area that is hydrologically connected or diverting from the same structure or source, are encouraged to cooperate for mutual

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[1] Associate Professor of Environmental Law and Economics, Department of Economics, Colorado State University, Fort Collins, Colorado.

benefit of improved local water management and for operation, maintenance and rehabilitation of their watercourses by organizing into formal or informal water user associations.

Section 2. Purpose of Associations--

The associations may be organized under existing organizational laws of the Province or as an executive committee responsible and responsive to the membership. The association may be for the purposes of construction, improvement, operation, maintenance or management of watercourses; assist in improved delivery of water and on-farm water use; removal and drainage of excess waters; conjunctive use of surface and ground waters; recommendation of joint tubewell location and installation; soil conservation practices within the association boundaries; utilize in-system storage, and any other lawful and beneficial purposes related to optimizing the use, development and conservation of water and increasing agricultural production.

Section 3. Registering of Associations--

Associations organizing formally under existing Company, Cooperative or Registered Societies laws, which require registration of the association as a condition to formal creation, shall furnish the Provincial Department of Agriculture with a copy of the registration. Associations organizing informally by declaration of mutual agreement, shall furnish the Provincial Department of Agriculture with a copy of the declaration. The Department shall adopt a simplified declaration of association form for use by water users desiring to informally organize under the provisions of this law and may, with the concurrence of the registrar of company, cooperative or registered societies, provide a simplified charter or form for use by farmers in meeting the basic requirements of formally organizing under such laws.

Section 4. Coordination of Efforts--

Water User Associations, Provincial Irrigation and Agricultural Departments and other governmental agencies (e.g. WAPDA and research institutions) affecting irrigation, water and agriculture are obliged to cooperate and coordinate their activities for the greatest public and individual benefits according to the Law of Islam, the Canal and Drainage Acts and those other laws enacted by the National and Provincial Governments.

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APPENDIX 31

LAND AND WATER DEVELOPMENT AND USE: FARM WATER MANAGEMENT

by
Colorado State University Field Party

A. The Resources and Its Present Productivity

The Indus Basin contains over 35 million acres of irrigable land, receives about 140 million acre feet of good quality river water each year and has a climate which allows year-round production of crops. One of the world's best canal systems delivers this water to the potentially rich agricultural areas. The basin is underlain by a highly permeable aquifer which allows storage of water for pumping as needed for irrigation. This tremendous storage reservoir is commonly within fifty feet of the plants which need the water. Extensive public and private tubewells have been constructed to make this water available to the crops. A manpower resource involving over fifty million people is available, with common labor costing less than a rupee per hour.

In spite of the availability of the components for one of the world's greatest food machines, in the average season only 15 million acres of this land is producing and the average yields are low with wheat at about 22 maunds/acre, maize at 13 maunds/acre, etc.

B. Determining the Potential for Improvement

The Indus Basin irrigation system was deliberately designed to command more land than could be adequately irrigated with the limited water supply available. Consequently, inadequate water is commonly the factor limiting the amount of land cultivated during a given season. Improved water management will, in general, relieve this primary constraint on crop production. The overall efficiency of water use after it leaves the canal system can be considered as the product of the delivery efficiency (water delivered to the field/water delivered from a canal to the watercourse), application efficiency (water stored in the root zone/water delivered to the field), and water use efficiency (crop production/water from the root zone). Delivery efficiency and application efficiency have been estimated by many consultants in Pakistan over the last 20 years but surprisingly few measurements were taken prior to 1973. Large numbers of application efficiency measurements were taken during the high rainfall year in 1973 in the Northern Punjab and application efficiencies averaged down near 20%. Delivery efficiencies averaged about 0.6 when determined by measuring the flow of water at the top and bottom ends of a section of watercourse using Cutthroat flumes under steady flow conditions. In that area in that year only about 12% of the water delivered from the canal system to the farm watercourses was stored in the root zones for crop use. Subsequent measures of application efficiencies, taken through the crop seasons in more normal rainfall years and in other areas indicate an average application efficiency of approximately 50%. Steady state measures of delivery efficiency have averaged about 60%. However, when all the water leaving the watercourse through nakkas to the fields is divided by all of the water which enters the watercourse, delivery efficiencies considerably lower than these steady state measurements are obtained because of water used to fill dead storage space in water channels, wetting of dry banks, frequent breaking of bunds and other operational losses common to the fragile watercourses which have evolved in Pakistan. Consequently, in the watercourses of the Punjab the delivery efficiency is about 0.5 and only about 0.25 of the water entering the watercourse is stored in the root zone for use by crops.

Water use efficiency has been determined on farmers' fields under the normal farmer practices and under conditions where optimum fertilizer was applied and water was applied as needed. Average wheat production was increased from about 16 maunds per acre to about 50 maunds per acre by this improved management and the amount of water applied was reduced from an average of about 24 inches per acre used on the farmers' fields to about 14 inches per acre where it was applied as needed.

These observations allow construction of the following table which indicates the existing and potential farm water efficiency for wheat in Pakistan. Similar tables may be constructed based on observations of kharif crops and it can generally be concluded that there is a potential for increasing the crop production by factors of from 5 to 10 using the amount of water presently available.

C. Developing and Evaluating Methods of Improvement

1. Delivery Efficiency

a. Identification and Reduction of Losses

i. Losses at Junctions

Studies show that almost half of the water lost from a watercourse is lost within 30 feet of the junctions due to the degraded nature of the banks in the vicinity of the junctions and the fact that the dams across the watercourse at these junctions are subject to leakage and occasional washouts. Refilling of the borrowed areas with soil from adjacent fields and compacting and shaping the watercourse banks to the proper cross sections in the vicinity of these junctions can often increase the supply of water to the farmer's fields by 10 or 20%. However, the constant necessity of borrowing soil from the vicinity of these junctions for making dams across the

POTENTIAL FOR IMPROVEMENT

Farm Water Efficiency	Delivery Efficiency	Application Efficiency	Water Use Efficiency*	Farm Water Efficiency**
Existing	0.5	0.5	13	3.2
Potential***	0.8	0.8	42	26.9

*Maunds of wheat/acre foot of water stored in root zone.

**Maunds of wheat/acre foot of water delivered through the mogha (calculated as the product of figures in the first three columns).

***These are potential efficiencies which have been achieved and can be achieved on the "average" watercourse or farm with reasonable effort and management.

watercourse each week initiates the degradation process as soon as the improvement section is used. The only permanent solution to this degradaton is the use of control structures which close the channel to water flow without using soil. Rubber gasket steel slide gates used in other countries are relatively costly in Pakistan (around 500 Rupees plus installation cost) and commonly have considerable leakage and become difficult to operate because of inadequate quality control in their installation and construction. Concrete panels with an open orifice, or pipes, closed by concrete lids have proved to be a more economical and satisfactory structure for controlling water at these junctions. Leakage is prevented in these concrete structures by either a rubber gasket or a groove about an inch wide and an inch deep around the circumference of the lid which can be filled with mud. In the latter case these lids and their seats are installed at a 45 degree angle from horizontal which allows gravity to hold the lid in its seat and to hold mud in the groove. These concrete control structures presently cost between 50 and 90 Rupees. The lid and its seat must be carefully formed with steel forms which do not warp when wet. When these lids are properly closed, leakage through these nakkas is generally less than .001 cusecs.

ii. Upper Portions of the Banks

Analysis of the rate of recession of the water surface when water is ponded in a watercourse section in Pakistan shows over two-thirds of the loss generally takes place through holes which are within 2 or 3 inches of the operating level of water in the channel. The bottoms of these watercourses are commonly sealed even in areas of sandy soil with sediment from the canal water. The upper portions of the banks are densely populated with roots, worms, grubs, insects and rodents and it is common for the upper portion of these banks to have permeability rates from 5 to 10 times that of soil in adjacent fields when these banks have been in place for several years. Newly constructed banks have permeabilities similar to that of adjacent fields and newly constructed watercourses commonly lose water at rates which are only 15 to 25 percent of those in adjacent old watercourses if the soil used in the construction of the banks in the new watercourses is compacted reasonably well.

Another procedure which has reduced the losses from the watercourse to less than 25% of the previous value is removal of most of the freeboard portions of the banks and using a two-inch wide packer to compact a core about 3 inches wide in the middle of these banks by pounding the resident soil downward as far as possible, filling the trench thus made with soil, compacting again and then replacing the soil which constituted the freeboard and compacting it by foot. This compaction of cores in the banks can be accomplished while water is in the channel and is an effective means of closing leaks which are observable from the outside of a channel and the inlets to these leaks cannot be detected on the inside of the channel.

Low loss rates associated with the construction of banks persist for at least a year. There has not yet been time to test the longevity of the loss reduction occasioned by the core compaction. Degradation of the banks is commonly rapid as a result of: animal traffic, use of the watercourse for bathing by the buffalo in warm weather, rodent activity and cutting of unauthorized outlets through these banks by farmers. In general, a program of maintenance is essential if improvments are to last more than a season or so. Use of concrete or masonry lining in trapezoidal and rectangular cross sections almost eliminates loss, reduces maintenance requirements and allows water to be switched from one ditch to another with minimal loss. The advantages of pakka lining are apparent to the farmers and they strongly prefer this type of improvement (as long as they do not have to pay the cost).

iii. Operational Losses

Bottoms of the watercourses commonly have sections which are below the level of adjacent fields and are lower than the bottom of the watercourse downstream. The water used to fill these low sections is lost to the farmers.

It is also common for weak sections of the banks and dams and junctions to wash out during use of the watercourse. This type of operational loss and the normal losses involved in filling and wetting a dry watercourse are generally eliminated by the careful alignment of the bottoms of the watercourses and the installation of concrete lining and control structures described above.

b. Economics of Improving Delivery Efficiency in Pakistan

Cost of materials for lining watercourses have ranged from 7 to 30 Rupees per foot of watercourse depending upon the size of the watercourse and the lining material used. Farmers can generally be convinced to supply most of the labor although they frequently have to go outside their village to find competent masons.

If the farmers are efficient in their water use and have the high yields shown in the last line of the previous table and if water is the primary constraint on utilizing the available land for crop production, the value of the water saved and the improved water control resulting from pakka lining of the watercourse and installation of pakka control structures generally exceeds their cost on portions of the watercourse which carry water more than 2 or 3 days per week. However, on the branches which carry water only one day a week or under conditions where the production is not optimized, only methods of improvement which require less capital are economically feasible.

Concrete control structures can be installed at major junctions of earthen watercourses at a cost of about 200 Rupees per structure. There is about one major junction for every 8 acres served and each junction requires two structures. A 500 acre watercourse requires about 125 structures at a cost of about 25,000 Rupees. Farmers have removed old banks and constructed new ones to proper cross section at rates of from 1 to 5 feet per hour depending on the size of the watercourse, condition of the soil, and number of trees to be removed. On a watercourse designed to carry between 4 and 5 cusecs in loam and sandy loam soils, farmers averaged more than 2 feet of watercourse reconstructed per man hour. There are about 20,000 feet of main channel and primary branches in the authorized watercourse serving a 500 acre command area and reconstruction of these watercourses to give the proper cross sections and alignment will require about 10,000 man hours of labor which is currently valued at about Rs. 1.0/hour. Providing 5 man months of engineers' time to properly align the watercourse, set the control structures at proper elevations, and supervise installation of the concrete control structures at proper elevations, and supervise installation of the concrete control structures will cost about 5,000 Rupees. Thus it appears that at present watercourses serving 500 acres can be realigned, the banks constructed to proper cross section and grade, and concrete control structures installed at the major junctions for a cost of about 40,000 Rupees or about Rs. 80/acre of land served, of which 20 Rupees can be farmer's labor.

The benefits of such reconstruction depend on the crops raised and the degree to which water is a constraint on cropping intensity and yields. To obtain a more general evaluation of the benefits derived they can be expressed in terms of the value of the water saved. Eckert et al. 1975 indicate that the value of the water saved is around Rs. 300/acre foot in Pakistan.

In areas where the groundwater is not saline, the cost of pumping water which is an alternative to saving water should be considered. Recent figures from WAPDA indicate that the cost of pumping water from public tubewells is about Rs. 50 per acre foot. Measurements on watercourse losses indicate that half of this pumped water is lost before it reaches the field so the cost of pumped water delivered to the field is about Rs. 100 per acre foot. Measurements of loss on existing watercourses indicate that an average loss rate of approximately 0.35 cusecs per 1000 feet of watercourse. Reconstruction realignment and furnishing of concrete control structures has reduced losses by 0.15 cusec per 1000 feet and on the average watercourse the average distance from the mogha to the outlets to the field is about 4,000 feet. Consequently, a saving of 0.6 cusec of water can be anticipated which amounts to 360 acre feet of water over a period of 300 days, which is the approximate time for which water flows in these watercourses per year. According to the figures of Eckert et al. the value of this water would be about 108,000 Rupees per year. The alternative cost of pumped water (at the field) would be about 36,000 Rupees per year. The value of the saved water in the first year would exceed the cost of the improvement by a factor of about 3. And the benefits will persist for many years if a maintenance program is followed.

c. Program for Improvement

The above cost and benefit figures were obtained on branches of watercourses involving specific sets of farmers and somewhat experimental procedures which were being evaluated in the process of construction. The procedures involved need to be tested under conditions which are on a full scale and this is being done on pilot projects in which whole watercourses are improved and conditions are close to those in a development project. Time spent and the various costs involved are monitored. The improvements and most economical procedures will also be evaluated on these pilot watercourses. Training is being provided to a group of personnel with educational training ranging from simple high school matriculation to graduate agricultural engineers. Their performance will be evaluated to determine the level of education needed for individuals to grasp the essential components of watercourse improvement and be able to pass these on to the farmers. The physical and socio-economic data and observations taken on these pilot projects will form part of the basis for proposed national programs for watercourse improvement in Pakistan.

2. Application Efficiency

a. Identification of Inefficiencies and Their Reduction

The primary causes of low application efficiency in Pakistan are unlevel land, small flows of water during irrigation (particularly at the tail ends of the watercourse where flow is often only 25% or less of the mogha flow), over-irrigation during the cool months and the monsoon season and substitution of water for power and information.

The unlevel land can be leveled and a program for training technicians to precision level land is now underway in Pakistan. Improvement of the watercourses as described above to increase the flows and give the farmer better control of his water will allow more uniform application of water to fields. Overirrigation during the winter months can be reduced by ridding the farmers of the popular misconception that "roots are primarily in the top 2 to 6 inches of soil and that consequently soils should be irrigated as soon as the surface appears dry." Practical methods of helping farmers time their irrigation are under development and a major program for determining the consumptive use of crops during various seasons is now underway in Pakistan. It should be noted, however, that a farmer's knowledge of when he needs to irrigate must be accompanied by a flexibility in canal diversions and a feedback mechanism whereby recognition of the presence of excess water in a given canal command area can result in water being transferred to other areas in which it is needed. For instance, when water becomes in excess in the northern Punjab in the winter months, this water should be transferred to areas of the southern portion of the Punjab or the Sind where winter supplies are generally inadequate.

Fields are often irrigated in Pakistan to soften the soil and allow its plowing by the bullocks and native plows commonly used. A substantial portion of the applied water is commonly allowed to evaporate until the moisture content of the surface approached the "wattar" condition in which seed can be broadcast, the land planked and reasonable stands obtained. Because this wattar condition is fairly dry there is often only a day or so between achieving wattar condition and the time the soil is too dry and if it is missed it is often necessary to irrigate again. The period for which water conditions will give good stands is several times as long if seeder is used, and consequently the availability of material can often save water. Recent studies have also shown that drilling into a dry field followed by irrigation oan give satisfactory wheat stands. The farmer frequently receives his water turn when he does not know whether it will do good or harm. If he had this information he could avoid excess irrigation and nitrate leaching and could either use the water for leaching salts on other fields, trade it with his neighbor, or return it to the river through drains.

Basin flooding of crops is the normal method of application in Pakistan and it requires a minimum of about two inches of water to gain coverage of the plot. Consequently, when only a light irrigation is needed to soften the crust to allow emergence, etc., 3 or more inches of water are commonly applied. Furrow irrigation with seed planted near the shoulders of the beds between the furrows allows wetting of the soil surrounding the seed using less than an acre inch of water per acre.

b. Economics of Improving Application Efficiency

The final evaluation must be in terms of crop production which is entwined with many other factors. However, data obtained so far on the cost of land leveling (which is about Rs. 3 per cubic yard of earth moved) can be combined with observations of farmers' irrigation practices to make the following evaluations in terms of cost of the water. Farmers generally irrigate an unleveled piece of land until the highest area within the field is covered with water. Data show highest yields generally occur on these highest areas, which indicates that these highest areas are receiving adequate water and other areas receive excess irrigation to an extent approximately equal to the water standing on their surface at the conclusion of the irrigation. This total volume of excess water is equivalent to about 4 times the volume of soil that would have to be moved to level this land. Consequently movement of a cubic yard of soil will result in savings of 108 cubic feet of water per irrigation. Land cropped twice a year will receive about 12 irrigations per year and consequently a cubic yard of soil moved will save about 1290 cubic feet of irrigation water per year on such land.

About 33 cubic yards of soil moved from a high to a low area will save one acre foot of water per year. This annual return of one acre foot of water for this initial investment of 100 Rupees can be obtained for at least several years. Other obvious benefits, such as uniform soil water content for cultural operations, accrue from land leveling, but they are difficult to evaluate.

Evaluation of soil water content or potential to determine when to irrigate is costly in terms of equipment and/or labor and can be justified only under research situations. Studies are now underway to define the coefficients of predictive equations which relate easily measured climatic variables to water use by the major crops at various seasons and stages of growth at locations representative of the major climatic zones of the irrigation system. These coefficients will be used in these equations to develop guidelines for irrigation scheduling which will be transmitted to farmers through extension agents and other communication media. Benefits derived from advice on irrigation scheduling and crop scheduling to optimum use of available irrigation supplied will be dependent on how many of the farmers can be contacted and motivated to make use of this information.

3. Water Use Efficiency

a. Crop Stands

Stands of crops, particularly in the kharif season, are commonly poor in Pakistan, and are a major factor causing low water use efficiency. Broadcast seeding, crusting of poorly structured soil above seeds and extremely high soil temperatures during germination are major factors causing these poor stands. Efficient low cost drills are being designed and manufactured to obtain more uniform seeding rates at controlled depths where proper water is available. Crusting and high temperatures have been alleviated by planting kharif crops on the shoulders of beds with water supplied in furrows between the beds. Capillary wetting of the soil above the seedling softens crust and reduces temperatures by 5 to 12°C and has allowed development of good stands where adjacent plots under normal flooding irrigation (or no irrigation) had stands less than 25% of those desired.

b. Yield per Plant

In the heavily cropped and frequently leached soils of Pakistan, where little crop residue is returned to the soil, adequate yields generally depend on applying practically all the nitrogen and phosphorus needed by the plants. Even when these nutrients are applied, low yields often occur. In basin flooded fields where some areas are 2 to 4 inches lower than the highest areas, yields in the low areas are commonly about half of the yields in the higher areas. Stands are commonly about 25% lower on the low areas, but the yield per plant is also lower indicating leaching of nitrate, and/or possibly poor soil aeration in these low areas. At least partially successful remedies for this problem have been land leveling and proper irrigation applications and the bed and furrow culture described above.

4. Improving Water Management and Crop Production in Pakistan

Dissemination of the knowledge described above to obtain the potential benefits will require a greatly expanded and better equipped and trained extension service. Many of the best practices described are practiced by some of the better farmers. However, the good practices spread very slowly due to a deficiency of publicity, well organized field days, demonstrations and printed guidelines.

The role of the better farmers acting as demonstrators is essential to the rapid spread of these practices. Helping the small and inefficient farmer is one of Pakistan's goals, but it must not be done at the expense of failure to achieve self sufficiency in food production through avoidance of the good managers who eagerly accept, utilize and demonstrate new technology. Efforts to help the small farmer should include variants of all new technologies which are adapted to his resources, and opportunities to share or rent equipment which he cannot afford to own.

The role of the better managers is particularly essential in watercourse improvement and maintenance which require organized group effort. Fortunately, when farmers elect the officers of their watercourse improvement committee they usually select these good managers as their leaders.

The facts presented above are based on data and observations generally recorded in more detail in research reports by water management scientists and engineers working with WAPDA, the Punjab Integrated Rural Development Program (IRDP), the Punjab Agricultural Research Institute and the CSU Water Management advisory team. Most of these reports are currently available through the CSU Water Management Team Offices, c/o P.O. Box 660, Lahore, Pakistan.

APPENDIX 32

SOCIAL AND ORGANIZATIONAL FACTORS FOR FARM IRRIGATION IMPROVEMENTS: A CASE STUDY[1]

Max K. Lowdermilk, David M. Freeman
and Alan C. Early[2]

> "The scientist atomizes, someone must synthesize;
> The scientist withdraws, someone must draw together;
> The scientist particularizes, someone must universalize;
> The scientist dehumanizes, someone must humanize."
>
> (John Fowels, The Aristos)

The kinds and quality of local organizations which farmers create and maintain for the social control of irrigation water intimately affect the efficiency of its use. This paper describes the importance of farmer organizations and farmer participation for the improvement and maintenance of farm irrigation conveyance systems in Pakistan. First, the case study and data presented describe the consequences of almost 80 years of benign neglect of the farm irrigation subsystem. Secondly, the importance of understanding and utilizing indiginous forms of collective action for designing and implementing improvement programs once acceptable technologies are made available is discussed. And thirdly, the need for continuous evaluation and improvement of local organizations is stressed.

Statement of the Problem and Background of the Case Study

The magnitude of the problem is seen from a brief description of what happens to the 142 MAF of water available from the famous Indus River system. Of this volume of water about 86 MAF are diverted into the modern canal system from impressive dams and headworks. However, approximately 64 MAF reach the farm system or 78,068 separate watercourse command areas serving about 3.2 million farms and 32 million acres. At the farm system an estimated 26 MAF are added by 125,000 public and private tubewells. Of about 90 MAF, roughly 35 MAF are lost in poorly maintained earthen channels from the public distributary to the farmer's fields. Therefore, farmers have approximately 55 MAF or 1.7 acre feet for crop use of which an estimated 23.8 MAF are attributed to field application losses. (World Bank, 1976)

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[1] Presented at the Second International Conference on Transfer of Water Resources Knowledge, June 29-July 2, 1977, Colorado State University, Fort Collins, Colorado.

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Neither the magnitude of the problem in Pakistan nor the reasons behind such high losses are unique to many irrigation systems in most low income nations as witnessed by the rising concern for improving existing systems first. The farm component of the irrigation system historically has been neglected. Since the development of the Pakistan system in the late 1800's by the British, the philosophy of the Irrigation Department and the Canal and Drainage Act of 1873 which still regulates the system is one of clear, benign neglect. The assumptions of this philosophy were: 1.) the system should operate with minimum involvement of officials at the farm level; 2.) farmers would maintain the system efficiently; 3.) canal supplies would be distributed equitable; and 4.) water received by farmers would be efficiently used because it is a scarce resource. Government intervention, therefore, has been limited to collection of revenues and settlement of gross violations. No attempt was made to organize farmers for maintenance of the system nor have farm level irrigation advisory services been made available from either the Irrigation or Agriculture departments. Secondly, given a long philosophy of benign neglect, the conventional "hardware" approach has been followed faithfully with chief focus on large structures as witnessed by famous dams, headworks and canals. Thirdly researchers in Pakistan (expatriot and local) until recently neglected studies of farm conveyance efficiencies, field application efficiencies, and the relationships of these physical variables with economic, social, and legal factors. Typical of evaluations of most irrigation systems, micro-organizational and legal problems have been largely ignored in Pakistan and considered marginal.

As a result of a long history of benign neglect of the farm system, "we have the wasteful paradox of a great and modern irrigation system pouring its waters on land cultivated as they were in the middle ages." (Revelle Report, 1964). The outlet at the distributary known as the mogha is not only a demarcation point in terms of modern and ancient features of the system, it is also the demarcation point of research, policy, development programs, and foreign investments until recently. Below the mogha many earlier assumptions have been proven false by intensive and comprehensive field studies by the CSU team members. Conveyance and field application efficiencies are not as high as had been previously assumed. Without public intervention farmers cannot learn now to manage water efficiently, nor will they distribute it equitably. More water, provided farmers through public tubewells or diversion works, will not be automatically utilized efficiently. Farmers without proven technologies and creditable advisors will most likely not organize to improve their farm systems, whatever laws are passed or exhortations given.

Increasingly, more attention is given to the improvements of existing farm irrigation systems. A new philosophy in international development which stresses farmer organization and participation, intensive labor utilization, and appropriate technologies are being accepted, as a result, past failures can be overcome. These emphases are more than passing fads because improvement schemes, programs for salinity water-logging controls, and the transfer of technologies are not effective nor maintained over time without effective collective action by farmers themselves. Expertise in engineering and other disciplines far exceed our knowledge of how to transfer and maintain technologies through farmer organizations. Wiener and others realize this and suggest that given a comprehensive approach, water management improvement programs can become the cutting edge of rural transformation in irrigation regions (Wiener, 1976; World Bank, 1975). A recent World Bank study in Pakistan states, "the technical input required to improve water management is relatively simple; the problem is to formulate practical programs on a large scale which will allow for the technical, social, legal, and political factors which have to be considered." (World Bank, 1976). In the future the problems of existing systems probably will receive more attention than the famous Mangla and Tarbella dams which have dominated irrigation thinking to date in Pakistan. Wiener states, that while engineering will continue to play a fundamental role in irrigation development, there is a need for "humanization of engineering," to include more emphasis on change and transformation of the social realities that have to be reshaped to achieve project successes.

Problem Identification Field Studies and Organizational Factors

A systematic method is needed to evaluate the efficiency of farm systems to identify and diagnose deficiencies, provide and evaluate alternative improvements, and promote diffusion of the improvements. This can be viewed as a technology transfer process.

Major efforts have been made by CSU researchers in Pakistan to systematically identify economic, social, agronomic, and legal problems inhibiting the performance of the farm irrigation system. The method used can be best described as a clinical approach which requires a careful and complete diagnosis before prescriptions are made. This team effort has resulted in an understanding of the interdependence and interaction between these complex factors. The problem identification stage is only one phase of the research-development framework which requires a team effort and much farmer participation. Other equally important phases are search for problem solution; assessment of technologies and design of and implementation of a pilot project. The goal of problem identification is to identify priority problems for research and solution and to gain an understanding of how the system operates.

This process, described in detail in another conference paper (Clyma, Lowdermilk and Corey), appears to be simplistic in that every researcher knows that a problem must be identified before it can be researched or solved. However, the more highly specialized and the more experienced we may be in a specific discipline the easier it is in low income nations to assume that we understand the problems of traditional agricultural systems. This is especially true because each researcher tends to see the problem for which he has expertise and interest and fails to see or understand the system problem (Chambers, 1975).

The neglect of systematic problem identification is not only downright foolish, it can be costly in terms of capital investments, resources of manpower, and benefits foregone to those who are the end users of research findings. For example, major irrigation field studies in the 1960's by notable foreign firms in Pakistan made no measurements of farm conveyance and field application efficiencies but assumed efficiencies respectively of 90 and 70 percent. (World Bank, 1976). These assumptions were used for 11 years in 12 major reports and several computer simulations for planning and development purpose and essentially took the focus away from farm level problems. Likewise in Pakistan, it was assumed that additional water from large public tubewells to supplement canal supplies would be used efficiently by farmers. And of 23 volumes in one comprehensive study only 18 pages were given to social and institutional factors involved which researchers stated "were marginal to their purpose." (Sir Alexander Gibbs, et al., 1966).

Table 1 provides data on farm conveyance efficiencies from a CSU field survey of 40 farm systems in the Punjab and Sind provinces (Early, Lowdermilk and Freeman). These data confirm earlier findings by Clyma et al. (1975). Instead of 90 percent, the conveyance efficiencies are more like 50 percent. For public tubewell augmented systems, they average about 40 percent. In Table 2, the farm system irrigation efficiencies are presented. Instead of the assumed 60 to 70 percent efficiency, these data show efficiencies more like 40 to 45 percent and public tubewell augmented systems have a lower efficiency of from 20 to 34 percent.[3] The magnitude of this error based only on assumption is suggested by a World Bank study which estimates that a one percent error in the farm system efficiency is equivalent to 1.4 MAF of water. In terms of Tarbella storage costs it is equivalent to about $280 million (World Bank, 1976). Given an error or 20 to 25 percent one can calculate the costs to Pakistan in neglect and benefits foregone.

3/These efficiencies are taken at only one point in time, therefore, this was to be taken into consideration.

Table 1. Summary of farm delivery efficiencies by village site (weighted for each farm).

Village site	No. of cases	Mean	Median	Range
101 - 2 wc	14	68.6	71.0	49-91
102 - 1 wc	6	65.0	62.0	45-87
103 - 1 wc	2	61.0	61.0	49-73
104 - 3 wc	25	47.6	50.0	0-100
105*- 1 wc	5	60.8	60.0	32-84
106*- 1 wc	6	45.2	41.5	27-66
107 - 3 wc	28	55.1	52.5	33-92
108*- 1 wc	4	51.0	53.5	12-85
109*- 2 wc	12	43.7	34.5	11-72
110 - 3 wc	27	66.0	70.0	28-95
111*- 2 wc	24	43.4	41.5	2-100
112 - 3 wc	33	54.5	52.0	27-82
113 - 3 wc	25	55.6	55.0	16-85
114 - 3 wc	35	53.1	57.0	10-90
115 - 6 wc	38	55.5	50.5	11-100
116**-4 wc	21	35.1	25.0	7-100
Total	305	53.2	53.4	0-100

*Denotes SCARP public tubewell supplemented commands; command area site 105 has main watercourse and some laterals lined.
**Denotes 4 command areas where there is excess canal supplies and where farmers block the mogha due to excess supplies.

Table 2. Farm Irrigation Efficiencies by Type Command and Tubewell Water Supply Situation.

Type of Command and Supplemental Water Supply Situation	No. Cases	Weighted Farm Irrigation Efficiency (Percentage)	
		Mean	Median
Perennial	197	39	41
101-2WC	14	52	52
102-1WC	6	62	51
103-1WC	2	61	61
104-3WC	25	44	45
106-1WC*	6	15	10
107-3WC	27	52	47
109-2WC*	12	23	24
110-3WC	27	37	40
112-3WC	33	45	46
113-3WC	25	45	45
116-4WC	21	18	14
Non-Perennial	95	45	47
105-1WC*	5	22	25
108-1WC*	4	16	6
111-2WC*	24	37	35
114-4WC	35	47	51
115-6WC	38	50	48
Type of Tubewell Supplements			
None	157	42	45
Private	110	47	47
Public	22	20	20
Public and Private	15	34	34
Density of Tubewells (Private Tubewell Equivalents)			
None	158	42	45
1-2	49	47	48
3-6	22	45	45
7 and above	75	37	36

*Denotes public tubewell supplemented canal commands.

Effect of Organizational and Social Factors

Data in Table 1 also show the variation in conveyance efficiencies at different sites. This results primarily from the frequency and the quality of maintenance, the length of the watercourse system, the total quantity of water available, and the level of organization among farmers. For example, at site 116 for four watercourses the median efficiency is 25 percent. At this site our data show the following: a surplus water situation; no organization for control or distribution of water; irrigation at will by farmers from seven illegal outlets; and irrigation water is conveyed across basins. Farmers report that there is no system of sanctions for those who do not clean the watercourse. Cleaning and maintenance is usually once or twice per year. In contrast at site 101, where the median conveyance efficiency is 70 percent, farmers clean the watercourse with more regularity, have a formal system of distribution through fixed turns, have a system of sanctions for stealing and for non-compliance in cleaning and maintenance efforts, and have strong leadership, therefore, cooperation is maintained within a watercourse committee.

These examples suggest the importance of social and organizational factors. In order to understand the farm system among other social variables, we examine the following aspects of the social systems relevant to irrigation: type and level of performance of farmers organizations, propensity of farmers to cooperate, power and influence in collective decision making, patterns of conflict and linkages with institutional services essential for improved water management. Selected findings necessary for understanding how to help farmers improve their informal organizations are:

1. Present organizational modes for cleaning and maintenance of the farm irrigation system.

    a. Village headmen (numbardars) and other influentials from major castes and brotherhood kinship groups provide collective leadership for cleaning and maintenance of the farm system and settlement of disputes. Leadership, power and influence are all highly and significantly correlated with size of land holdings.

    b. Farmers have many informal types of collective action such as building and maintaining mosques, schools, settlement of disputes and cleaning the main watercourse. Definite norms, status rules, and sanctioning systems exist for non-compliance in these activities from informal social pressure such as shame to explicit fines.

Of the 40 systems studied, definite sanctions were used with social controls related to irrigation matters on 60 percent of the systems. Of 112 reported major conflicts in the past five years, sample farmers report that 48 (43%) were water related. Thirty-three of 40 systems have informal farmer committees for watercourse matters.

c. Many variations exist in both the forms of cooperation and the propensity of farmers to cooperate in Pakistan. Cooperation for such activities as exchange of tools, animals, labor purchase of tractors and private tubewells, follow kinship lines. Cleaning of the main watercourse channels usually is done by groups of farmers and the sections cleaned are clearly defined in terms of a certain length per hour time of the irrigation turn. Usually kinship groups work together in teams.

2. Findings related to lack of regular cleaning and maintenance.

   a. For the 40 irrigation systems, no farmer reported that the provision in the Canal and Drainage Act which calls for the closing of canal supplies when farmers fail to maintain the watercourse in proper customary repair had ever been enforced. Due to lack of intervention by officials, farmers largely ignore this provision and those prohibiting buying and selling of water, trading irrigation turns, manipulation of outlets, allowing water to run to waste, payment of bribes to officials to reduce water rates and manipulation of the mogha discharge. Long non-enforcement of codes has resulted in disrespect of the law and lack of local discipline. World Bank officials estimate that an immediate saving of 3 MAF of water per year could be saved without any financial cost, simply by government enforcement of regular maintenance of the existing codes (World Bank, 1976).

   b. Combined with lack of government intervention, our data show that farmers are not aware of major sources of losses, the magnitude of these losses, nor have the technical knowledge for major improvements. Also, there are no incentives, effective sanctions, or advisory services for improved regular maintenance. Until recently, no effort was made to provide farmers with acceptable technology for watercourse improvement and for collective activities to improve the system.

c. Where water is readily available, such as on public tubewell augmented watercourse commands, farmers are less inclined to clean and maintain watercourse channels. Farmers on systems with only non-perennial supplies clean their channels with more regularity than farms on perennial systems.[4] Farmers on 7 of 40 systems investigated have no formal regulated turn systems. Farmers on these systems are less regular in cleaning, use fewer sanctions and have no watercourse committees.

These are only a sample of the findings related to social and organizational factors which are used in the design of experimental watercourse improvement activities. Our attempt has not been the design of new or formal organizational farms, but the discovery of local norms, status roles, and organizational forms to use as a building block to help farmers strengthen present organizations.

Lessons Learned from Experimental Improvement Programs

As described in an earlier paper presented at this conference (Clyma, Lowdermilk and Corey), our research-development approach constitutes a unique technology transfer process. From problem identification, we move the search for appropriate solutions phase and then to a phase known as the assessment of social and technical soluctions. At each phase there is farmer involvement, a team effort and action-oriented research methods implemented under farmer conditions. The on-farm and farmer focus forces us to maintain a management perspective in our applied and adaptive research. Known technologies are adapted, tested and assessed for acceptability with farmer assistance and feedback.

For example, our first attempts at using contractors for building lined brick and cement channels and steel control structures reduced conveyance losses from .3 to .8 cusecs/1000 feet to .03 to .3 cusecs but, the benefit-cost ratio dropped below 1 and neither the government nor the farmers could afford the high cost of Rs. 40 per foot. Government built channels using contractors required about twice the labor input of farmer built sections and farmers felt no responsibility to clean the new system they described, as "belonging to the government and provided by Allah and the Americans!" At another site in the search for solutions, several village leaders were by-passed and due to factionalism the project stopped before completion though cement and brick had been provided free. Gradually new technologies and approaches were evolved based on these earlier experiences.

4/Non-perennial systems receive canal supplies only for the summer seasons.

Additional research showed that 45 percent of the losses were within 30 feet of junctions where farmers divert supplies. Also, it was found that the upper portions of channel banks were major sources of losses due to porous banks with high infiltration rates and pipe holes created by rodents and soil microorganisms (Kemper et al., 1976). Locally made junction structures and field diversion structures were developed along with techniques to rebuild earthen channels with compacted banks. A package of low cost labor intensive technologies were developed and procedures developed to organize farmers to do the major work themselves.

Using their own systems of status, norms, and sanctions they choose their own leaders, representative of major social (brotherhood kinship) groups, formed a watercourse committee, provided all labor, hired local mason, purchased field diversion structures, and settled all disputes. On some experimental watercourses, sediment traps, special places for buffalos to bathe, and a place for washing clothes were suggested and implemented by farmers. At one site farmers rehabilitated 30,000 feet of earthen watercourse channel assisted by engineers and extension workers in 40 days. Later they completed 10,000 more feet at a cost of Rs. 2 per foot ($.20). The conveyance efficiency before improvements was 51 percent and afterwards was 77 percent (Kemper et al., 1976).

The demonstration effect was immediate. Farmers from other areas requested technical assistance and in several cases they attempted to duplicate the process without engineering help. At another site farmers worked through the holy month of Ramazan in the hot humid month of August. At one site farmers hired their own ditch tender who was trained by engineers and extension workers to check and repair leaks, clean vegetation from ditch banks, and provide surveillance to reduce stealing of water. This was similar to the earlier tradition of hiring a watercourse time keeper for regulation of irrigation turns.

The keys were a carefully tested package of technologies, which reduced losses 40 to 50 percent, and doubled the amount of water at the tail of the farm system and farmer organization. Farmers realizing visible benefits became vehicles of transfer to other farmers and placed pressure on government officials for more services, such as precision land leveling and farm irrigation advisors to help them improve irrigation practices to take advantage of extra water. Farmers themselves became spokesmen to government through carefully planned meetings and field days. Experience to date suggests that the most effective vehicles of technology transfer in Pakistan are the farmers themselves. This is supported by the findings for 389 sample farmers who report that at the trial and adoption stages of the diffusion process, 58 percent of their information about technologies is received from other farmers, 19 percent from the radio, and 23 percent from agricultural extension workers (Early, Lowdermilk and Freeman, 1977). Other studies also show that the majority of farmers first learn of new technologies, become interested and put it to trial as a result of information from other farmers (Lowdermilk, 1971; and Lowdermilk, Clyma and Early, 1976).

Research and training continues to refine technologies, provide additional services to farmers, and to find ways to extend the watercourse improvement technology to Pakistan's 78,000 watercourses. A minimum improvement program is now being tested which will consist of increased freeboard on channels, permanent junction structures, improved field diversion structures and the plugging of obvious holes in channel banks. This process reduces losses by 25 percent and costs only five cents per foot. It will require trained extension workers for successful implementation.

Such applied and adaptive procedures may not appear sophisticated to some academic researchers. They do promise to provide benefits to the farmer who is the main building block of agricultural irrigation systems. The farmer is too often considered as illiterate, tradition bound, and resistant to change, however, major reasons for his refusal to adopt new technologies may result from the type technology made available and the methods used by change agents. Research, such as skimming wells, irrigation scheduling, nitrate leaching and complex economic modeling continues but the experimental watercourse improvements and the involvement of farmers in collective action have changed the attitudes of farmers, planners, and central government officials to the prime minister. Thus, farmers themselves, became vehicles of technology transfer and we must not forget this in our transfer models. As a result of demonstration efforts by researchers and farmers; planners, officials, and the World Bank are now convinced that investments in improving management at the farm level in Pakistan may be more profitable than building new reservoirs and networks of channels. On a worldwide basis it has been estimated that to expand the irrigation facilities by 40 million acres would probably require as much as $20 billion. World Bank new projects often take from 8 to 10 years to yield significant farm benefits. Quick yielding programs are needed, especially to benefit small farmers. The opportunities for improving existing systems present a tremendous challenge and by nature of farm improvements also, require labor, intensive approaches and require farmer participation. Through collective action such programs can play a significant role in rural transformation and should include the present major emphasis in development strategies. Techniques for improvement of existing farm systems is probably simple in comparison to the problem of creating action programs to transfer farmer expectation, motivation, farms of organization and the production process itself (Wiener, 1976 and World Bank, 1975).

This view has resulted in a recently approved water management Pilot Improvement Program to cover 1500 watercourses and 600,000 acres costing $47 million including farmer inputs. The World Bank is now providing increased financial assistance for water management and developing strategies with Pakistan which over the next 20 to 30 years will bring improvements to the entire Indus Basin. This includes further research, formal training programs and comprehensive nation-wide improvement programs. In sum, the major contribution has been the dramatic change in the attitudes of planners and officials and this resulted from convinced farmers who proved what is possible when acceptable technologies are made available.

Evaluation of Farmer Organization in Pakistan's Pilot Project

Since farmer organizations are critical to the success of improvement programs, a major component of the Pilot Project is the careful evaluation of the collective actions of farmers to ascertain how more effective water user organizations can be established. The present purpose of the evaluation of farmer organizations is to provide feedback for improvement of the Pilot Project's efforts in organizing farmers who assist in the planning, supervision and implementation of improvement activities. Several formal and informal types of organizations will be evaluated and data will be provided to government officials for establishing codes and regulations which will provide greater incentives for farmer organizations on a nation-wide program. Key initial premises and hypothesis representative of those tested through structured evaluative research methods follow:

1. Initial Premise

   a. If watercourse delivery efficiencies are to be improved on watercourses where there is more than one controlling farmer, informal or formal organizations are required for constructing and maintaining watercourse improvements.

   b. Improved watercourses represent collective goods because in the absence of adequate organization of the collectivity of farmers significant benefits of an improved watercourse cannot be denied to those "free riders" who do not contribute to the improvements. Organization with power to control "free riders" is essential to build and maintain improved watercourses.

   c. The nature of formal and/or informal organizational arrangements must be heavily influenced by local indigenous decision-making groups and processes.

d. One major task of research is to examine the uses and limits of such local indigenous decision-making groups and processes for conducting water management improvement programs.

e. Conflict is omnipresent in social life. It cannot be eliminated; it can be controlled and diverted to productive use through appropriate organization of decision structures and through appropriate organization of the issues or cleavages.

f. The distribution of power and influence among members of the social organization will centrally affect the organization's efficacy in creating and maintaining water management improvements.

2. Selected Hypotheses

   a. The greater the distance of a watercourse from the head of a canal, the greater the propensity of watercourse farmers to collectively organize to secure watercourse improvement.

   b. The less the availability of public tubewell water on the watercourse, the greater the propensity of watercourse farmers to organize.

   c. The greater the land fragmentation on a given watercourse, the less the propensity of watercourse farmers to organize.

   d. The more conflicts associated with water management improvement programs reinforce and polarize already existing social and economic cleavages the less the propensity of farmers to organize.

   e. The greater the percentage of watercourse farmers who score high on the power/influence scale the greater the likelihood of successful collective watercourse organization.

   f. The more power on a given watercourse is evenly distributed such that it takes one half of the farmers to account for one half of the power attributed to all watercourse members, the greater the propensity to organize.

   g. The more power is concentrated toward the tail of a watercourse, the greater the propensity to organize for watercourse improvements.

Conclusion

In sum, this paper has contended that effective local farmer organizations are essential for the creation and maintenance of improved water management technologies which require collective action. In particular, watercourses require collective action because if any single farmer makes an investment and others do not, one's sacrifice is wasted. On the other hand, if all other farmers do make investments of time, money, and labor in improving a watercourse the non-investing "free rider" enjoys the benefits of other investors' sacrifices. The solution is disciplined local social organizations that will insure that "free riding" is eliminated and that benefits are distributed according to mutually acceptable rules. Such organization can thereby create a social climate for watercourse improvement and maintenance.

At present, given the absence of widespread effective local organizations, watercourses are in generally poor repair and losses are typically high. Yet, an action-research process described briefly herein reveals that there are social bases for creating effective local organization. Results of initial efforts, where the action-research process has been implemented by the CSU interdisciplinary team and its Pakistani counterparts, suggest that there is great demand among farmers for the socio-technical package that can result in a doubling of water supply for many farmers as well as providing for reduced waterlogging and salinity. In order to determine the factors which promote and retard the effective functioning of local organizations, many variables are investigated but special focus is given to local conflict patterns and power distributions.

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APPENDIX 33

RESEARCH AND LINKAGES NEEDED TO SUPPORT THE PROVINCIAL FARM WATER MANAGEMENT IMPROVEMENT PROGRAMS

W. D. Kemper[1]

NEED FOR IMPROVEMENT

Recent survey and research studies (Early et al., 1976; Clyma et al., 1975) have shown that only about half the water leaving the distributaries and SCARP tubewells is reaching the farmers fields (i.e., delivery efficiency is about 50%).

Studies of elevations within bunded areas show average difference of over two inches which indicate that it is common for low portions of a bunded unit to receive over twice as much irrigation water as the high portions. Data on maize and cotton (Wahla and Reuss, 1976, and B. Sabir, 1976) indicate that the yields/acre on the low areas of bunded units are about half the yields/acre on the high areas in a SCARP project area. Data by Clyma et al., 1975 and Early et al., 1976 indicate both under- and overirrigation at various times of the year and different parts of the country.

Underirrigation, overirrigation and the surface flooding method of irrigation and associated sealing and crusting of the soil surface are primary factors in the poor stands and low yields, particularly of kharif crops, in the Indus Basin.

Inadequate water, particularly at planting time, is a primary constraint on the acreage of wheat that can be planted.

Watercourse improvement programs by farmers have increased delivery efficiencies from 50% to 75%, which increased the amount of water available at the farmers fields to 150% of its previous value. Research studies indicate a potential for improved earthen watercourses to increase the delivery efficiencies to about 90%, which could increase the amount of water delivered to farmers fields to 180% of present values.

These and other data on the benefits of surface drainage, benefits of furrow vs flood irrigation, benefits of ground water management and benefits of runoff control on barani areas, indicate that improved farm water management has the potential for facilitating major increases in crop production in the Indus Basin.

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ACTION AGENCIES

On the basis of the potential for improvement in crop production that can result from improved water management, the Government of Pakistan has organized a Farm Water Management Improvement Program which is being initiated in the Punjab and Sind Provinces and is scheduled for initiation in the North West Frontier Province in 1977-1973. The purpose of these projects in these Provinces is to increase the delivery efficiency and the application efficiency of water, and to increase the efficiency with which water is used to improve crop production. The programs will accomplish these goals by helping the farmers to:

1. Cooperatively improve their watercourses,
2. level their lands, and
3. improve their irrigation methods and timing, surface drainage, and associated cultural factors such as crop scheduling, seeding, weed control and fertilization.

These Farm Water Management Programs in these three Provinces are the only major action programs designed to help farmers manage water from the mogha to the crop.

The Irrigation Departments have authority to settle water delivery disputes among farmers and played a major role in the design of the original delivery channels of the sarkari khal and in developing the rules (e.g. number of outlets per square, etc.) and schedules (i.e., pakka warabundis) for its operation. They even have authority, through the Canal Act, to close the moghas if the farmers have allowed their watercourse to deteriorate so its delivery efficiency is poor. In actual practice, the Irrigation Department takes responsibility for the water in the canals and for design, construction and maintenance of the moghas. But since their manpower is limited they have no action program to help the farmers to improve and maintain their watercourse, increase their application efficiencies or improve their methods of irrigation. They have limited themselves to a regulatory responsibility beyond the mogha (and the tubewell). The Irrigation Departments show little desire to expand that role into a major action program for helping farmers improve their water management (although there is a possibility that the tubewell operators supervised by the Irrigation Department could be trained and motivated to play a positive role).

One other set of agencies that could help the farmers to improve their water management are the Extension Services of the Provincial Departments of Agriculture. Their mission is to help the farmers improve their crop production. However, their personnel have not been given training in water management which would give them the ability to help the farmers in this respect. The Secretary of the Punjab Agriculture Department has deputed a man from his extension service to cooperate in research with the Mona research program to develop the most efficient means for maintaining watercourses and motivating farmers to initiate the best maintenance programs. When the study has progressed to the point where procedures are evaluated which allow farmers a return obviously exceeding their investment (labor), this man will work with the Mona Research and Training Staff to develop a training program which will enable extension personnel to help farmers increase their water supplies through watercourse maintenance.

The Water and Power Development Authority are conducting surveys to further determine the status of water management on the farms. They are considering the feasibility of farm water management improvement programs as coordinated parts of their Salinity Control and Reclamation Projects in which tubewell installation has been the primary factor in the past. If the farm water management aspects are integrated into the SCARP program, this modified SCARP program could become a major action agency for improving water management in the future.

RESEARCH AGENCIES

Sufficient data were available to indicate that an investment in a water management improvement program would yield a good return which provided justification for initiation of the Provincial On-Farm Water Management Programs. However, it is apparent that additional research could further refine the procedures and extension techniques involved, refine the program to increase the benefits compared to the costs, and adapt it more specifically to the farmers resources and needs.

In developing the action programs for water management improvement, there was a strong temptation to build in integrated research programs which would be directly responsive to the needs of the action program. As a minimum there should be an economic evaluation of the action program. Strong arguments arose against developing a research program (beyond this minimum) that was closely integrated with the action program. These arguments included the fact that trained personnel available to the Agriculture Departments were limited in number and were needed in the training and implementation functions. A research program would dilute their efforts and could lead to a decrease in the quality of the implementation programs.

As tentative plans were made to set up a research program in one Province, it became apparent that the contemplated research was largely overlapping with research underway or planned at other research institutions and that having a substantial research program integrated with the action program would drastically reduce the effort spent by the personnel to maintain linkages and information transfer with the other research agencies. Consequently, it is recommended that the Provincial Farm Water Management Programs "specialize" in implementation and essential training, and that they do not dilute their action effort by competing with research agencies. Instead, it is proposed that each provincial program assign one or two good men trained in research and implementation to act as "research focus and implementation coordinators" who will facilitate information transfer between the research and the implementation agency and play a major role in refinement of the Farm Water Management Program, and in helping the research agencies understand the high priority needs of the implementing agency and the farmers. The details of the roles of these coordinators will be discussed later. Their general function is to provide linkage with the research agencies which will allow the rest of the Farm Water Management Project personnel to be implementation specialists. A major reason for this proposal that the Provincial Farm Water Management Project personnel specialize in implementation is that the FWMP of the Provinces are essentially the only action agencies helping the farmers to improve their water management. The research agencies that can feed information into this program are listed below, with indications of how they can contribute to the farm water management research programs.

Mona Reclamation Experimental Project

This project has done much of the research leading to the Farm Water Management development projects, and the Mona Project is being strengthened to play a continuing support role for water management development projects. It will conduct research on the relationships between the physical and crop production variables, and these will be tested under conditions where the farmer is involved to insure that they are acceptable to the farmer and adapted to his resources (or that essential missing resources are provided). Extension methods for delivery of these techniques to the farmers will also be studied at Mona. Different alternatives for working with the farmers on improvement projects will be evaluated to determine the support level where the farmer is being given only those inputs which he cannot (or will not) supply himself.

Water Management Survey Project (WAPDA)

This group is conducting a survey of water management and associated practices to determine the seasonal variation of these and obtain data to help WAPDA decide whether a program to improve farm water management is needed as a major and integral component of the nation's best investment to improve water supply, drainage and crop production.

Irrigation, Drainage and Flood Control Research Council

This agency has a broad responsibility to develop research needed in the hydrology area. They could also help develop linkages between research and action agencies.

Drainage Research Institute Pakistan

This research unit, located in Hyderabad, is advised by Wageningen University (Netherlands) where some of the outstanding theoretical work on drainage has been done. Their research is directed primarily to determine the best methods for drainage in Pakistan.

Agricultural Research Council

This council is primarily a funding and coordination agency. They are in an excellent position to help establish and fund additional water management research adapted to the needs of different parts of the country and to help develop linkages between the research agencies which they are supporting, other research agencies and the implementing agencies.

Pakistan Agricultural Research Center

This research center is under the direction of the Agricultural Research Council and is located near Islamabad. They have a supplemental tubewell irrigation supply, but are in an area which has high rainfall and is primarily barani. They could do some of the research needed on methods to conserve, manage and use rain to increase crop production. However, because rainfall at this location is high, development of a data base to cover the range of barani rainfall conditions would require a coordinated research program with two other research locations with medium and low average annual precipitation.

National Cotton Research Institute (Multan)

This agency is becoming more interested in water management in cotton production and is developing a water measurement and distribution system on their research area which will allow them to conduct controlled water management studies. Their staff has good training in Agronomy, but could use an Agricultural Engineer well trained in water management and tillage practices to supervise construction and operation of the delivery system, and assist in planning of research to improve water management and cotton production.

Land Reclamation Directorate

This research agency, supervised by the Punjab Irrigation Department, is headquartered in Lahore where they have at least three sets of lysimeters in which they are studying effects of depth of the water table on surface irrigation requirements, magnitude of upward water and salt movement, etc. They also have several field stations where they are determining consumptive use of water by various crops, and can study management of saline water and soils for optimal crop production, irrigation methods and water and crop scheduling for increased production.

Irrigation Research Institute

This institute is a research arm of the Punjab Irrigation Department. It has conducted measurements to determine the rate of unavoidable loss from earthen watercourses. They have also tested pakka lined and polyethylene lined watercourses and determined rates of loss from these watercourses. Their work is generally done very carefully, under experimental conditions, rather than under farmers operational conditions.

The Punjab Agricultural Research Institute

This institute has several crops research institutes and sections and a soils research institute where research in water management and crop production is in progress. Some of the best practical crops research in Pakistan is underway in the various units of PARI. In several instances, an agricultural engineer well trained in water management and tillage could strengthen their research program.

Data collected by these units is being used by the University of Agriculture and CSU as a major part of the basis for the crop management recommendations taught to the water management extension specialists who will be part of the development teams of the On-Farm Water Management Projects of the Punjab and Sind.

Punjab On-Farm Water Management Project

This is the project which has primary responsibility for implementing improved water management in the Punjab. It will lease a small farm for training and research where limited water management research will be conducted. However, the project will utilize research from the other units of the Punjab Agriculture Department (PARI), Mona and other research agencies to allow this project to concentrate in implementation. The project will also cooperate with UAL, encouraging them to participate in research which will lead to evaluation and refinement of the project.

University of Agriculture - Lyallpur

The training and research personnel at UAL associated with water management will do their research primarily in those areas which deal with teaching, extension, and their evaluation and refinement. In addition to teaching, they will evaluate the performance of the trainees, the degree of motivation of the farmers, and where necessary, the physical and economic improvements in order to determine the changes in direction needed in the training for this program. They will be particularly concerned with the water users organizations to accomplish the specific objectives of this project. They will also be evaluating the potential of the positive experience in cooperation in watercourse improvement as a good launching pad for cooperative effort to achieve other benefits. Considering the enhanced water supply and other resources and cropping alternatives available to the farmers, farm plans will be developed to achieve maximum economic return. When these plans have been adequately tested, learning how to help farmers develop such plans will become part of the training of the water management advisers.

UAL will also be developing promising alternatives for the weaker components of the On-Farm Water Management Program.

Lahore University

The civil engineering department has a continuing interest in water management research and are currently developing programs on utilization of saline water in crop production. They are also developing a "Center of Excellence in Water Management" and sponsor a series of seminars in this subject area.

Tandojam Agricultural University

They have been conducting studies on consumptive use of water and water fertilizer interactions and have developed an effective well trained interdisciplinary team to work on water management problems.

Sind Agricultural Research Institute

Their research in recent years has not involved water management, but it could if they were to add a person well trained in this subject to their staff, or have one of their present staff members take such training at one of the other research agencies which has an active program in water management.

The North West Frontier Province Agriculture Department

The department has two major research centers at Tarnab and Pirsabak, and several smaller research locations. Tarnab is conducting studies on consumptive use of water by crops and is developing some expertise in water management research. However, if they are to play an effective role in the national water management research effort, they will need additional expertise, either by training of their present personnel, or by bringing in a well trained water management specialist.

The Maize and Millets Research Institute at Pirsabak is instituting graded furrow irrigation on part of their research farm, which will provide an opportunity for an evaluation of this type of irrigation compared to the standard basin flooding system commonly used. While they have no internal specialist in water management, they have some Australian advisers who are specialists. If the Pirsabak staff learns what these advisers have to offer, they will be able to play a positive role in the national water management program.

Peshawar University

The University has conducted some studies on nutrient and water requirements of crops, but their farm water management research has been limited by meager funding. They do have personnel who are trained in the subject area and could play a significant role in the national program if properly oriented and funded.

Baluchistan Agriculture Department

While they have done little research on water management because there are not many acres irrigated in Baluchistan, the value of water and the potential value of crops (i.e., apples) grown on this water are so high that irrigation systems that have high distribution and application efficiencies, and reasonably low costs, should be studied from the point of their economic feasibility. The "hose pull" irrigation system proposed by Jack Keller is one of the most promising and should be one of the first tried.

LINKAGES NEEDED

Specialization of agencies in research or implementation allows the participants to become more effective experts in their jobs. However, separation of the research and implementation function in different agencies can reduce the information flow from the participant researchers to the implementers and vice-versa. This flow of information is essential for efficient relevant research and an efficient implementation program.

Maintaining this two way flow of information will be necessary if farm water management in Pakistan is to be efficiently improved. The linkages needed between the research and implementing agencies are shown in the chart, but many of these are non-existent, or "weak". The provision of some formal linkages between these institutions will help keep these information flow channels open and the following "linkages" are proposed for this purpose.

Research and Development Coordination Committee and the Thikriwalla Test Watercourses

The water management extension specialists to be trained at UAL for the On-Farm Water Management Programs are to be given extensive field experience in working with farmers who have recently improved their watercourses and have an enhanced water supply. Freshly improved watercourses will be needed for this purpose twice a year.

Wasting of time in bargaining and uncertainty on the part of farmers and the On-Farm Water Management team members can be avoided if the watercourse improvement program is specifically defined. However, the researchers developing new methods and organization for watercourse improvement and the implementation teams will continuously be formulating methods and organizational patterns. A linkage is needed where these alternative methods and organizational patterns can be evaluated under conditions similar to those specified in the action program and considered for implementation in the action program.

A series of "Test Watercourses" to be improved on a schedule of at least one every six months is proposed at Thikriwalla to satisfy these needs. The watercourse improvement would be done primarily by the Punjab On-Farm Water Management Team, using funds from the action budget of that program. When new and experimental items are not appropriate for payment under that program, they will be paid for from the USAID grant research budget carried over from the old IRDP Water Management Research Project.

The specific improvements to be made, procedures used to make them, approaches to be used with the farmers and methods to be suggested to the farmers for organizing to carry out the improvement and follow-up maintenance, will be decided by a Research and Development Coordination Committee at semi-annual review meetings. This committee will be composed of a voting member from: (1) the Punjab On-Farm Water Management Project, (2) the University of Agriculture at Lyallpur, (3) the Mona Reclamation Experimental Project, (4) the Sind On-Farm Water Management Project, (5) the North West Frontier Province On-Farm Water Management Project, (6) the Punjab Irrigation Department, (7) the U.S. Soil Conservation Service, and (8) Colorado State University. The Sind and North West Frontier

Province Irrigation Departments will also be invited to send members if they choose to do so. Decisions will be by simple majority vote. The Federal Director of the On-Farm Water Management Program could serve as chairman of this committee. The UAL member of the committee will serve as the convenor of the meeting, setting the date and place, and announcing the meeting to all of the other agencies at least three months in advance of the meeting. Proposals of new innovations to be evaluated at the Thikriwalla Test Watercourses should be prepared in written form and submitted to the committee members at least ten days prior to the meeting. If the committee decides that two or more of the proposed innovations are both promising, but are incompatible on the same watercourse, they may propose the improvement of more than one test watercourse during that time period to accommodate the promising innovations.

Utilization of a regular Punjab On-Farm Water Management Project team to make the innovative improvement will allow observers to see whether the team will need any special training to handle such innovations.

Research Focus and Implementation Coordinators

These individuals would play a vital linking function between implementation and research agencies. They would spend sufficient time in the field with farmers and implementation personnel to understand the problems and the urgency of their solution. They should also invest a considerable portion of their time in personal and group consultations with researchers to help the reseachers understand and focus on the problems whose solutions have the highest priorities.

The CSU advisers should help these RFIC's establish contacts with international and foreign institutions where pertinent research is being conducted and the RFIC's should be funded to purchase publications and establish libraries on water and crop management to increase crop production.

If research funding is provided to the RFIC's, it should be sufficiently limited that they will invest most of their efforts in coordination. Their publications should be guidelines, reviews and discussion papers based on recent research findings from all pertinent research studies in the subject area. In the beginning, CSU advisers will assist in writing these papers.

Annual Review of Recommendations For Crops

As part of their training, the Extension Water Management Advisers on the Farm Water Management Improvement teams, will be given the most recent recommendations for irrigating, fertilizing, seeding and variety selection, weeding and otherwise managing their crops to achieve optimum yields. These recommendations will be formalized in a loose leaf "crop and water management guide" based on data collected by research agencies such as the PARI, Mona, Cotton Research Institute, University of Agriculture at Lyailpur, Sind Agriculture University, Land Reclamation Directorate, etc.

The output of relevant water and crop management findings from these research institutions is increasing rapidly, and substantial increases in the information base are expected each year. To help ensure that this information base is closely related to needs of the action agencies and the farmers, and to provide a forum in which relative merits of new management practices suggested by research findings can be discussed, it is proposed that a national review of research on each major crop be held annually. Since the Agricultural Research Council either has, or is in process of developing, "National Research Programs" for most of the major crops, they should convene the researchers working with their support and invite the other researchers dealing with the particular crop to this annual meeting. All researchers dealing with these crops should distribute their major findings in printed form prior to the meeting so the possibilities of modifying the guidelines in light of these findings can be considered at the review meeting.

The Research Focus and Implementation Coordinators from the Provincial Farm Water Management Projects should also be invited to these Annual Review meetings. These coordinators should prepare a review of problems encountered by the farmers that need the attention of the researchers, and this review should be distributed to the researchers at least two weeks before the review meeting so they can discuss these research avenues with their administrators. At the meetings researchers with the capabilities to solve these problems should be encouraged to focus their efforts on the relevant high priority items.

The Provincial Agriculture Department extension agencies should also be invited to send extension specialists to these review meetings who would perform functions similar to the Research Focus and Implementation Coordinators of the Farm Water Management Projects.

Extension Water Management Specialists

Extension field assistants at Mona have been trained to use levels to determine elevations of fields served, to use flumes to measure flow of water and water losses in watercourses, and to set alignments and elevations for improved watercourses from the designs prepared by engineers. It is apparent that field assistants are capable of playing more technical roles than those normally assigned to them if the proper training is provided.

Preliminary results of cleaning and maintenance studies indicate substantial increases in water delivery efficiency as a result of the organized input of labor, with no capital input. Such cleaning and maintenance should definitely be a part of the Provincial On-Farm Water Management Programs. However, the apparent benefits and cost ratio of such cleaning and maintenance programs appear to be so high that it would be almost immoral to withhold such information from the farmers as a whole. The only agencies presently capable of contacting all the farmers and carrying this message to them are the Extension Services of the Provincial Agriculture Departments.

To accomplish this, about 4,000 field assistants would need training. Logistics of personnel movement and the field nature of the training involved argue for taking the trainers to the field to teach the field assistants.

It is proposed that a new classification of personnel be developed within the Provincial Extension Services to be titled - Extension Water Management Specialists.

The responsibilities of these specialists should include:

1. Obtaining information from water management researchers and work with the researchers to develop effective techniques for motivating the farmers to improve their water management;

2. Training Extension Agricultural Officers and Field Assistants in the technology and extension methods required to help farmers achieve better water management (leaving successful programs in their areas which can serve as demonstrations);

3. Identifying problems limiting farmers water management and crop production and helping researchers to devise and conduct studies which will help the farmers and field assistants to remove those limitations.

Training of the Extension Water Management Specialists should include:

1. The four month water management course currently being developed by the UAL.

2. Participation with research agencies in research to develop technology and methods of efficiently motivating farmers to accept the technology.

The Punjab Agriculture Department has already taken a step toward developing one Extension Water Management Specialist by assigning Mr. Awan to work with the extension researchers at Mona on the watercourse cleaning and maintenance study. As a result of participation in this study Mr. Awan will have first hand knowledge of the technology, the range of benefits/cost ratios that result from using this technology, and the most effective methods for inducing farmers to implement this technology. Additional Extension Water Management Specialists should be developed as needs for their services become apparent. Possibilities of their participating effectively as trainers in the regular extension training program and as trainers in the UAL training program should be considered.

Additional Linkages as Needed

The above linkages are presented as examples of positions and regular meetings needed to help research agencies contribute effectively to action programs and allow action program personnel to help researchers identify the problems of high priority to the farmers and orient their research accordingly. Additional linkages will be needed as the program develops. These linkages represent substantial outlays of personnel time and travel funds. They should be evaluated annually to determine whether they are fulfilling their functions or if they should be modified to do the needed job.

SUMMARY

The attached listing of research and action agencies which can contribute to Farm Water Management improvement shows the existence of several agencies which are, or could be, contributing to the research needed. In the past, the farmers have received little guidance in how to use the water more effectively. The forthcoming Provincial On-Farm Water Management Projects will provide some farmers with such help and the Provincial Extension Services could also give the farmers guidance. These action agencies now have few personnel trained in water management. To allow them to place their primary emphasis on implementation of improved water management, it is suggested that they do not develop major research efforts of their own. To help them draw on relevant research from other agencies to improve their implementation program and to allow the action agencies to help the research agencies focus on the farmers most pressing needs, the following "linkages" are proposed:

1. Research and Development Coordination Committee and Test Watercourses on which promising new innovations will be evaluated.

2. Research Focus and Implementation Coordinators in the Provincial On-Farm Water Management projects.

3. Annual Reviews of Recommendations for Crops.
4. Water Management Specialists in the Provincial Agriculture Extension Programs.
5. Additional linkages as needed.

Maintenance of these linkages should allow the researchers and implementers to become effective specialists in their jobs and still provide the interchange of information essential to use of research information and improving the relevancy of research.

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APPENDIX 34

SOCIOLOGICAL ANALYSIS FOR IRRIGATION WATER MANAGEMENT--A PERSPECTIVE AND SOME ANALYTICAL APPROACHES TO ASSIST DECISION-MAKING

David M. Freeman and Max K. Lowdermilk[1]

INTRODUCTION

> The technical input required to improve water management is relatively simple. The problem is to formulate practical programs on a large scale which will allow for the technical, social, legal and political factors...[2]

The Problem

Irrigation water is sociological because people must organize collectively to secure it, transport it, divide it into usable shares, enforce rules for its application, pay for it, and dispose of unused portions. The kinds of social organizations, the patterns of power, decision-making, conflict, and cooperation which people create and maintain for the social control of water intimately affects the productivity of its use. Attempting to comprehend physical and agronomic problems of irrigation without probing into surrounding social organizational webs is like attempting to understand deficiencies in plant growth without reference to conditions of climate. When water moves efficiently from rivers, through a network of canals, to plant root zones, it is because people have effectively organized a decision system capable of enforcing technically sound rules for pursuing the collective interest. Defects in the delivery and application of irrigation water are typically associated with deficiencies in social organization.

The central premise of this paper, therefore, is that programs to improve the management of irrigation water must center on the design and improvement of irrigation organization at local, regional, and national levels.

The multi-faceted process of organization building and reform so central to the transfer of improved irrigation technology encompasses a range of crucial tasks such as:

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[2] See World Bank Report No. 922a PAK, Pakistan Special Agricultural Sector Review, Volume III: Annex on Water Management, General Agriculture Division, South Asia Projects Department

1. Mapping strategic variables accounting for behavior associated with poor irrigation efficiencies in existing systems, including identification of central constraints;
2. Identification and testing of potential alternative socio-technical "solutions" for relaxing constraints;
3. Verification of "optimum" organizational-technical "packages" through systematic adaptive research;
4. Pilot project design and implementation;
5. Project evaluation with "feedback" to policy makers and practitioners;
6. Diffusion of the "improved" organizational-technical "packages" with focus on communication and supporting services thereby altering the strategic factors identified in step one.

Two implications must be noted about such a listing. First, no single discipline can adequately deal with any specific area mentioned above. Interdisciplinary efforts are essential in all phases of water management improvement programs and we stress interdisciplinary rather than multidisciplinary efforts. Second, each item requires extensive analysis--no paper of modest length can adequately comprehend the complex interdependent problems, the available tools, and the many uses and limits of potential analytic approaches for all six tasks even within a single discipline. This paper represents only a modest and partial effort to delineate a sociological approach to irrigation water management which focuses on step one--problem and constraint identification. The objectives are:

1. To define the roles of sociological research in water management by sorting out social properties of irrigation water management technologies--a task complicated by their multiple dimensions. The technologies which supply, control, divert, and convey water have different properties than do the technologies employed by farmers in applying water to the fields, for leveling land, for tilling and planting, or for removing water through drainage systems. This bundle of highly diverse technologies needs to be analytically broken down so as to clarify sociological research approaches. The role for sociologists in water management must be articulated at the very minimum to the disciplines of agronomy, engineering and economics. For example, in the case of economics and sociology, earnest discussion has taken place about the potential contribution of sociological

research to improved water management. One central question seems to be: why research sociological factors associated with farmers if one thinks that farmers are "rational" in response to economic incentives? If a technology can be designed which can be demonstrated to have a favorable benefit-cost ratio, will it not be employed by substantial numbers of farmers regardless of whatever interesting sociological factors may be at work? After all, did not many farmers, even smaller ones to some extent, adopt the technologies of the "green revolution?" It will be contended that the "economic man" approach is viable given certain properties of the technology, but that given certain other important properties of technology, the sociologist's "organizational man" analysis is an essential companion to economic analysis. Social organizations are the central vehicles through which water management technologies are delivered, utilized, improved, and maintained. The point of pursuing objective one is to demonstrate that the nature of sociological research must shift as the properties of water management technologies shift. A sociological research and action approach which is highly useful to the decision maker for one-kind of technological system constraint will be most inappropriate when the technological dimensions of the problem have shifted into other configurations.

2. To present two sociological tools for analyzing problems of organization building and reform so as to facilitate the transfer and implementation of improved water management technology. It is beyond the scope of this paper to set forth sociological approaches to problem identification for all technological configurations, but it is possible to present two complementary methodologies for analysis of the sociologically most central problem on water management improvement programs--organization building and reform. Many sociological variables are potential candidates for analysis, but two are advanced with the contention that they centrally condition the ability to introduce and reform the social organizational webs which conduct and control potential improvements in water management technology. The two variables selected for analysis are:

    a. conflict polarization--who is fighting with whom over what issues and how negotiable are the conflicts?

    b. the equality/inequality of power distributions--to what extent can organizational participants effectively sanction noncompliance with technically sound rules for securing the common interest?

In essence, it will be contended that one useful contribution which sociological research can make for the decision maker in the problem identification phase is to identify those social environments which are most conducive to organization building and reform efforts such that scarce resources will not be lost in futile attempts to plant vulnerable organizational "seeds" in hostile social environments. The thesis is that organization building and improvement efforts will enjoy success in direct proportion to the extent that they can be undertaken in environments of low conflict polarization and under power distributions of high centrality and low concentration.[1]

Selective Review of the Literature[2]

The sociology of water management is in a state of infancy; theoretical structures to suggest questions, and provide a context of meaning, remain undeveloped. Yet, some initial work in the field is highly suggestive and will be briefly reviewed.

The dependent variable, quality of water management, has generally been measured in terms of either yields per cusecs of water applied, yields per acre or application and delivery efficiencies.[3] Independent or explanatory variables range from the physical, climatic, and agronomic,[4] to Vohra's concern with official/public opinion, and technical/administrative infrastructure.[5] Gekee Y. Wickham has examined explanatory variables such as communication between farmers and the Philippine National Irrigation Administration, cooperation among farmers, farmer fee payment, farmer satisfaction with yields and with water supply, farmer evaluation of irrigation administrative services, and adoption of improved farm practices.[6] Gustafson and Reidinger[7] and Reidinger[8] discuss the inability of farmers to control the timing and quantity of their water deliveries--factors which limit farmer's ability to participate in the "green revolution." These analysts all explicitly recognize the importance of collective action on the part of farmers to secure and allocate a "community commodity" which irrigation water represents. Wickham, working in the Philippines which enjoys an established organizational framework for farmer decision-making, assumes the existence of farmers' associations and studies variables having to do with their functioning. Reidinger, on the other hand, confronts in India an irrigation system which is designed to operate with only minimal linkage to the farmer/user. Reidinger concludes his analysis by advocating farmer associations on each watercourse to organize distribution of irrigation water and eventually replace the warabundi system so as to increase flexibility and farmer control.

Radosevich and Kirkwood have reviewed the organizational and institutional setting of irrigation development in both the United States and Pakistan.[9] In the U.S., as elsewhere, water development and allocation has been achieved through the building of social organizations capable of undertaking activities for a range of collectivities--from small groups of individual farmers diverting surface flow near a river, to ditch companies, to large irrigation districts. To have foregone organization building would have been tantamount to foregoing irrigation development.

Coward examines the problems of interaction between local organization and national water bureaucracies and points out our dearth of knowledge about the realities of local indigenous organizations. He also has discussed the diverse, traditional, small-scale irrigation organizations that exist in Southeast Asia and finds three themes reflected throughout: (1) a common concern for accountable leadership, (2) a recurrent necessity to create small scale local organizations around "mini-units" which are (3) parts of larger canal-based networks extending beyond local village boundaries.[10] Coward contends that important lessons are to be learned from analysis of traditional irrigation organizations and that thought should be given to ways in which local indigenous elements might be integrated into current irrigation development efforts.

Hunt and Hunt have assembled a most useful and detailed review of several anthropologically oriented case studies with a view toward extracting important questions which need to be pursued by social science students of irrigation systems.[11] Their review of the literature leads them to suggest that future socio-cultural studies of irrigation systems should pay more attention to attributes of the physical environment, that the role system for management of water be more carefully articulated to the political role system, and that the larger encompassing social environment (economic, political, religious) be more systematically connected to the analysis of local irrigation management systems.

Lowdermilk, Clyma and Early have completed a detailed case study of the physical and socio-economic conditions along one Pakistani watercourse and discuss how farmers informally organize around brotherhood groups to distribute water and the lack of effective linkage between these informal groups and the formal bureaucratic provincial level organizations. The lack of adequate organizations is shown to be intimately related to low delivery efficiencies and poor irrigation practices.[12]

Although the literature is largely case study oriented, lacks overall theoretical coherence, and evidences non-comparable data, there is consensus that irrigation technologies fundamentally condition, and are conditioned by, patterns of social organization. If we wish to comprehend successes and failures of irrigation projects, we must carefully examine the interaction between physical, economic, and social organizational variables. It is equally clear that there is little consensus as to how to go about the process of building a coherent conceptual framework. This is understandable because properties of different technologies have not been adequately delineated and the role of social organizations in helping people obtain and utilize technologies with different properties has not been sufficiently articulated. An analysis of the role of social organization in water management technology is essential. This paper now proceeds to develop the rudiments of such an analysis.

THE CONCEPTUAL APPROACH--TOWARD ANALYSIS OF TECHNOLOGY AND SOCIAL ORGANIZATION

The approach is to distinguish between types of technology on two important dimensions:

1. The dimension of divisibility--a technology is said to be divisible if it can be utilized productively in "small" units as well as large--"small" being defined relative to farmer resources. For example, seeds, fertilizers, and pesticides are highly divisible because farmers with varying amounts of cultivatable land can utilize whatever number of units of those inputs needed. An indivisible technology, on the other hand, is one which is "lumpy"--units of some minimum size must be purchased with no possibility of subdividing as in the case of large pieces of machinery. Interest in "fractional" technology has to do with making relatively "lumpy" technologies more divisible by developing mini-pumps, engines, tractors, etc. It is worth noting that much water management technology, on the engineering side of things tends to be relatively indivisible--e g., aligned and lined watercourses, large water lifts, dams, power generation and transmission facilities. Agronomic technology tends, on the whole, to be highly divisible.

2. The dimension of collective/public vs. private goods.[13] A good is said to be "private," if its major benefits can be captured by the investor-owner and denied to those members of the community who do not invest in it. A public or collective good is a significant benefit of which cannot be denied to those who do not help bear the costs. For example, an improved watercourse is a collective good because individual village farmers will calculate as follows with regard to potential improvements: if one makes an investment of time, energy, and money to improve the section running through one's land and many other farmers do not do so, then the payoff of one's work is

> negligible. On the other hand, if many others for some reason undertake lining and straightening, one will still enjoy a share of the benefits if one does little or nothing. Therefore, the rational calculating individual will choose to do nothing either way--even assuming that he has information about potential benefits, the know-how and resources to make improvements. This situation can only be mitigated by the presence of some social organization with sanctions to control "free riders" so that each can be assured that one's contributions will be matched by some acceptable proportion of contribution by a sufficient number of others who benefit.

These two dimensions can be combined into a six-fold table which looks like Table 1.

> Cell One: High divisibility is combined with private goods in this cell. Although small farmers tend to lag behind large farmers in adopting these kinds of technology, smaller farmers can and do respond to economic incentives to adopt them whenever they are: (1) aware of them; (2) certain of their efficacy; (3) able to secure necessary credit and technical assistance; and (4) when there is sufficient supply such that more powerful members of the community do not utilize most of what is available. If any single irrigation related discipline can be associated with technologies of this sector it probably would be agronomy; the "green revolution" was centrally dependent on new technological inputs of this type. Many observers agree that the green revolution is now stalled, and that if higher plateaus of production are to be reached, technologies outside of cell one must be advanced and utilized--e.g., water management. Although technologies with the properties of cell one are the most likely to secure relatively rapid adoption, there are substantial problems--even here--of getting them employed by small farmers. Yet, economic man is viable here--if technologies of this type can be demonstrated to have good cost-benefit ratios, if risks are manageable, chances are that the technologies can be diffused through the marketplace. The required research here is that of demonstrating technical and economic feasibility combined with sociological diffusion work having to do with communication channels, extension, and of insuring that the market place is functioning.

> Cell Two: This sector presents moderately divisible technologies of a private type. Economic man works here only for "large" farmers who have access to the capital and credit to make these relatively "lumpy" purchases of items such as large units of farm machinery. Also these technologies generally require substantial

TABLE 1

Divisibility

Type of Goods	High	Medium	Low
Private	1/ Seeds, fertilizers pesticides, small plows, drills Sector of economic man for big and small farmers. Green Rev. based on these kinds of technology	2/ Large farm implements, (tractors, land scrapers, tubewells, left pumps) Economic man works only for large farmers; sector of social organizational man for small farmers	3/ Centralized non-divisible production of private products employed as inputs into farming/irrigation operations; e.g., fertilizer, machinery
Public/Collective	4/ Fractional cusec tubewell located to pump up seepage from watercourse. Sector of small scale subcommunity social organization	5/ Watercourse improvement (realignment, lining) Sector of social org. man--community scale	6/ Centralized non-divisible production of collective by large scale public enterprise; e.g., power grids, dams, barrages, major canals

amounts of land to make them productive. Therefore, normal market incentives tend to apply to larger farmers; small farmers are in no position to adopt these kinds of technology, except if they are organized collectively to do so. The central sociological problems associated with cell two have to do with equality of power and income and of organizing smaller farms so as to make possible their utilization of "lumpy" private technologies.

Cell Three: Representing a combination of technologies of low divisibility but of a private nature, this sector might be exemplified by "lumpy" centralized factories for providing agricultural inputs such as inorganic fertilizer, chemical pesticides or agricultural machinery. On the farm output side, such large scale private organizations might process farm products such as cotton, sugar or jute. The sociological problems in this sector are those traditionally defined by industrial sociology--how to organize the work process such that it is integrated well within needs and perceptions of the work force. The tools for investigating problems of this type are those that have been traditionally developed by industrial sociologists and social psychologists.

Cell Four: Here one finds a combination of collective goods which are relatively divisible--not requiring large investment relative to farmer resources at any single time. Since these technologies are bundled up in "small" projects, it may be that smaller sub-units of community (joint family, kinship groups) can undertake to supply them. Since individual men who are rational and calculating will not find it in their interest to invest in projects which produce major benefits for "free riding" noninvestors some social organizational structure must exist to insure that the recipients of benefits will also pay an acceptable share. An example of this kind of technology in the domain of on-farm water management might be the small "fractional cusec" tubewell positioned halfway down a watercourse to pump return flow or seepage water back into the watercourse. Although private tubewells have widespread use in Pakistan, it is no accident that they are not generally positioned for this purpose. The sociological problem here is how to create and sustain organizational conditions for small scale sub-community cooperation.

Cell Five: The sector contains those technologies which have the attributes of moderate divisibility and of collective goods. Rational "economic man" will not invest in these types of technology because he will calculate as follows: (1) if any single one should make an investment and many others do not, then the single contribution comes to naught; (2) if many others make the investment and he does not, the project will be completed without his relatively negligible contribution. Therefore, the individual will tend to decide to do nothing and avoid those technologies either way--unless there is a strong and viable local social organization which will provide assurance to each member that sacrifice for a collective good will be matched by others in some acceptable proportion. Specific cases in point appear to be those of large model farms located in Pakistan. Improved, realigned, concrete lined watercourses were installed to demonstrate their superiority to farmers. Yet reports of informants reveal that no other farmers in the adjacent area have adopted this innovation of realigned or lined watercourses--in some cases after two decades! A case can be made that at least some of the reasons are to be found in the absence of appropriate social organization of farmers to make it possible for small and medium sized farmers to construct and operate a "lumpy" collective good.

Cell Six: This represents highly indivisible technologies which are "public" or "collective" in nature. If any single technologically related discipline can be associated with this sector, it would probably be civil engineering--especially in the field of irrigation water management. For example a great share of the products of civil engineering--dams, barrages, large canals, and various control structures cannot be purchased by individuals but must be purchased by large scale public organizations which can capture the costs from socially diverse and geographically widespread benefitting groups. Individuals or private organizations cannot purchase or maintain technologies in this sector no matter how well informed they are, how technically feasible the project, or how great the cost benefit ratios, simply because, as in cell five, individual action is irrational if one's sacrifices will not be met by proportionate sacrifies of each other significant member of a region, province, or nation. The central sociological issues revolve around the analyses of large scale bureaucracies and their linkages to local organizations.

In sum, it is suggested that the constituent technologies of water management can be usefully divided into six mutually exclusive categories. Each category represents a unique combination of properties which, it is asserted, affects adoption and utilization of the technologies. Each major type of technology implies a different research thrust on the part of social scientists.

In essence:

1. If irrigation problems appear to center in cell one, the primary problem is to work with economic analyses to insure that the technological "packages" are attractive from a benefit-cost standpoint, and to do that sociological research which focuses on identifying and resolving problems of communication which limit farmer awareness and interest. Also sociological work is needed which will identify and overcome problems of mal-distribution of power, status, and income.

2. If one has reason to believe that irrigation project problems are those of cell two, the focus can be largely economic for the larger farmer, but will have to be "social organizational" for small operators who cannot individually purchase and operate technologies too "lumpy" relative to their small resource base.

3. If one sees cell three irrigation project problems, the appropriate response would be to ferret out the economic problems preventing private firms from supplying necessary inputs to farmer irrigation operations or processing farm outputs. The role of sociology here would be to perform industrial sociological analysis getting at questions of internal firm organization and operation which affect firm productivity.

4. If irrigation project problems are those identified in cell four, the problem is to design ways to create local small scale organizations which can provide collective goods to sub-community units. No matter how technically feasible or economically attractive, these irrigation technologies will not be provided in the absence of viable local organizations. The task of the sociologists and anthropologists is to determine feasible ways of creating and/or redirecting such organizations.

5. If one believes irrigation project problems center around cell five, the analytical problem is to design larger community level organizations to provide collective goods not just for some sublocal unit but for the entire village or community. Sociological/anthropological problems here are larger scale versions of those in cell four.

6. If one views irrigation project problems to be those in cell six, the problem is to sociologically examine the problems of intra- and inter-bureaucratic

relationships and the linkages of the large scale regional or national bureaucracies to local organizations.

In sum, irrigation projects can associated with any one cell or any combination of cells. The tasks of sociological analysis must differ significantly as the diagnosis of irrigation project difficulties shifts from cell to cell. A sociological analysis of farmer "awareness" problems--highly appropriate to the problems of cell one--would be insufficient and misleading if project problems are those represented by cells four, five, or six.

Some Sociological Tools of Analysis for Cells Two, Four and Five

The remainder of this paper will be devoted to a presentation of two "packages" of analytical tools each of which address issues central to problems of building viable local organizations so as to promote farmer adoption of improved irrigation related technology.

The array of sociological concepts and methodological procedures which can potentially be brought to bear on social problems related to irrigation is much too vast to be characterized in any single paper. It is, however, useful to present a most limited set of "tools" which are geard to the problems of creating and sustaining local farmer organizations necessary to purchase, maintain, and utilize collective goods--cell two problems for small farmers, cell four, and five problems for farmers of all sizes. What follows will not focus on farmer awareness and communications--the primary sociological problem of cell one, nor will it deal with problems of industrial organizational management (cell three), nor will it center on the analysis of large scale bureaucracies (cell six). The discussion turns now toward two sets of tools for examining strategic aspects of local farmer organizations and their environments. The meaning of these complementary analyses is that it is possible to:

1. choose in advance those local settings or environments more hospitable to local farmer organizing efforts; and

2. diagnose problems with existing organizations which are experiencing problems in servicing their members and clients.

IDENTIFYING SOCIAL ENVIRONMENTS CONDUCIVE TO ORGANIZATION BUILDING AND REFORM, PART I--THE ANALYSIS OF SOCIAL CONFLICT POLARIZATION

Introduction

Water management improvement programs inevitably are involved in, and generate, social conflict among affected groups. Each set of program impacts strikes affected parties unevenly--some people are advantaged at direct or indirect costs to others, some values are promoted, others are undercut. Implementation of water management improvement programs tends, therefore to generate conflict cleavages between groups perceiving themselves to be impacted favorably and unfavorably. Benefits for farmers at the "tail" of a watercourse may clearly disadvantage those toward the "head," and what assists "small" farmers may be opposed by larger ones, what members of one kinship group may enthusiastically endorse, members of competing kinship groups may just as heartily reject. It is no accident that, worldwide, conflict resolution is a significant function of irrigation organizations everywhere.[14]

Conflict cleavages are lines of division within or among social groups reflecting patterned differences over value preferences which create fronts of mutual opposition among actors.[15] Conflict cleavages are omnipresent in social life; they cannot be eliminated. The critical question is whether conflict is patterned so as to be negotiable, and conducted in a non-violent manner, or whether it is patterned such that it creates high propensity to commit violence and make cooperation between opponents impossible. The pattern of cleavages is a key to whether farmer organizations will likely be undercut by hostile opponents or be effective resources for social change programs and water management improvements. There are two polar types of conflict structures:

1. The overlapping-associated with limited capacity to absorb change, and with high propensity to commit violence. Change agents should introduce programs in such a way as to reduce tendencies for this type of conflict pattern to develop.

2. The cross-cutting--associated with greater capacity to absorb change and with low propensity for violence. Change agents should introduce projects in such a manner as to facilitate growth of cross-cutting conflict structures among social groups.

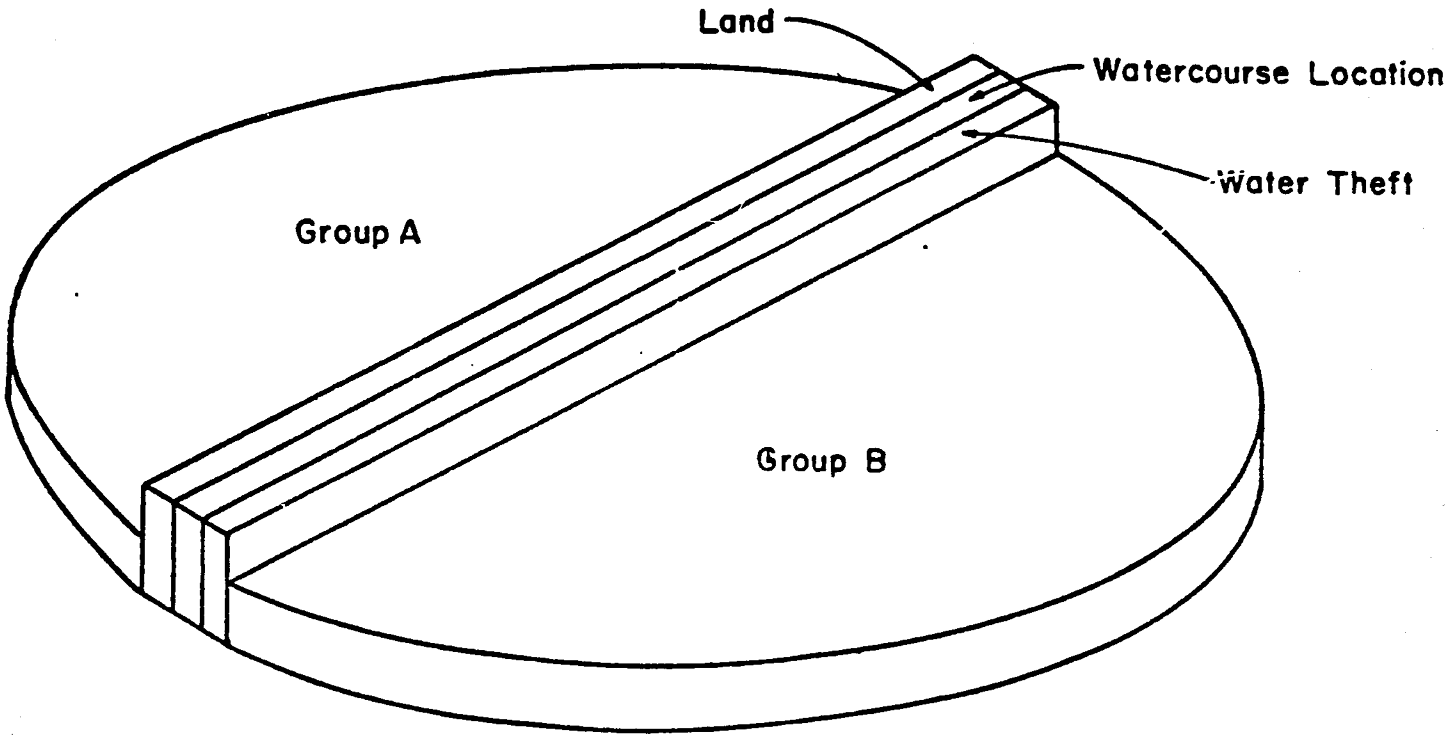
Overlapping conflict structures, creating high polarization, exist when opponent groups are cleaved apart by differences on all significant values fronts--e.g., economic, political, educational, religious, caste, tenancy status, etc. Adversaries on one issue are opponents on all. There are no cross-cutting attachments to common values, no common grounds upon which to compromise, no incentives to negotiate. Opponents ascribe to each other less than human qualities reflecting their lack of shared values. Violence is frequently condoned by both groups in order to protect against the extreme threat represented by the other (See Figure 1).

Cross-cutting conflict structures exist when opponent groups are in opposition over a limited number of cleavage fronts, but are allied in common cause in other significant conflicts (See Figure 2). Actors in disagreement over one or more value preferences find shared attachments when they approach other issue areas. Here lay the roots of social cohesion and the potentials for effective organization building. Cross-cutting cleavages over values stitch the social web together by facilitating constantly renewed willingness to negotiate disputes and seek grounds for compromise. Total involvement of an actor in any one conflict against any single opponent is precluded. Roles and statutes include interaction with a range of opponents on some issues who are allies on other conflict fronts. Multiple involvements in cross-cutting social cleavages precludes polarization on any one axis and keeps social groups open to ideas, trade-offs, and innovations from each other. Cross-cutting cleavage patterns make for low propensities to engage in violence and for high propensities to tolerate change, deviance, innovation, and for cooperation in organizational efforts.

Sample farmers and key informants on sixteen sample Pakistani watercourses were asked about village conflict patterns.[16] Specifically, they were requested to identify conflict cleavages between groups (who fights with whom) the dominant issues which make up the cleavage (what opponents fight about).

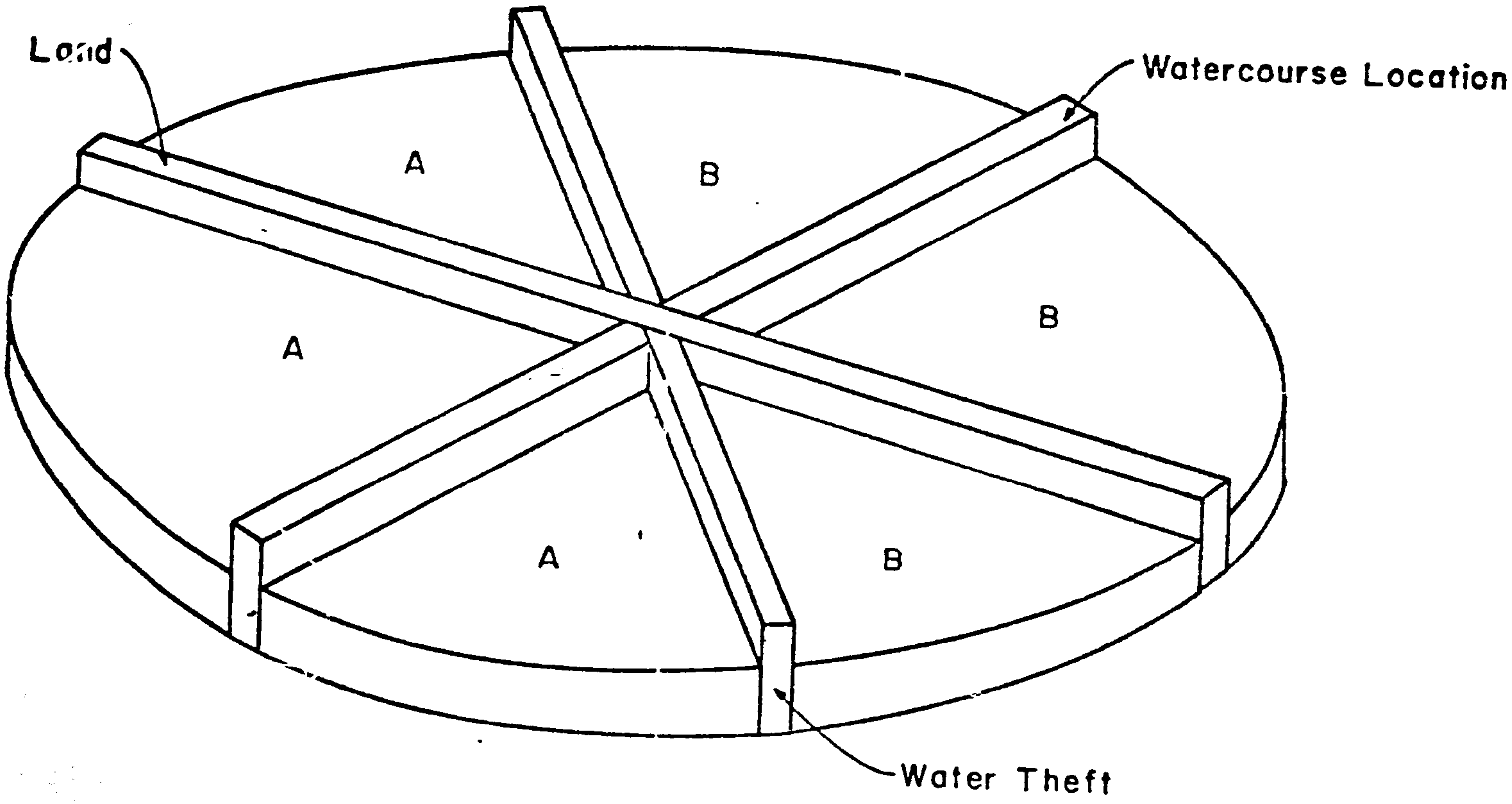
Sample farmer respondents and key informants identified 76 important village conflicts which have been important to villagers within the last five years on the 16 sample watercourses. (See Figure 3). To be counted, conflicts must represent a cleavage in the social network. The term, as used here, excludes personal dissatisfaction, jealousies, and pique which do not affect the social or community web. There must be issues which involve at least a small group of people who agree as to the nature of the issues, and there must be consequences for the group, not just for a particular individual. Of the 76 conflicts, almost 45 percent were directly related to water. Water and land conflict clearly dominate patterns of sample Pakistani village social life.

The most important thing about conflict cleavages, however, is not their number or the specific nature of the



Note: A's are Allied Against All B's on All Issues
Over which there are Cleavages.

Figure 1. Overlapping Cleavages - High Polarization.



Note: Some A's are Allied with at Least Some B's on Each Issue Over which there are Cleavages.

Figure 2. Cross-Cutting Cleavages - Low Polarization.

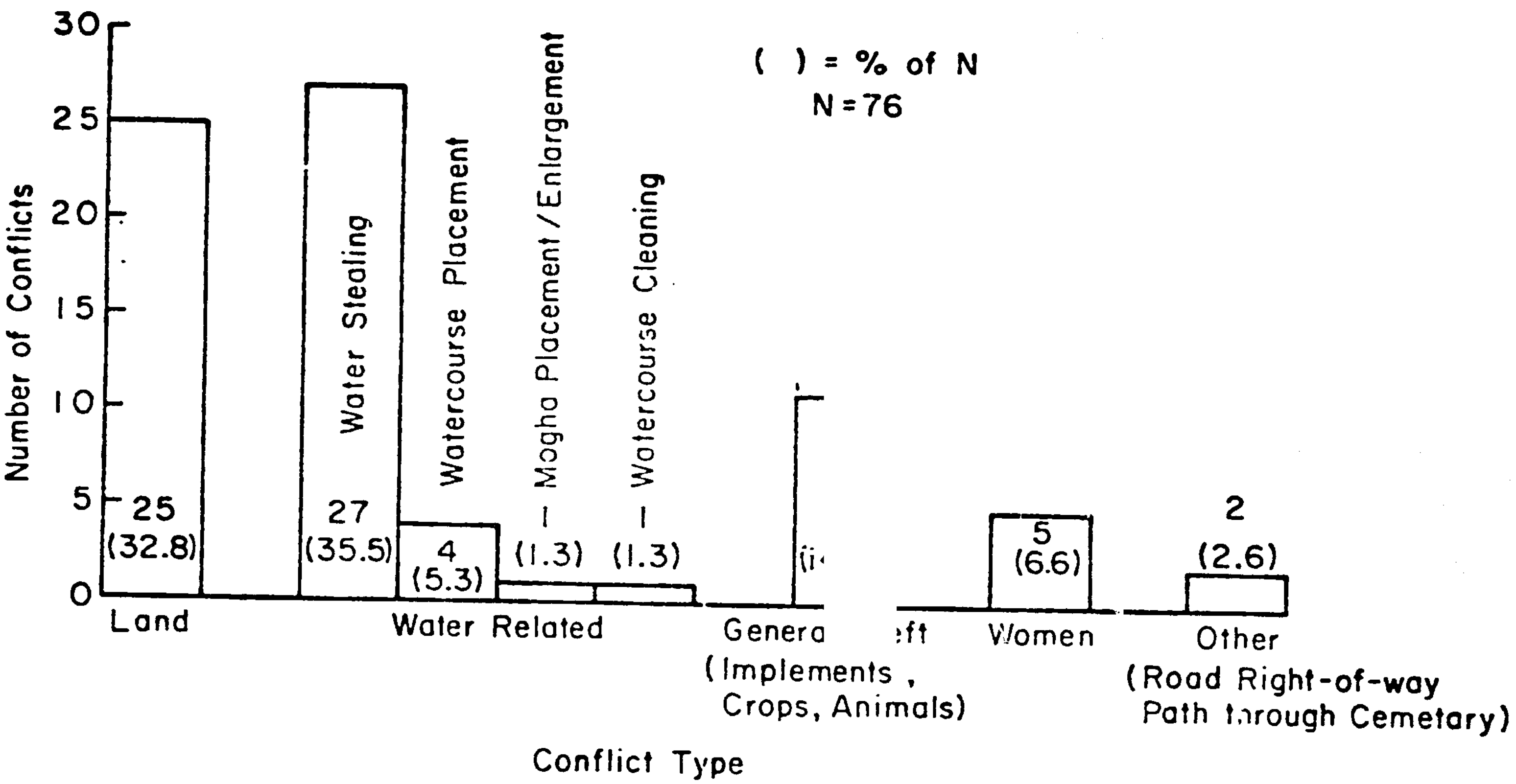


Figure 3. Distribution of Social Conflicts by Type, 1971-1975.

issues per se, but the manner in which cleavages are organized vis a vis each other. Are groups again and again divided by conflict cleavages such that they never ally together in common cause (high polarization) or are groups stitched in a web of cross-cutting attachments in which sometime enemies are sometimes allies (low polarization)?

One example of the importance of conflict polarization for water management improvement efforts is provided by a situation in a highly polarized Pakistan village. One kinship group, the Jam Jats, took a unanimous stand on one side versus Rid Jats, Pahore Jats and Arians. This cleavage has its roots in a bitter land dispute over which at least two antagonists have been killed in the last ten years and has overlapped a cleavage between cooperative society member vs. noncooperative farmers. Jam Jats, without a single exception, have refused to participate in the cooperative farming effort which has been controlled by their antagonists. Because the cooperative society has played a major role in financing the local school, the Jam Jats have refused to contribute to it--placing another cleavage right on top of the land, and cooperative fights. This tendency toward high polarization was exacerbated in 1974-75, when the engineers of the CSU field party--attempting to initiate construction of an improved watercourse--dealt exclusively with the anti-Jam Jat leaders. Although a most innocent oversight, the direct consequence was that the watercourse improvement project was abruptly halted midway through the construction phase by Jam Jat resistence.

This paper now turns to the specific concepts and procedures necessary to perform a conflict analysis.

Concepts and Procedures for Conflict Polarization Analysis

Part One - Gathering the Data

1. Establish a "panel" of three-seven key informants who will be interviewed independently of each other. Informants, as a minimum, must be knowledgeable about the social unit being investigated, and must represent at least the major factions. There is no theoretical limit to the number of key informants to employ but field testing reveals that informant cross-checking becomes excessively cumbersome if the number exceeds six or seven.

2. Have each key informant list the central issues over which at least some village farmers have divided. Sort out and discard those which have to do with personnel pique and have nothing to do with group involvements.

3. Have each key informant independently and anonymously inspect the list of issues created by each other informant. Allow each to indicate acceptance or rejection of each issue. Where there are disagreements among informants as to whether an issue should be listed, note the reasons for the disagreement. Include issues over which there is disagreement on the list of issues unless it is obvious to the interviewer that it is inappropriate to list it. The interviewer must note which, if any, issues were not listed and why they were withdrawn.

4. List the major distinct social groups and organizations in the system--kinship groups, cooperative societies, bureaucratic offices, etc.

5. Given the list of issues, have each key informant provide estimates about:

   a. the position of each village group (item 4) on that issue--plus equals for; minus equals against; and 0 equals neutral.

   b. the importance of that issue to each group which has a plus or minus position--importance will be recorded by 3-high importance;

6. Have each key informant independently and anonymously inspect the responses of each other informant making provision for each informant's rationale for acceptance, rejection, or suggested modification of other estimates.

Part Two - <u>Analyzing the Degree of Conflict Polarization Prior to Initiating any Planned Change Program</u>

1. Set up a Conflict Analysis Table for Displaying Data Generated by Informants (See Table 2, to left of vertical double lines)

   a. Select a base group---any group may be selected so long as it is involved in most, if not all, conflicts.

   b. Each other group then can be seen as taking a position of alliance with, opposition to, or neutrality toward the base group. For example, a given kinship group will be estimated to be allied with, in opposition to, or neutral toward the base group on each issue.

   c. Enter the appropriate position and importance values for each group on each issue relative to the base group. See the "A" columns on Table 2.

LAYOUT OF A
CONFLICT POLARIZATION DATA SHEET

	Issues		
Group Listing	Issue 1 +3,+2,+1,0,-1,-2,-3	Issue 2 +3,+2,+1,0,-1,-2,-3	Issue N +3,+2,+1,0,-1,-2,-3
Kinship Group 1			
. .			
Kinship Group N			
Office 1			
. . .			
Office N			
Cooperative Society 1			
. . .			
Cooperative Society N			
. . .			
Relevant Group/ Organization N			

TABLE 2

CONFLICT PATTERNS OVER SIX EXISTING ISSUES

ESTIMATED ALTERNATIVE PROGRAM IMPACTS ON EXISTING CLEAVAGE PATTERN

Organ & Groups in Unit of Analysis	Observed Positions of each group on six Issues relative to Base Group			Ideally Expected if there is Pure Cross-Cutting Pattern			Deviation From Ideally Expected	Program X Base Group				Program Y Base Group				Program Z Base Group			
	For	Against	Neutral	For	Against	Neutral	+=For -=Against	For	Against	Neutral	Deviation X Importance	For	Against	Neutral	Deviation X Importance	For	Against	Neutral	Deviation X Importance
	A_1	A_2	A_3	B_1	B_2	B_3	B_4	C_1	C_2	C_3	C_4	D_1	D_2	D_3	D_4	E_1	E_2	E_3	E_4
A	6	0	0									X			+1 2	X			+1 2
B	6	0	0	3	3	0	+3-3	X			+1 3	X			+1 1	X			+1 2
C	6	0	0	3	3	0	+3-3	X			+1 3	X			+1 2	X			+1 1
D	5	1	0	3	3	0	+3-3	X			+1 2	X			+1 1		X		-1 1
E	5	0	1	3	3	0	+2-2	X			+1 1	X			+1 1		X		-1 3
F	5	0	1	3	3	0	+2-3	X			+1 1	X			+1 1		X		-1 2
G	5	1	0	3	3	0	+2-3		X		-1 2	X			+1 1		X		-1 2
H	4	1	1	3	3	0	+1-2		X		-1 1	X			+1 1		X		-1 2
I	4	0	2	3	3	0	+1-3		X		-1 1	X			+1 2		X		-1 3
J	4	0	2	3	3	0	+1-3	X			+1 2	X			+1 2	X			+1 1
K	4	2	0	3	3	0	+1-1	X			+1 2	X			+1 2		X		-1 2
L	3	2	1	3	3	0	0-1			X	0 0	X			+1 1		X		-1 1
M	3	0	3	3	3	0	0-3			X	0 0	X			-1 2		X		+1 1
N	0	6	0	3	3	0	-3+3		X		+1 3	X			-1 2		X		+1 3
O	0	6	0	3	3	0	-3+3		X		+1 2		X		+1 2	X			-1 2
P	1	5	0	3	3	0	-2+2		X		+1 3								
Units of Polarization							ε = 65 units				ε = +18				ε = +15				ε = -8

2. In the section to the left of the vertical double lines on Table 2, compare the "observed" pattern of support and opposition to that which would be "expected" if there were a perfect cross-cutting of conflicts in the social unit. "Perfect" cross-cutting patterns are displayed in the "B" columns of Table 2.

   a. If conflicts were perfectly cross-cutting, one could expect that each group category would be half the time for the base group category and half the time against it. Given, say, six issues the expected pattern for perfectly cross-cutting conflicts is 3/3 for each group category down the left hand column.

   b. The observed pattern of support and opposition is then recorded in the "A" columns. The numbers shown in these columns include the number of times that each group is allied with, opposed to, or neutral to, the position taken by the base group.

   c. The question is now: how much deviation exists between observed patterns of conflict and the ideally expected pattern? Scores are computed by measuring the difference between the number of times a given group is "for" the base group and the "expected" (in this case, 3) as well as the number of times a given group category was "against" the base group and the expected value (See column B-4). We then sum all deviations from the 3/3 split ignoring differences in the signs of the numbers and obtain a sum of deviations from that which would occur if there is a pure cross-cutting pattern. The higher the number of units of deviation, the greater the polarization of the social unit. The more that the number of units of deviation approaches zero, the greater the cross-cutting of conflict patterns.

Part Three: Estimating the Impact of New Programs on Conflict Polarization. (See Table 2 to right of vertical double lines.)

1. Employing key informants, estimate the position and the importance which each group would grant to the program using the procedures specified in Parts One and Two.

2. The question now is: given the existing conflict patterns (see values to left of double vertical lines on Table 2), will the proposed program (with the associated position and importance values)

insert more or less cross-cutting conflict into the existing pattern? More polarization will be reflected in increasing the units of deviation from the pure cross-cutting (3/3, 3.5/3.5, 4/4) pattern. Less polarization will reflect a reduction of the number of deviation units.

3. Each plus or minus deviation value is then multiplied by the appropriate "importance" or "salience" value, with the result that each increase or decrease in deviation from the perfectly cross-cutting pattern is weighted by the estimated "importance" factor. If one sums the product of all the plus/minus deviation values and their importance scores one derives a polarization score for each proposed program or policy alternative. Scores are recorded at the bottom on Table 2.

4. Programs which can be organized to most reduce the deviations units are the most preferred. Compare alternative programs (alternative organizational forms, alternative policies, alternative watercourse alignments) according to their polarization scores and select those which have the lowest deviation from the pure cross-cutting pattern.

There are two primary outcomes of the conflict polarization analysis:

1. Given social units (villages, districts, irrigation circles) can be ranked according to the degree of estimated conflict polarization and thereby compared to other comparable units of interest. Units evidencing low deviations from pure cross-cutting patterns can be clearly distinguished from those with high polarization. It is the working hypothesis that social units with low polarization will provide more receptive environments for programs of organization building and reform to promote improved water management technologies than will those social units which are highly polarized. Therefore, if one is attempting to initiate organizational efforts which by virtue of their innovative nature are likely to have problems of securing acceptance, it is important to identify those social environments which pose the fewest additional problems of conflict polarization which can destroy the prospects of even the best designed programs.

2. Alternative planned change programs can be systematically compared as to their estimated impacts on conflict polarization before comments are made to implement. Those project alternatives which are estimated to break up and reverse tendencies toward polarization

> are to be valued over those which would be estimated to further exacerbate polarizing patterns. Organization building efforts can be advanced by determining which set of policies and program can be expected to have the most de-polarizing effects.

In conclusion, the argument of this section is that it is possible to quantify important dimensions of conflict behavior and to construct tables which display strategic dimensions of cleavage patterns. When social units are highly polarized, planned change programs to introduce farmer water management associations are likely to encounter more problems of resistence, subterfuge, lack of cooperation, and failure than are those same programs in non-polarized social units. It is possible to suggest that conflict polarization is a primary sociological criterion for selecting social environments for programs of improved water management.

IDENTIFYING SOCIAL ENVIRONMENTS CONDUCIVE TO ORGANIZATION BUILDING AND REFORM,
PART II: THE ANALYSIS OF POWER/INFLUENCE DISTRIBUTIONS

Introduction

The capacity to successfully build organizations so as to make possible the adoption, implementation, control, and maintenance of improved irrigation related technology is fundamentally affected, not only by patterns of social conflict, but also by the distribution on power/influence within and among organizations. The problem of power/influence analysis presents one with a treacherous domain of inquiry in which concepts have typically been less than well-defined, operationalizations slippery, and in which little of an empirical nature has been done with regard to irrigation water management. Most analysts are prepared to agree that irrigation organizations represent power structures, and they readily apprehend that equal or unequal distributions of power/influence have repercussions for the availability, timing, and application of water. Yet, there is not explicit analytical approach to the problem of power/influence which has been adapted to the problems of water management--at least to the knowledge of the authors.

The analysis must begin with two qualifications:

1. Much confusion still exists over the precise meaning of concepts of power and influence. A variety of scholars have attempted to arrive at conceptually clear definitions. One of the most useful approaches in our judgement, is that of Bachrach and Baratz who define power as the ability to invoke the threat of sanctions upon another party in order to secure

that party's compliance.[17/] Influence, on the other hand, has to do with securing compliance without employing the threat of sanctions, but through use of logical or moral persuasion. Because the measures do not identify the extent to which compliance is or is not based on the threat of sanctions, reference will be made to power/influence. There is little doubt, however, that in the irrigation systems known to the authors, power probably far outweighs influence in farmer's irrigation water management behavior. The ability to control sanctions--credit, contacts with officials, threats to withhold food, machinery, animal feed, the capacity to threaten armed force and to interfere with water flow, are known by farmers in irrigation systems worldwide.

2. The approach presented here for the measurement of power is constructed for local level analysis. It is useful for examining the kinds of organizational problems facing small farmers in cell two of Table 1, and for farmers of all sizes in cells four and five. The procedures will require modification before they can be useful in the analysis of cell six problems.

Concepts and Procedures for the Power/Influence Analysis

Part I: Gathering the Data

A social unit must be defined within which participants interact sufficiently such that they can reasonably make estimates about the extent of each other's relative power/influence. In Pakistan this unit is the watercourse or the village. In other countries, the unit might well be a district, town, or canal settlement. Because the data used to illustrate the power analysis was gathered in Pakistan from watercourse units, all further reference will be to watercourse data. Watercourses are farmer constructed and maintained channels which conduct water from a major or minor canal to field channels. On the average, about forty farmers conduct irrigation operations on a watercourse. A random sample of farmers is drawn from a census list of all farmers on each watercourse stratified by location--"head", "middle," and "tail." Sample farmers are asked to rate each watercourse farmer, including themselves, in response to a two-part question: How much power/influence does the farmer have in matters of: (1) watercourse maintenance; and (2) settling disputes. Values are recorded as follows:

No influence/power	0
Little influence/power	1
Some influence/power	2
Much influence/power	4

The result of this procedure is a series of scores attributed to all watercourse farmers by each sample farmer respondent. A table of such scores would appear as follows:

Listing of All Farmers On Watercourse	Scores Attributed to All Watercourse Farmers by Sample Farmers Sample Farmer One	Sample Farmer Two	Sample Farmer N
Watercourse Farmer 1	4	2	4
Watercourse 2	1	0	0
.			
.			
.			
Watercourse Farmer N	2	2	2

Because the estimates of power/influence were identical for the two parts of the question, the data was collapsed in this case and it is not necessary to distinguish between the different areas of power.

Part II: Computing a Percent of Potential Power/Influence Score

Because it is necessary to compare scores among watercourses and because it is also necessary to arrive at a single overall score for each farmer from among the sample farmer attributions, the scores granted to each farmer are summed and converted into a percentage of the total possible score which could have been granted by all of the sample farmer "judges." The highest score which a given farmer could potentially obtain is secured by multiplying the value of "4" (the highest score any single farmer judge can give) by the number of sample farmer judges. Each farmer power/influence score is then "normed" vis-a-vis all other scores by deriving its percentage value of the potentially highest score. Example: For a farmer to obtain an influence score of zero, all farmer judges would have to have granted zeros which would sum to zero and be zero percent of the potential score which could have been obtained if all judges had estimated his power/influence to be "much" thereby granting him a series of "fours."

This individual influence/power score can be of much research interest in examining the relationship between it and variables having to do with land ownership, education, adoption of improved technology, knowledge and use of farming and irrigation practices, religious behavior, kinship attributes and contacts with authorities. These matters are taken up in a forthcoming research report.[18]

At the individual level, however, little can be said about the nature of social environments for organization building in water management. The discussion must now turn to watercourse level power/influence analysis.

Part III: Examining the Distributions of Power/Influence on Watercourses--The Meaning of Centrality and Concentration

Individual farmer power/influence analysis reveals something about the attributes of particular farmers, but now it is possible to proceed to an analysis of watercourse social network characteristics. We approach the watercourse network, as distinguished from the individual farmer, armed with two concepts:

1. Centrality of Power/Influence--a dimension which tells one what percentage of farmers on a given watercourse score some specified amount of the potentially highest influence score--90%+, 80%+, 70%+, 60%+, 50%+. Obviously farmers who score 90%+ of the potentially highest score that is possible to obtain are more "central" in the watercourse decision network than are farmers who score 30% of their potential. A centrality value of twenty-five, for example, means that 25% of the watercourse farmers score at a specified level or above. That specified level might be 90% of potential 80%, or any other arbitrarily specified figure. It is conceivable that everybody on a watercourse could score high or low.

2. Concentration of Power/Influence--a dimension which defines the extent to which power/influence is equally distributed among farmers in the watercourse network. This score answers the following questions: If one proceeds downward from the highest score on a ranked frequency distribution of farmer power/influence scores, how many farmer scores does it take, when

> summed, to equal or exceed 50% of the sum of all scores? A condition of greatest possible equality will be obtained if it takes exactly the top 50% of farmer scores to equal 50% of the sum of farmer scores. A condition of greatest possible inequality will occur if it only takes the topmost farmer's score to equal or exceed 50% of the total scores--something which will occur when many farmers are given low or zero ratings, but one farmer is granted a high rating.

An equality score may reveal equality when all farmers are weak or when all are powerful; it must be employed in conjunction with the centrality score which reveals the degree to which there is weakness or strength on the sample watercourse.

Data for power/influence centrality and equality are displayed in Figures 4 and 5 which are identical in all respects save one. Figure 4 reflects the distribution of watercourse power/influence when the centrality level is set at 80+--meaning that the value for centrality equals the percentage of all farmers on that watercourse who scored 80% of their potential or more. Figure 5 shows the distribution of watercourses when the definition of centrality is shifted to include all farmers who scored 50% of their potential or more. One observes that, overall in this instance, the distribution of watercourse units shifts relatively little under the changed definition of centrality. The most notable single shift is that of village 116, watercourse 3, which moves from the lower right of Figure 4 to the upper right of Figure 5. This watercourse is populated by many farmers who have centrality scores of less than 80%, but 50% or more.

The hypothesis is: the greater the percentage of farmers who score highly on the centrality dimension and the greater the equality of power/influence, the greater the probability of success in initiating and sustaining watercourse farmer associations.

Stated in the graphic terms of Figures 4 and 5, the hypothesis is that the more watercourse power/influence distributions shift toward the upper right corner, the more favorable the social environment for organization building and reform. The underlying premise is that organization building efforts will be more productive and sustainable when members can mutually sanction each other as opposed to those conditions of great inequality of power/influence in which "lambs" have little chance to effectively sanction the "lions"--in such cases organization building serves to do little but provide new opportunities for the powerful to exert themselves upon the weak. The hypothesis requires further research for verification and elaboration.

Figure 4. Distribution of power/influence on 36 watercourses in Pakistan representing 15 villages.

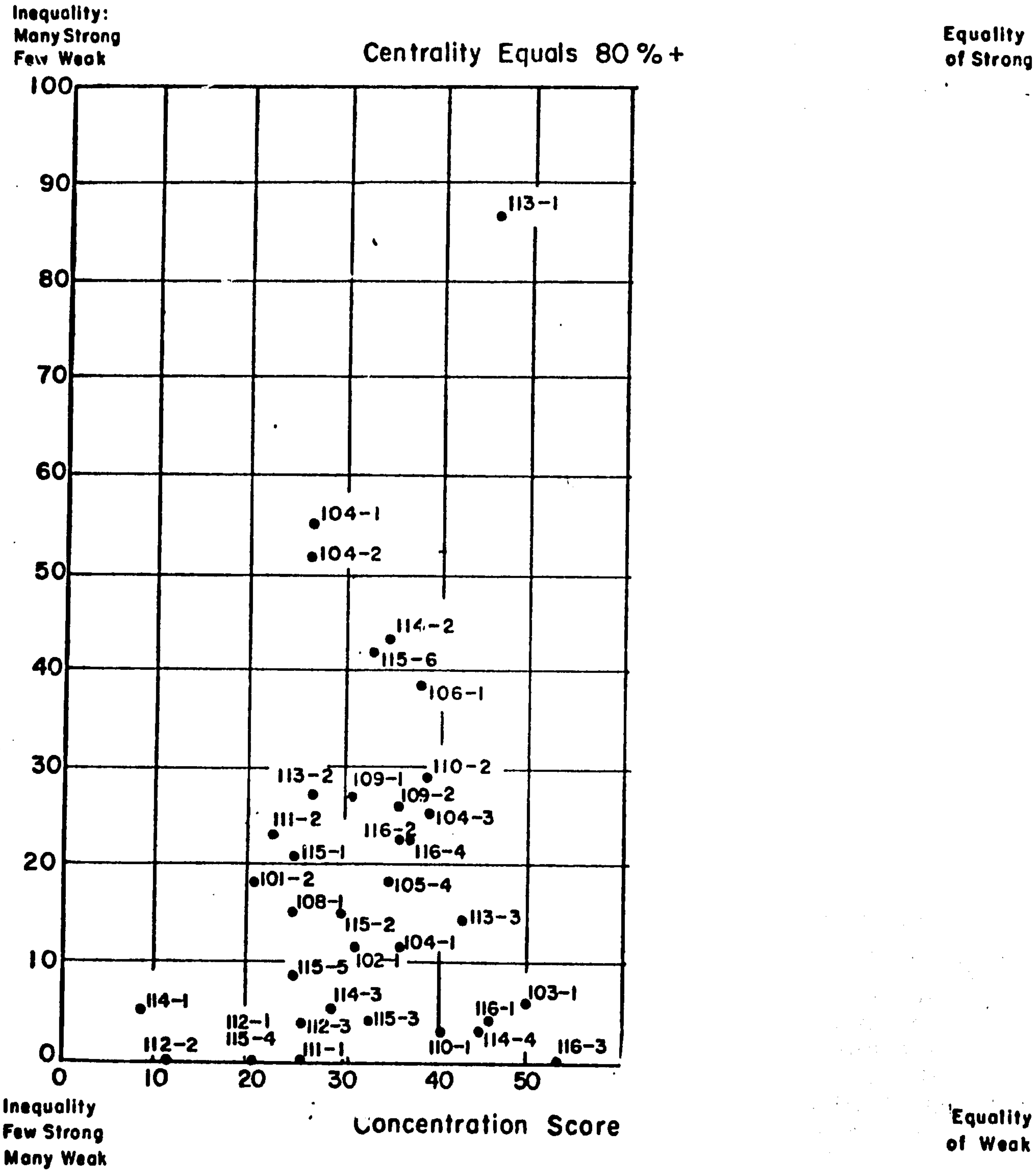
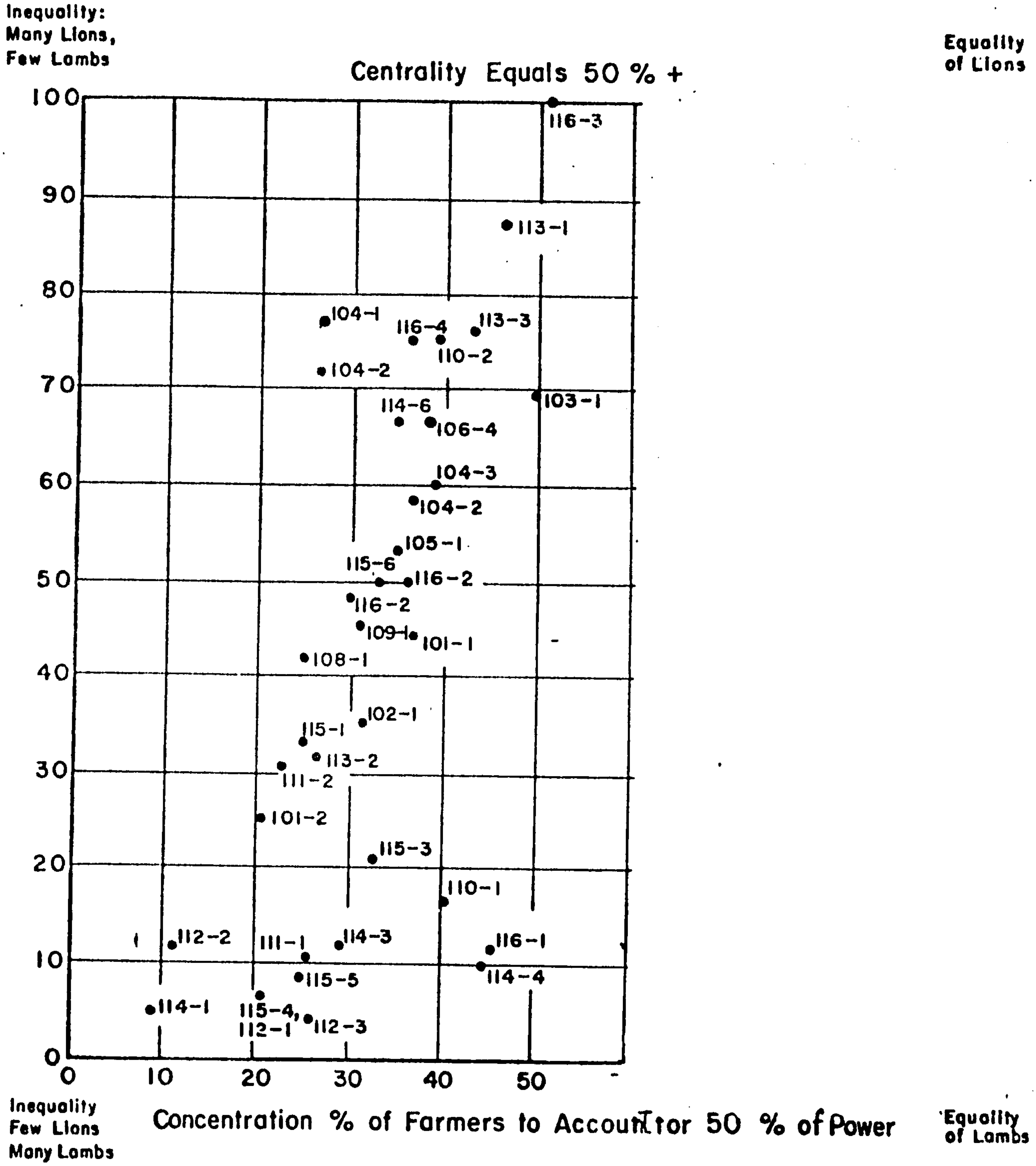


Figure 5. Distribution of power/influence on 36 watercourses in Pakistan representing 15 villages.



Our exploratory inquiry could not focus intensively on the problem of securing data about quality of water management behavior and power/influence distributions. For example, crop yields, delivery and application efficiencies would be appropriate variables on which to compare centrality and equality across watercourse social networks. Yet, there are many uncontrolled variables affecting the values of yields and efficiencies--rainfall, soils, etc.--such that there simply is no useful way with available data to establish that a watercourse such as 113-1 or 116-3 with characteristics of greater centrality and equality evidence higher delivery efficiencies than do watercourses which have the least desirable social attributes that can be hypothesized (such as 114-1 or 112-2).

What can be done, however, in a highly tentative way is to suggest that candidate villages for water management improvement program which have low polarization scores then be screened according to the criterion of power/influence equality. Those social networks which prove to be non-polarized, which gives evidence of high centrality, and which are characterized by low concentration of power/influence in the hands of the few can be identified as the most promising for planned organizational building efforts. For those social units which violate the hypothesized criteria, planned change may well be undertaken, but it must be done so with mechanisms to cope with the threats which polarization and mal-distribution of power/influence can pose for water management improvement programs.

CONCLUSION

This paper has contended that:

1. The role of sociology in water management has been unclear to both decision-makers and researchers. There is a high probability that decision-makers will obtain sociological research inappropriate to the type of water management problem with which they are faced.

2. Water management problems can be broken into six major varieties based upon two properties of water management related technology--its divisibility and its private-collective nature.

3. For three types of problems--cells, 2, 4 and 5--the task of building or modifying small scale local level organizations is central--water management improvement programs will stall without effective local organization building and/or reform so as to

allow acceptance, utilization, and maintenance of improved technology.

4. Organization-building and reform is centrally affected by environmental conditions--specifically in the social environment, the degree of conflict polarization, the proportion of member-clients who enjoy high centrality in the network, and the extent to which power/influence is in the hands of a few are hypothesized to significantly affect the prospects of successfully organizing farmers for adopting, utilizing, and maintaining improved water management technologies.

5. If one wishes to identify those social units most conducive to successful organization building, it is hypothesized that one should seek out those units characterized by low conflict polarization, high centrality, and low concentration of power influence.

An important question is suggested. How much conflict polarization should one justifiably trade off for how much of a gain in power distribution? No useful answers can be formulated at this stage of the research. Yet, it can be hypothesized that conflict polarization should be the criterion of the first order and greatest weight. If polarized, social unit members will be constrained from employing their resources for constructive developmental purposes no matter how great the equality and centrality of power.

It must be clear that the hypotheses suggested here are not confirmed by research to date--they are only suggested by it. Additional research must be undertaken to test and elaborate each hypothesis. One promising way to proceed would be to select a sample of social units including those violating each of the criteria and those conforming to them and compare the dynamics of organization building in each sub-sample.

Organizational efforts could then be attempted in each sub-sample under controlled conditions, to test the null hypothesis that the conflict and power criteria have no effect on village propensity to organize effective farmer water management organization. The working hypothesis is that organizations will be more effective in units which are not polarized, which have more equal power distribution and have stronger leadership than in units violating the criteria, but it will take systematic research to establish that the criteria suggested are appropriate guides for planned organizational change in water management.

Above all it is remembered that the analytic approach forwarded here is but a small piece of the larger effort which must encompass at least economic, engineering, agronomic, legal, as well as sociological variables in the indentification of constraints and problems significant to the behavior of farmers as they struggle to improve their well-being through better water management. An interdisciplinary team of which the authors are a part, is presently involved in developing and applying interdisciplinary sets of procedures providing a coherent research and development approach for improving water management. The United States Agency for International Development, which is supporting this effort, has stipulated as a contract obligation that efforts be made to disseminate the approaches developed. In keeping with this responsibility, arrangements are currently being made to present the more encompassing analytical and action program to World Bank staff responsible for irrigation development.

ENDNOTES

[1] There are applied sociological approaches and principles available to overcome these polarization problems. However, we do not deal with these in this presentation.

[2] For a more complete listing of materials than will be reviewed here, see: E. Walter Coward, Jr., Irrigation Institutions and Organizations: An International Bibliography. Ithaca, N.Y. Department of Rural Sociology, Cornell University, January, 1976. Also: Garth N. Jones, Abdur Rehmon Rizqani, Bashir Malik, and Robert F. Schmidt, Informational Sources on Water Management for Agricultural Production in Pakistan with Special Reference to Institutional and Human Factors. (two volumes). Water Management Technical Report No. 31. Fort Collins, Colorado: Colorado State University. April, 1974. Also of use is the Bibliography on Socio-economic Aspects of Irrigation in Asia. International Rice Research Institute and the Agricultural Development Council. Singapore University Press, 1976.

[3] See, for example, Clyde E. Houston and Michel Grehan, "A Worldwide View of Implementation of Improved Water Management," in Dean F. Peterson (ed.) Research Needs for On-Farm Water Management. Published for the U.S. Agency for International Development by Utah State University, Logan, Utah, March 1, 1974, p. 64-72. Richard B. Reidinger, "Institutional Rationing of Canal Water in Northern India: Conflict Between Traditional Patterns and Modern Needs," Economic Development and Cultural Change. Vol. 23, No. 1 (October, 1974), p. 79-104. Gekee Y. Wickham, The Sociological Review, (January/April, 1972). Reprinted by A/D/C Teaching Forum, No. 31, June, 1973. Gilbert L. Corey and Wayne Clyma, Improving Farm Water Management in Pakistan. Water Management Technical Report No. 37. Fort Collins, Colorado, Colorado State University, March, 1975.

[4] For a good overview of physical, climatic, and biological variables in water management see: Jack Keller, Dean F. Peterson, and H. B. Peterson, "A Strategy for Optimizing Research on Agricultural Systems Involving Water Management," in Dean F. Peterson (ed.), op. cit., p. 101-109.

[5] B. B. Vohra, "Implementation of Water Management Programs in Canal Irrigated Areas," in Dean F. Peterson (ed.) op. cit., p. 61-69.

[6] Gekee Y. Wickham, op. cit., passim.

[7] W. Eric Gustafson and Richard B. Reidinger, "Delivery of Canal Water in North India and West Pakistan," Economic and Political Weekly, Vol. 6, No. 52. Review of Agriculture. (December 25, 1971), p. A157-A162.

[8] Richard B. Reidinger, "Institutional Rationing of Canal Water in Northern India: Conflict Between Traditional Patterns and Modern Needs," Economic Development and Cultural Change. Vol. 23, No. 1 (October, 1974), p. 79-104

[9] George Radosevich and Craig Kirkwood, "Organizational Alternatives to Improve On-Farm Water Management in Pakistan." Water Management Technical Report No. 36. Fort Collins, Colorado, Colorado State University, June, 1975. Stephen C. Smith also describes how important collective organization was to irrigation development in the United States. See his: "Legal and Institutional Controls in Water Allocation," Journal of Farm Economics, Vol. 42, No. 5 (December, 1960), p. 1345-1358.

[10] E. Walter Coward, Jr., "Peasants and the dilemma of Irrigation Development: Bureaucracy and Local Organizations," Paper presented to the-Fourth World Congress of Rural Sociology. Torun, Poland. August 9-13, 1976. Also see: E. Walter Coward, Jr., "Indigenous Irrigation Institutions and Irrigation Development in S. E. Asia: Current Knowledge and Needed Research." Paper prepared for Symposium on Farm Water Management, Asian Productivity Organization, Tokyo, September 7-11, 1976.

[11] Robert C. Hunt and Eva Hunt, "Canal Irrigation and Local Social Organization," Current Anthropology. Vol. 17, No. 3 (September, 1976) p. 389-398. See also exchange of comments, p. 398-411.

[12] Max K. Lowdermilk, Wayne Clyma and Alan C. Early, Physical and Socio-Economic Dynamics of a Watercourse in Pakistan's Punjab: System Constraints and Farmer's Responses. Water Management Technical Report No. 42. Fort Collins, Colorado State University, December, 1975.

[13] The problem of "collective" or "public" goods received its original formulation, in economic terms, at the hands of Paul Samuelson in his "The Pure Theory of Public Expenditure," Review of Economics and Statistics. Vol. 36 (November, 1954), p. 387-389. Mancur Olson further developed the analysis in The Logic of Collective Action. New York: Schocken Books, 1971. One may wish to consult the following pieces for extensions and critiques of the collective goods analysis: James M. Buchanan, The Demand and Supply of Public Goods,

Chicago: Rand McNally and Co., 1968. John Chamberlain, "Provision of Collective Goods as a Function of Group Size," American Political Science Review, Vol. 68, No. 2 (June, 1974), p. 707-735. Norman Frolich and Joe Oppenheimer, "I Get by with a Little Help From my Friends," World Politics. Vol. 23 (October, 1970), p. 104-120. Bruce M. Russett and John D. Sullivan, "Collective Goods and International Organization," International Organization. Vol. 25 (Autumn, 1971), p. 845-865.

[14] For a case study relating to this point see: Eva Hunt and Robert C. Hunt, "Irrigation, Conflict, and Politics: A Mexican Case," Chapter 12 in Theodore E. Downing and McGuire Gibson (eds.), Irrigation's Impact on Society. Tucson: University of Arizona Press, 1974, p. 129-157.

[15] For discussions of the conflict cleavage concept, see: Douglas W. Rae and Michael Taylor, The Analysis of Political Cleavages. New Haven and London: Yale University Press, 1970, S. M. Lipset, Political Man. New York: Doubleday, 1960 and David M. Freeman, Technology and Society: Issues in Assessment, Conflict, and Choice. Chicago: Rand McNally, 1974.

[16] See: David M. Freeman and Max K. Lowdermilk, "Community and Irrigation in the Pakistan Punjab--Physical and Sociological Dimensions of the Water Management Problem." Paper presented to the Association for Asian Studies, Annual Meeting, Toronto, Canada, March 20. 1976.

[17] Peter Bachrach and Morton S. Baratz, Power and Poverty: Theory and Practice. London: Oxford, 1970.

[18] See Alan C. Early, Max K. Lowdermilk, and David M. Freeman, Watercourse Command Survey in Pakistan's Punjab and Sind: System Constraints and Farmer's Responses. A report of research conducted under contract with the United States Agency for International Development. Fort Collins, Colorado: Colorado State University, forthcoming, 1978.

APPENDIX 35

A RESEARCH-DEVELOPMENT PROCESS FOR IMPROVEMENT OF ON-FARM WATER MANAGEMENT

Wayne Clyma, Max K. Lowdermilk
and Gilbert L. Corey[1]

> Concern for man and his fate must always form the chief interest of all technical endeavors. Never forget this in the midst of your diagrams and equations.
>
> Albert Einstein

Concern for man's fate is the primary motivation for the evolvement of the research-development concept presented in this paper. Given past experiences in development and present critical food shortages, new approaches are necessary for rapid transfer of appropriate technology to food deficient nations. A major challenge for the next decade is the development and implementation of workable methods to increase food production in low income nations.

INTRODUCTION

Irrigated agriculture is the most effective means for making rapid increases in crop production. Improvements in irrigation can result in higher levels of living in low income nations because they have approximately 80 percent of the world's irrigated land.[2] In many countries, irrigation projects designed originally to increase food production radically and to benefit all classes of farmers have failed to meet objectives because of their low levels of crop production in contrast to their apparent potential.

Development of irrigation systems has traditionally meant the construction of new projects or the enlargement of existing projects. The emphasis has been on capital-intensive components such as dams, hydraulic structures and water delivery systems.

Water management in agriculture is the process by which water is manipulated and used in the production of food and fiber. Water management is not water resources, irrigation facilities, laws, farmers, institutions, procedures, or soil and cropping systems. Water management is manifest in how

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[2] President's Science Advisory Commission Report. 1967. World Food Problem, The White House, May, Ch. 7 and 8.

these tools and resources are used to provide water for plant growth. It encompasses all water used for that purpose; not just irrigation. but rainfed as well.

Large financial resources are being directed to solving the problems of irrigation water management. Previously, few systematic approaches to evaluate existing irrigation systems, analyze weaknesses and failures, and prescribe technologies for improvement have been developed. Usually, each system that is evaluated becomes a case study in itself. Improvement programs are developed within a short time period utilizing little more than the experience of the project developer. Most frequently these improvements treat symptoms rather than real problems. Such conventional approaches generally ignore the farmer, his attitudes, his knowledge, and his constraints. They have not resulted, therefore, in sufficient improvements at the farm level.[3] Water management improvement is important because there are an estimated 200 million acres of land presently under irrigation. New areas are being added at the rate of less than 10 million acres annually. Most irrigation systems in low income countries, or anywhere for that matter, operate at relatively low levels of water use efficiency and at low levels of production.[4] Thus, a major need is for the improvement of existing systems. The reasons for focusing on improvement of existing systems are as follows:

1. Conserve water supplies by improved management for rapid increases in food production;
2. Improve the return on investments of existing systems;
3. Reduce the costly waterlogging and salinity problems which are often mere symptoms of poor management;
4. Reduce the need for large capital investments in new systems;
5. Gain knowledge which can provide new criteria for the development and management of other systems.

A concerted effort to improve irrigated agriculture, if focused at helping the small farmer solve his problems, could bring improved income and living conditions to a substantial percentage of the world's disadvantaged.

The cost of expanding the present 85 million irrigated hectares by 90 million acres is estimated at $130,000 million. This is not only exceedingly

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[3] Wiener, Aaron. 1972. The Role of Water in Development. McGraw-Hill Book Co., New York, p. 422.

[4] Bos, M. G. and Nugteren, J. 1974. International Institute On Irrigation Efficiencies, Pub. No. 19, International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands.

> costly but also a slow process because projects from design to completion often take 10 to 12 years. Investments in new projects will continue but more quick yielding programs are needed to help the small farmer. These new programs seldom improve the efficiency of farm water use, therefore the focus in the years ahead must be given to farm-level problems. There is much exciting drama in building large structures but we must not forget the small and often tragic dramasthat take place daily on millions of small holders' farms where water conservation is a matter of success and failure and even life and death.[5]

A transfer process which results in rapid adoption of appropriate technologies, is generally applicable, saves time, money and resources, and produces documented positive results is of immense value in attacking the problem of food production.

Purpose

The purpose of this paper is to describe a technology transfer process for rapid improvement of on-farm water management. The process focuses on systematic research to identify problems, develop and assess solutions, and implement development programs at the farm level. An interdisciplinary team executes the research-development process.

Farmers are Members of the Team

This paper discusses the background for the development of the research-development process. The overall transfer process is described with the concepts and essential elements for the complete process. Recommendations for using the process are also included.[6]

Background

Experiences in an on-farm water management research program in Pakistan form the basis for this research-development process. A research process has evolved in Pakistan which has helped formulate relevant technical and socio-economic specifications in five major areas:

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[5] World Bank, The Assault on World Poverty, John Hopkins University Press, 1975, pp. 95-96.

[6] This paper does not include detailed procedures for implementing the process. Subsequent papers will describe procedures.

1. On-farm water management improvement programs with farmer involvement;
2. Empirical field data for policy-planning decisions on water and farm production questions;
3. Training of host country personnel and institution building.
4. Information transfer processes which make research results immediately available to farmers;
5. A research-development process for use in other countries.

Pilot programs in Pakistan have demonstrated that with limited capital costs and much farmer participation, watercourse improvements can be made. Farm water losses have been reduced by half or more. These low cost improvements are relatively easy to implement, highly visible, and economical. Farmers are enthusiastic because they are able to increase both cropping intensities and crop yields with the water saved from the improved practices. The Government of Pakistan and donor agencies are developing programs to extend the research findings. An Agency for International Development loan program will extend the new technologies to 60,000 farms and a World Bank program proposes to develop a strategy to improve water management within the entire 30 million acre system.

The possibility of transfer of the research-development process to other countries is viable. Egypt and Sri Lanka have initiated on-farm water management projects to essentially replicate the Pakistan experience. Given the experience gained in the Pakistan field laboratory, a systematic approach has been developed which can advance on-farm water management in the irrigated regions of the world.

TRANSFER PROCESS OVERVIEW[7]

The transfer process consists of four overlapping phases as follows (Table 1);

I. Priority Problem Identification

II. Search for Problem Solutions

III. Assessment of Solutions

IV. Pilot Project Implementation

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[7] Table 1 includes four phases. Other phases being considered as essential include evaluation and full scale project implementation as distinct phases in a future publication.

TABLE 1. Phases and Major Characteristics of the Research-Development Process.

Key Concepts for All Phases	Essential Components for All Phases
1. Systems approach	1. Client involvement
2. Interdisciplinary research	2. Communication
3. On-farm client focus	3. Team collaboration
4. Host country involvement	4. Training (selection and evaluation)
5. Management oriented	5. Institutional building and linkages
6. Action research	6. Monitoring and evaluation

Phased Sequences for Transfer Process	Major Emphases*	Major Activities
Phase I Priority Problem Identification	Clinical approach Understanding the system Integrated system operation System constraints	Reconnaissance and field surveys Delineation of the system Preliminary and formal field investigations Quantitative system description Priority problem identification
Phase II Search for Problem Solutions	Applied research Adaptive research Evaluative research Farmer conditions Farmer interest Trial and adoption	Experiments, trials and demonstrations on-farm with various types of technologies.
Phase III Assessment of Solutions	Farmer acceptance Evaluative research Transfer vehicles Institutional linkages Diffusion requirements	Adoption-diffusion studies Evaluation of communication systems Farmer linkage with organizations
Phase IV Pilot Project Implementation	Farmer-client and management oriented, integrated planning protective research	Implementation, planning, training, monitoring and evaluation

*These major emphases are derived from the key concepts and essential components listed above.

When a set of technologies has been adopted successfully, the new system operation may be further improved by the transfer and adoption of additional technologies. This process is capable of continuously improving the operation of water management systems by further iterations through the four phases.

The unique feature of problem identification and perhaps the process itself is the interdisciplinary approach with farmer participation to achieve an understanding of system operation. This results in an objective, quantitative definition of priority problems. It also permits the traditional system to appropriately and systematically impact the country's research and development efforts. Systemic mapping including a clinical approach to the farmer-client are used to diagnose physical, socio-economic and institutional problems in Phase I (Table 1). Because all problems can not be solved initially, priority problems, from which highly visible solutions can be evolved, are defined.

Phase II in Table 1 is the search for problem solutions which produce results highly visible to farmers. Direct solutions from known principles and experiences are sought first and adapted to specific farmer problems and resources. On-farm testing or demonstrations of known technology is the next priority approach to developing solutions. Applied research at the experiment station is reserved for evaluating complex alternative solutions to high priority problems which require more careful study. The interdisciplinary team combines knowledge and experience with systematic research to develop solutions which farmers can use to priority farm problems.

A systematic, quantitative assessment of each solution is made to assure farmer acceptance, determine complementary inputs and supporting services, and evaluate socio-economic and environmental impacts in a unique framework. Applied, adaptive, and evaluative research methods are used under farmer conditions in Phase III for the assessment of solutions. These results are used to redefine problems and improve their solutions. These assessments are used to determine resource communication and institutional needs of farmers to assure continued adoption. Farmers' trial and adoption experiences are evaluated over time to select a technology package for the pilot project. Socio-economic and environmental impacts are also monitored for long term projections.

An institutionalized development program evolves as a pilot project. Trained personnel use the carefully designed technological package to work directly with the farmers to solve their problems. Many authors have observed that known technologies for irrigation improvements are available.[8] A major constraint is the lack of effective transfer of

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[8] Wiener, op. cit. and World Bank, op. cit., pp. 95-96.

technology to farmers because institutions do not have the necessary capabilities. The focus in Phase IV is on the development of selected institutional capabilities for effective transfer of technology by carefully designed training and evaluative strategies. At the beginning of the pilot project phase, the institutional capability and appropriate technologies are evolved into an effective development program.

Key Concepts

While each phase of the process emphasized particular concepts and components, the overall process has certain key concepts and essential components that are vital to every phase. The key concepts for the process as given in Table 1 are as follows:

1. A systems approach which includes the socio-economic, institutional and physical aspects of the irrigation system.
2. An interdisciplinary team plans and executes the program.
3. The farmer, as the manager and beneficiary of improvement, is the primary concern and focal point.
4. The program is a host-country program and must be accepted and executed by host-country personnel.
5. The process is management-oriented and must focus on management improvement.
6. The research approach is action or problem oriented.
7. Problems, improvements and benefits are the focus at the farm level.

Systems Approach

The farmer manages a system composed of many components. Agricultural research, however, has traditionally focused on single factors or restricted components of the farm system. As long ago as 1931, a researcher of the Ontario Research Foundation drew attention to a method of agricultural research, management, and production that would view the whole agricultural system.[9] In 1961, Bradfield[9] gave special emphasis again to this "new approach" to research and development.

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[9] Bradfield, Richard, in International Congress of Soil Science Transactions of the 7th International Congress of Soil Science, Madison, Wisconsin, 1961, Volume I, Official Communications, p. XXXII. (See Richard Bradfield's "Opportunities of Soil Scientist in Freeing the World from Hunger,"--presidential address.)

The plight of the small farmer, the food and population crisis, and lack of institutional development are all critical problems today in part because of the lack of an adequate systems approach. Ronninger[10] suggests that valuable time and opportunities have been lost in environmental system problems such as animal wastes, nitrate and pesticide pollution as well as in evolving the high yielding varieties. Millikan and Hapgood[11] and others[12] have also concluded that insufficient and inadequate system - type field studies have been conducted to improve traditional farming systems.

The traditional research model in agriculture is the research station with experimental plots. The unstated, but usual primary objective of such research is refereed journal articles or reports. In contrast, all phases of this research-development process, the focus is on understanding problems, developing and assessing the solutions, and implementing the development programs in the context of the total on-farm system. This focus suggests the importance of the next concept, the interdisciplinary team.

Interdisciplinary Research

An effective interdisciplinary research team is a necessary condition for solving problems in complex systems. The key concept for an effective interdisciplinary research team is that it has all the essential disciplines necessary to adequately understand the operation of a system. This provides the corresponding ability to define priority system problems. The essential elements of an effective interdisciplinary team are: (1) respect for the contributions that each discipline can make; and (2) desire to establish effective communication between the various disciplines.

Disciplinary respect is fraught with many difficulties. In academic environments, disciplinary pride and arrogance are fostered to such a degree that professionals in a discipline act as members of a caste. This causes the professional to pursue narrow disciplinary goals without considering the contributions of other disciplines.

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[10] Ronninger, T.S., "Systems Research in Agriculture," Agricultural Science Review, Vol. 6, No. 1, Cooperative Research Service, Washington, 1968, pp. 102.

[11] Millikan, Max F. and David Hapgood, No Easy Harvest: The Dilemma of Agriculture in Underdeveloped Countries, Little, Brown and Co., Boston, 1967.

[12] See Mellor, John W., The Economics of Agricultural Development, Cornell University Press, 1966, p. 357, and Dalrymple, Dana G., Technological Change in Agriculture, International Development, Foreign Agriculture Service, Washington, D.C., 1969.

Respect for other disciplines and team members is basic to effective communication. While it is essential that team members be technically qualified, experienced professionals in their disciplines, they must also learn to communicate effectively.

A strategy for executing an effective interdisciplinary program is as follows:

1. The team defines the parameters of the system to be studied.
2. The primary variables to quantitatively describe the system are identified.
3. A strategy for describing the operation of a system with the defined variables is then evolved.
4. A research program is executed to collect data which quantitatively describe the operation of the system.

In some instances, variables must be measured in a coordinated, carefully-planned manner to relate certain variables in the context of management. For example, physical variables must be related to farmer perceptions of the physical system to evolve an effective strategy for improvement.

On-Farm Client Focus

Strong farm and farmer focus is essential in all phases of the process. Actions in any phase of the process are developed from farm level data without allowing prior assumptions about farm problems dictate research or development programs. Farmers, researchers, trainees, and all other personnel, both expatriate and host country, are involved as a team. This is a unique aspect of the research-development process. In the past, both in research and in development, inadequate focus has been given to the primary beneficiary, the farmer.

Host-Country Involvement

While the circumstances under which a water management program is initiated in given countries will vary, it must be the program of the host country--executed by the people and for the people of the country. If expatriate advisory leadership is involved early in the program, explicit program strategies and training must be planned in order that leadership is transferred to the host country at the earliest possible date.

Host country personnel should include the farmers, senior researchers, field party members, and governmental administrators.

Moreover, involvement from the field party to the head of the government should provide better articulation of problems, alternative solutions, knowledge of institutional constraints, and greater credibility for the program. This integrated involvement also insures that the program is fully a host-country program. Programs suggested by expatriates must be articulated by host country personnel who believe in and participate in the program.

Host countries should evaluate their ability to supply technically qualified, experienced personnel as team members. If this is an initial restraint, an expatriate team can provide leadership early in the program until host country personnel are trained.

Management Oriented

Water management with its biological, physical, socio-economic, and institutional components is a complex development process. Social, economic and institutional factors usually outweigh the technical ones. Farmers must make complex decisions before change occurs. These are not on/off or use/not use decisions. They are management decisions involving risk and uncertainty of farmer relationships with the physical system, fellow farmers, and governmental institutions. Therefore, efficient utilization cannot be achieved by simply presenting a single technology, e.g., seed, fertilizer, more water, improved implements. A definite management process is involved. Management is important because a change in one component of a dynamic system causes a chain of interactions. For example, when increased irrigation water is made available to the soil-crop complex much more than water is involved. Changes are made in other factors which may require new management approaches, new crop mixes, new markets, new forms of collective action with other farmers, improved means of credit, or additional services. This illustrates the chain of interactions that the manipulation of one component of the farm system can set in motion.

Action Research

Action research involves the concept that systematic, investigative approaches are used to solve problems as they occur throughout all phases of the process. Research does not start at the experiment station but on the farm. Research does not stop at the research station but goes on to the farm. Research does not stop at the farm but builds the institutional capability to transfer the solution to other farmers. The solution of a problem has not been accomplished until there is an institutionalized procedure to facilitate wide scale use by farmers.

Essential Components

Embodied in the key concepts above and throughout the four phases are certain essential components (Table 1). The essential components for each phase are:

1. Farmer participation and involvement in all phases.
2. Communication and feedback between farmers and researchers.
3. Effective, interdisciplinary team collaboration in planning and executing the process.
4. Careful selection, training and evaluation of all personnel--expatriate and nationals.
5. Institutions developed to serve farmers.
6. Monitoring and evaluation of all aspects and phases.

Involvement of the farmer is the first priority. The results of his actions must be measured. His explanation of his actions must also be obtained. Before his actions can be changed, his trust is essential. Farmer participation is essential in problem identification, in searching and assessing solutions and in implementing the solutions.

Farmer participation can not be obtained without effective communication. The evolvement of program goals and procedures for the host country requires careful planning but also effective communication. Training is a formalized transfer of ideas and skills through visual, written and manual procedures. Team collaboration requires effective communication and was listed as an essential component for interdisciplinary research.

Building an institutional capability for each phase of the program and linking the phases together is essential for a successful program. In some instances old institutions may be modified or new ones developed. Until the process is institutionalized, the transfer process is not complete.

Monitoring and evaluation begins at the formulation of an interdisciplinary team. Team effectiveness, research accomplishments, training, and other administrative aspects should be monitored, evaluated for performance and continually improved. Field programs as research or implementation programs should be planned and evaluated according to written criteria. This emphasis on evaluation is to improve program effectiveness and not for the purpose of fault-finding.

Unique Aspects

The research-development process described in this paper will seem familiar to many researchers. It involves the conceptual steps in most formalized research procedures in which the problem is defined, a solution is sought and the final product is evaluated. There are several unique aspects in the process not included in present research programs. These unique aspects are as follows:

1. Formalized problem identification.
2. Assessment of solutions at the user (farmer) level;
3. Project implementation including institutional building as a part of the research process;
4. A focus at the farm level with the farmers;
5. Research as a mode of operation throughout the process;
6. An interdisciplinary integrated research-development process;
7. As a development process it is continuous;
8. The process can be adapted to system problems other than irrigation.

SUMMARY AND RECOMMENDATIONS

An irrigated area that has significant potential for improvement of yields and water use or solution of problems is selected. An interdisciplinary research team quantitatively measures the variables that describe system operation such as water inputs and outputs, agronomic inputs and outputs, and costs and returns of various cropping systems. Institutional and social constraints, such as legal restrictions and organizational problems which restrict proper water use, are quantified. Priority problems are identified and ranked by their potential for improvement and the expected effectiveness of their solution.

When a solution has been selected, assessment of the solution will be conducted under farmer conditions and evaluated to determine costs, benefits, institutional and resource needs for successful adoption. A strategy for institutional implementation of the solution will then be devised. For example, delivery channel improvements can involve capital or labor intensive approaches, be executed by agriculture or irrigation departments (or both), and involve service, development or research personnel. Knowledge of the benefits and costs of such a program are provided both to the farmer and government officials by the executing agency. Particular strategies for implementing each technology or set of technologies are devised as well as procedures which insure farmer acceptance.

The last emphasis is on assisting a particular institution to implement technology transfer with the farmers. Perhaps training of personnel must be provided. Specific materials for the institution and farmers may also be needed. A policy paper may be needed to influence public attitudes or to effect new laws and change old laws. The emphasis here is on insuring that technology which solves farm problems effectively is transferred.

This technology transfer process is recommended for application to irrigation systems in low income nations or in high income nations. The systematic, systems oriented, management improvement, interdisciplinary team approach can be applied effectively to the improvement of any complex agricultural system such as animal and dryland-cropping systems.

This framework also has relevance to the general field of rural development. In fact the authors' position is that the improvement of farm irrigation systems provide the cutting edge or lead innovations which can make rural development successful. Water management touches all facets of rural life and programs of improvement should become one of the vehicles for the transformation of village life.

This process is recommended as appropriate for use in improving other complex systems such as municipal tranportation systems, educational systems, and even industrial and governmental research systems.

APPENDIX 36

APPARENT INVESTMENT POTENTIALS FOR INCREASING FOOD PRODUCTION THROUGH IMPROVED WATER MANAGEMENT IN SRI LANKA[1]

W. Doral Kemper[2]

I. DEPENDENCE OF CROP PRODUCTION ON SUPPLEMENTAL WATER

The "dry zone" with average annual rainfall ranging from 50" to 75" per year occupies over half of the land area of Sri Lanka. Most of the rainfall in this area occurs during the Maha monsoon which generally begins in October, last into January, and leaves an average of about 37" of rain during that period. Since the average crop use during this cloudy period is less than 0.2" per day and most crops can be matured in periods from 90 to 180 days, the fact that most of these dry zone lands are not cultivated appears to be a case of gross under-use of available resources.

However, two major constraints prevent the proper use of these resources. The rainfall is variable, as illustrated by the fact that in one year out of four the Maha monsoon will bring less than 24" of effective rainfall. This is of special concern to settlers in the low income brackets who have not accumulated the capital to tide them over a year of no economic return and no food production.

The other major production constraint in the dry zone is the limited capacity of these soils to hold water. The Red and Yellow Latosols have capacities for holding available[3] water ranging from 1.0 to 1.3 inches per foot of soil and the Red Brown Earths and Low Humic Gley soils which are dominant in this area have capacities for holding available water ranging from about 1.4 to about 1.7 inches per foot of soil (Joshua, 1977)[4]. This water holding capacity times the feet of rooting depth of crops gives the amount of water available to the crop after a good rainfall has filled the soil profile. In the Red Brown Earths and Low Humic Gleys the rooting depths

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[1] Part of an agricultural sector review of Sri Lanka conducted by USAID.

[2] Professor of Agricultural and Chemical Engineering, Colorado State University, Fort Collins, Colorado.

[3] Available water is that water remaining in the soil after free drainage has taken place, minus that water which is held so tightly by the soil that plants cannot extract it.

[4] W. D. Joshua, 1977. Physical Properties of Soils as Related to Irrigation and Water Management. Occasional Report, Land Use Division, Irrigation Department.

of annual crops commonly does not extend below about two feet because of a gravel layer and consequently water available to the crops between rains is about 3 inches. Rooting depths in the latosols are 3 to 4 feet but their low water holding capacity gives them about 3 inches of available water. Since the crop water use rate is about 0.25"/day, during the Yala season this stored water supply lasts only about 12 days before the plants experience extreme water stress which stops their growth and may cause irreversible damage and death to some crop species. In fact reductions in growth rate often begins when about 70% of the available water has been used and consequently optimum growth for these crops requires watering of these soils at intervals not exceeding 8 or 9 days.

Rainfall is so sporadic that it does not provide this optimum water supply and consequently production of most crop species is less than satisfactory, even in the average rainfall years. This low capacity for holding water is related to the coarse texture of these soils and to the fact that the primary component of the clay in these soils is kaolinitic minerals, which hold much less water than the montmorillonitic clays. Since neither texture nor clay type can be changed, the low water holding capacity is an inherent part of the system which must be accepted in any proposed water management system.

Basically, any successful water management system will have to provide water when that water is not provided by rain. This explains the historic importance of irrigation and the tremendous effort expended by the ancient Sri Lankan civilization to build the great storage tanks and irrigation systems used in the past.

Basically the regular irrigation for additional production in the dry areas must come from: 1) Diversions from rivers rising in the wet zone, 2) water stored in reservoirs from the monsoons, 3) water stored in the ground water and pumped during the dry periods or seasons and 4) improved utilization of developed irrigation supplies.

II. DIVERSIONS FROM RIVERS

The following data summarizes the number of additional acres that could be brought under irrigation in Sri Lanka, according to present thinking of the Irrigation Department and their advisers.

Region	Acres
Mahaweli Project	650,000
South East Dry Zone	150,000
North West Dry Zone	150,000
Minor Irrigation Projects (not included above)	100,000
	1,050,000

III. MAHAWELI PROJECT, SOILS INCLUDED AND THEIR PRODUCTIVE CAPACITY

The Mahaweli Project[5] includes about 61% of the potential new development area, has been designated by the new government as their first priority. They have decided on an accelerated development program which will "complete the project within six years." The soils to be served by the new projects appear, from the soil survey handbook[6] and on limited site observations, to be essentially as well suited to irrigation as those presently irrigated.

The Red Brown Earths constitute about 40% of the lands to be irrigated. They are reasonably well drained, capable of producing upland crops and occupy the tops and sides of the undulations. The Red Brown Earths are intermixed with Low Humic Gley soils which occupy the bottoms of the valleys and undulations. Because the water table in the bottom lands often rises to the surface during Monsoon seasons, in irrigated areas, these L.H.G.'s are suitable only for paddy rice. They occupy about 18% of the new lands.

Alluvial soils constitute 15% of the new lands. These soils form primarily along the streams and include relatively high "levy soils" built up by sediments deposited at flood stages. These sediments are highly porous and the levy soils are relatively well drained. Control of the stream flow by upstream dams often allows these levy soils to be productive upland type soils. The rest of the alluvial soils, lying closer to the river are darker, finer, less permeable, poorly drained and are good paddy rice soils when they are not flooded by the streams.

The Red-Yellow Latosols are highly permeable, well drained and have a lower water holding capacity. They constitute about 2.5% of the new lands and are suitable for citrus cultivation, but irrigation ditches in them leak like sieves!

The Non-calcic Brown soils occupy about 8% of the new lands. They are well drained and suitable for high value upland crops. They are generally rated less productive than the Red Brown Earths because they are sandier and have lower clay contents.

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[5] The details of this project have been printed and discussed in so many references that they will not be repeated here. The most recent summary was prepared by the Mahaweli Development Board in November of 1977. Officially the project is called the "Mahaweli-Ganga Project."

[6] K. A. De Alwis and C. R. Panabokke, 1977. Journal of the Soil Science Society of Ceylon, Volume II.

An indication of the economic yields can be gained from the following current yields and prices.

Crop	Yield/Acre	Price (Rs.)	Months of Land
Rice (Paddy)	65 bushels	40/bu	4
Chillies	1500 lbs.	10/lb	5
Sugar Cane	40 tons	230/ton	12
Cowpeas	800 lbs	2/lb	2.5
Ground nut	1600 lbs	3/lb	4
Grapes	2000 lbs	10/lb	12
Citrus	6700 lbs	4/lb	12
Maize	40 bushels	40/bu	4
Soy beans	30 bushels	180/bu	5

There is either an in-country or foreign market for these crops at these prices. The government is seriously considering guaranteed price supports on all crops where production is less than country demand. This, coupled with the 75% subsidy on fertilizer, should shelter the settler on the standard 2 acre/ farm irrigation schemes from most of the economic uncertainties.

IV. IRRIGATION SUPPLIES AND EFFICIENCY OF USE

Supplies

Sri Lanka is commonly divided into four zones for hydrologic considerations and the table below indicates the water supplies in terms of average annual yields and current and projected (AD 2000) demands by agriculture. All figures are given in thousands of acre feet.

Supply or Requirement	Mahaweli Project Region	South East Dry Zone Region	Western Wet Zone Region	Northwest Dry Zone Region
Average annual yield	5,996	2,263	13,600	682
Current Requirements	851	1,755		175
Requirements (est.) 2000AD	4,983	1,245		1,620
Excess	162	-737	2,410	-1,113

The Irrigation Department provided this table and assumed an average water requirement of 10 acre feet per acre of irrigated land in determining the requirements.

Efficiency of Use

Chambers (1975)[7] indicates issues of water from several existing reservoir sluices equivalent to 12 to 39 acre feet of water per acre/year. This "usage" involves considerable wastage to the drains, percolation down thru paddy fields and the amount of this irrigation water needed to supplement rainfall to meet the evapotranspirational demand for two crops is less than 2.5 feet of water per year in three years out of four (Panabokke and Walgama, 1974)[8] for a rice crop during Maha and a legume crop during Yala at Anuradhapura.

At current costs of construction, as estimated by the Irrigation Department, and assuming interest rates of 8% the cost of water per acre foot is about Rs. 140 and the cost of maintenance of the reservoir and distribution system is about Rs. 100/acre of land. Assuming 8 acre feet of water issued from the sluice per acre of land per year the total cost of the water per year per acre is about Rs. 1120.

If 18 acre feet of water are required by the farmer at the sluice to satisfy his "needs" the cost of water per year per acre is about Rs. 2620. The farmer pays nothing for this water. Other sectors of the economy are subsidizing him to the extent of these water costs and it is highly improbable that his return to the economy can justify subsidy at the Rs. 2620 rate!

The times when water has been used at the 12 to 39 ft/year rate in many of the irrigation projects were primarily during early years of the projects histories when sluice openings were not properly coordinated with needs and settlement of the farms was not complete so the share of water planned for the lands not yet settled was available for use by the early arrivals. The extra water was used to some extent by the farmers as a substitute for labor since water constantly standing on the surface of a paddy prevents the growth of most weeds. Moreover with more water available than needed, there was no incentive for farmers to maximize their delivery efficiency by spending substantial amounts of time to clean their private channels and to collectively clean and maintain shared field channels. This neglect resulted in rapid disintegration of this portion of the delivery system. Once the farmers have adopted these bad habits they are hard to break.

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[7] Robert Chambers, 1975. Water Management and Paddy Production in the Dry Zone of Sri Lanka, Agrarian Research and Training Institute. Occasional Publication Series 8.

[8] C. R. Panabokke and A. Walgama, 1974. The Application of Rainfall Confidence Limits to Crop Water Requirements in Dry Zone Agriculture in Sri Lanka. Jour. Natn. Coun. Sri Lanka s:95:113.

Farmer Cooperation

However, when the incentives are sufficiently strong the farmers will respond and adopt better practices. For instance, at the beginning of the Yala season of 1976, the Rajangana tank contained only 42,000 acre feet of water and the cultivators committee ignored the advice of the resident engineer (based on previous usage) to curtail planting to 5,500 acres and began planting the whole 13,000 acres of commanded area (Shanmugarajah and Atukorale, 1976)[9]. By a series of meetings with the farmers the Irrigation Department was able to convince them that the shortage was real and that conservative measures had to be adopted to avoid crop failure. The farmers were advised to clean and maintain the field channels and a rotation system of delivery was initiated. Despite the fact that there was no rain after April 1 and less than average inflow into the tank, rice yields in the scheme were 58 bushels per acre with a total delivery from the sluices of 5.54 acre feet.

In studying cleaning and maintenance of watercourses by farmers in Pakistan, Mirza et al. (1975)[10] found that when water was in short supply farmers were much more inclined to overcome their differences, cooperate and maintain the watercourses than when water was plentiful. Wickham (1973)[11] also found that cooperation by farmers in the Philippines was greater in the area where water was scarce. Farmers in general tend to work together and conserve their water resources when those resources are scarce in spite of the extreme potential for competition for those resources at such times.

Other irrigation schemes have been monitored in Sri Lanka since 1975-76 "under controlled conditions" by the Irrigation Department. These conditions involved closer coordination between the farmers and Irrigation Department so that: farmers were ready to use the water when it came, flow through the paddy to the drain was minimized, water was provided on strict rotation schedules and in general the farmers were brought to an awareness of the need to conserve water. The water issues from the tank sluices in terms of equivalent acre feet per acre served are shown in the following table provided by the Irrigation Department.

9/Shanmugarajah and S. C. Atukorale, 1976. Water Management at Rajangana Scheme Lesson Learned from Cultivation, Yala, 1976. Journal of the Irrigation Department, Volume 1, pp. 60-65.

10/Ashfaq Mirza, David Freeman and Jerry Eckert, 1975. Village Organizational Factors Affecting Water Management Decision-Making Among Punjabi Farmers. Colorado State University, Water Management Technical Report No. 35.

11/Gekee Y. Wickham, 1973. The Sociology of Irrigation: Insights from a Philippine Study, A.D.C. Teaching Forum. The spread of innovation, No. 31, 1993. Agricultural Development Council Ind., New York.

Scheme	Maha 1975/76 Ac.ft.	Yala 1976 Ac.ft.	Maha 1975/76 Ac.ft.	Yala 1977 Ac.ft.	Average Maha Ac.ft.	Duty Yala Ac.ft.
Rajangana	-	5.54	4.63	5.60	4.63	5.57
Hakwatuna Oya	3.25	-	-	-	3.25	-
Kaudulla	-	-	3.68	5.12	3.68	5.12
Wahalkada (with lined field channels)	-	-	2.92	5.60	2.92	5.60
Vavunikulam	4.01	4.39*	-	-	4.01	4.39*
M.I.K.				4.72*	-	4.72*

*Chillies - all other figures are for paddy rice.

These "use figures" make the 8 acre feet per acre per year assumed for the Mahaweli Project look much more reasonable and argue well for the probable success of that project.

However, as stated earlier, if it is assumed that rain water did not run off or percolate on through the profile, the actual needs for supplemental water are less than 2.5 feet in three years out of four. Making these same assumptions, the need for supplemental irrigation in average years in the dry zone is only 1.25 feet! In this light, assuming that the years of 1975-77 were average rainfall years, it is apparent that the efficiency did not have to be very high to allow eight acre feet of water per acre at the sluice to satisfy the 1.25 acre feet of water per acre deficit.

V. HYDROLOGIC BALANCE CONSIDERATIONS

The assumption that all the rainfall is held in the root zone and does not run off the surface or percolate below the root zone is not realistic. However, an overall hydrologic balance of the Island shows an average potential evapotranspiration (assuming 12 month cropping) of 72 inches/year and an annual discharge through the rivers to the ocean of 28 million acre feet per year, minus what is used in irrigation. Rainfall which does not stay in the plant root zone either runs off toward the sea as part of the 28 million acre feet or goes down to feed the ground water. Examination of the limited data indicates that less than 3 million acre feet per year are leaving the Island via the underground strata. This would amount to an average of less than 0.2 feet per year over the 16,000,000 acres of the Island. Deep percolation in excess of 0.2 feet per year must travel along the bedrock until it is picked up by roots of the crops or trees and leaves the soil by transpiration or enters a deep drainage channel, from which it can generally be used again for irrigation. With the restoration of the old tanks and construction of the possible new tanks and diversions, most of the run off water could be caught and held for irrigation. Consequently the pertinent question is not "Will there be sufficient water to expand the irrigated area to the projected total of 3,174,000 irrigated acres?" but is "How can this water be utilized on more of the 10,000,000 acres of 'dry zone' lands?"

During an "average year" the hydrologic deficit (potential crop transpiration minus rainfall) is only 1.25 feet in the "dry zone." The irrigation water released from the sluice is about 10 acre feet per acre.

The surplus 8.75 feet of water is leaving the irrigation project area via leakage from canals and field channels, percolation past the root zones and drainage (surface and subsurface) from the area. In some cases where one irrigation project follows another along the same channel, planners have assumed that 20% of the sluice flows from the first project flows into the second project, which would account for 1.7 feet. As discussed earlier, present estimates indicate that about 0.2 feet may go to the sea via underground aquifers, but this still leaves about 6.8 feet unaccounted for. It is possible that surface drainage is greater than indicated. Measurements may have been taken during good weather when sites were accessible and peak flow periods during heavy monsoon rains missed because the site was not accessible. It is also possible (conversations with Dr. W. D. Joshua) that the potential evapotranspiration is about 0.5 feet greater than indicated. However, this may be more than balanced by periods when crop cover is incomplete and actual evapotranspiration is less than potential evapotranspiration. The other major avenue by which the excess water could escape from the irrigation areas is by percolating down through the root zone, moving out of the cultivated area through the porous decomposing rock that overlies the solid rock and being picked up outside the cultivated area by the deep roots of the plants in the surrounding jungle. Roots of native jungle plants were observed in newly dug wells to be down to ten feet below the surface, and were in the capillary fringe of the existing water table. However, in most cases, the downhill direction which flow would follow is into the project and finally into the drain and the stream channel.

The conclusion of these hydrologic balance considerations is that during an average year an amount of water equivalent to about 80% of the irrigation water released to the present projects is escaping from the project areas by surface or subsurface drainage. Since there are several million acres of good land that will still not be irrigated when the currently estimated surface waters are used, tracking this escaping water and determining possibilities for its interception and use should be a high priority endeavor. It is probable that the development and use of this escaping water may have a high benefit/cost ratio.

Possibilities of where this water may be found and how it might be recovered are indicated as follows.

1. More surface run off (from rain and irrigation return flow) than currently estimated. In this case the interception and use would involve the construction of more down stream diversions, holding reservoirs, irrigation systems and possibly canals to more distant unirrigated areas than are currently planned.
2. More penetration into the base rock and unrecognized deep aquifers than is now estimated. If a substantial amount of water is escaping via this route, there may be much more deep ground water available than currently estimated. Pumping from these deep aquifers could recover this water and in this system where supplementation at the proper time is so critical, the control and timeliness of pumped water makes it highly valuable.
3. Migration through the decomposing rock to areas outside the cropped area where deep rooted jungle plants are extracting and using the water. If this is the route by which an appreciable amount of the water is escaping: (a) commercially valuable deep rooted planted species should be identified which could extract this deep water to satisfy their needs and should replace the uneconomic plants presently occupying most of the jungle or (b) this water could be intercepted by underground barriers and specifically designed tile lines and wells and pumped to the surface for use at points where it can be effective for irrigation of currently recognized field crops.

VI. COSTS OF WATER

A. Current Development of Surface Supplies

Irrigation Department personnel estimated amortization of construction costs (assuming an international loan at 8% interest) would cost about Rs. 140 per acre foot of water delivered at the sluice. Maintaining the reservoir and delivery system would require about Rs. 100 per acre of land served.

Estimated (by the Irrigation Department) losses in the delivery system are 30% which would mean that costs at the farm would be Rs. 140/.7 or Rs. 200/acre foot of water (plus Rs. 100/acre of land).

Losses observed by the author on field channels and farmers private ditches lead the author to estimate that real losses from the sluice to the field are about 50% which would mean that water at the field would cost about Rs. 140/.5 or Rs. 280/acre foot of water plus Rs. 100 per acre of land.

B. Pumping from ground water

1. From shallow ground water via dug wells.

At Jaffna, wells (15 to 20 feet diameter) dug to a depth of 30 feet were costing about Rs. 6,000 to Rs. 12,000. Much of this digging was through fragmented limestone. These wells are commonly serving about 4 acres and producing about 30 acre feet of water per year.

Pumping costs reported varied from Rs. 500/acre foot of water (reported by a custom farmer who was buying his water from a "contractor" who owned a kerosene powered centrifugal pump) down to about Rs. 110/acre foot (reported by a man who was computing costs of his pump and fuel).

Assuming interest at 15% from the private sector, and a nondepreciating well, payment of the interest on the installation cost would be Rs. 1500/year for a Rs.10,000 well. Assuming 30 acre feet of water from this well at a pumping cost of Rs. 110/acre foot, the cost per acre foot of water would be Rs. 50 + Rs. 110 = Rs. 160 per acre foot of water pumped, at the pump.

The land served was usually within 250 feet of the pump. However, Mr. J. A. Lewis estimated losses of one-third of the water over a distance of only 100 feet in this extremely permeable soil and had developed sand and cement ditch liners which can be produced for small channels (carrying up to 0.3 cusecs) at a cost of about Rs. 3/foot. Lining 1050 feet of these channels would cost about Rs. 3150 which could serve as distribution channels to four acres with furrow irrigation and rows 100 feet long. This lining at 15% interest and 10%/year maintenance would cost about Rs. 790 or approximately Rs. 200/acre and would generally be an economically sound investment since it would commonly save up to one-half of the pumped water and would, therefore, reduce the cost at the field from about Rs. 160/.5 = 320 to about Rs. 160 + 27 = Rs. 187 per acre foot when 7.5 acre feet of water are being pumped per acre per year.

2. From deep wells at Vanathivillu

Costs of these drilled deep wells, with well casing and screen, at current prices would be about Rs. 40,000 per well drilled down to a depth of about 160 feet. They are capable of delivering from 200 to 500 gallons per minute depending on the strata encountered. Average lift distance is about 100 feet. Estimated cost of the turbine pump is about Rs. 30,000 and the 140HP diesel motor operating them would probably cost about Rs. 40,000 and use about 25 gallons of fuel to pump 400 gallons of water per minute for 24 hours. With diesel fuel costing about Rs. 5 per gallon (subsidized) the fuel cost would be about Rs. 72 per acre foot of water pumped. The motor observed appears to have more power than is needed for the pumping rate and higher efficiencies could probably be obtained with a smaller motor. (An electric motor, properly sized and drawing current at a rate of Rs. 0.3 per kilowatt hour, would cost about half as much to buy and 80% as much to operate).

The estimated cost of water using the diesel pump, assuming 15% interest on the cost of the well, pump and motor and Rs. 72/acre foot for operating, Rs. 28/acre foot for maintenance cost and pumping for 200 days/year would be Rs. 16,500 + 20,000 = Rs. 36,500 for 355 acre feet of water, or about Rs. 103 acre foot at the well.

Since the Red Yellow soils such as those at Vanathivillu have sustained infiltration rates of about 20 inches per hour[12/] lining of the distribution channels or otherwise decreasing the rates of loss thru the soil is particularly essential if the water is to be delivered to the crops at reasonable cost.

C. Water from Small Village Tanks

Many of the ancient village tanks which had ruptured their banks have been repaired by the government. However, they have analyzed the cost involved in the construction of new village tanks and have concluded that the large tanks discussed above are a better investment in terms of acre feet of water provided per Rupee invested. Consequently, new small village type tanks have not been constructed. It can be assumed that water from these small tanks would cost more than Rs. 280 per acre foot by the time it reaches the farmers fields.

[12/] As determined by Dr. W. D. Joshua, Land Use Division, Irrigation Department.

D. Water saved from loss in watercourses

1. By Cement - Sand Plaster lining

As discussed above under Part II, cement-sand plaster linings costing about Rs. 3 per foot have been developed which appear to practically eliminate seepage. At Muthu Iyan Kaddu in the Kulam Scheme a farmer near the end of one of the field channels has a private channel extending about 300 feet from the field channel to his fields of chillies. This channel passes up slope from his house and immediately adjacent to a plantation of (about 40) banana trees. He had dug an interceptor drain about 18" deep alongside the channel for about 100 feet to reduce the seepage damage to the bananas and his house. This interceptor channel carries away about half as much water as reaches the farmers field. Only about one-third of the water leaving the field channel was reaching the farmers field because the private channel was cutting into the gravelly horizon of the Red Brown Earth. This farmer with slightly less than two acres of land was probably receiving about 16 acre feet of water per year at the field channel, but only about 5.3 acre feet of water was reaching his field. Assuming that he lined the 300 feet channel with the sand-cement plaster used by Mr. Lewis at Jaffna at a cost of Rs. 3/foot his cost would be Rs. 900 and his water saved per year would amount to about 10.7 acre feet. Assuming that the lining would last for about 10 years and that the interest rate on the funds used for the improvement was 15% his annualized cost would be about Rs. 225/year for 10.7 acre feet of water or about Rs. 21/acre foot of water delivered at the field.

In what may be a more typical situation a farmer was running water about 400 feet from a field channel and was probably losing about 25% of his water. Lining the 400 feet at a cost of Rs. 1200 could probably save him about 4 of his 16 acre feet of water. His annualized cost of about Rs. 300 would give him a cost of Rs. 75 per acre foot of water saved and delivered to his field.

2. By Cleaning and Maintenance of Field Channels

Two field channels were observed near Uda Walawe into each of which about 0.3 acre feet were discharging from the canal. Both of these had dwindled to a mere trickle by the time they reached the fields because grass had grown in the channels, raising the level of the water and causing a high rate of loss. On the basis of findings by Akram and Kemper (1978)[13] it is estimated that the

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[13] Mohammad Akram and W. D. Kemper, 1978. Effects of Cleaning a Watercourse on Rates of Water Loss. Colorado State University. (Forthcoming)

losses of about 60% and 90% in these channels could have been reduced to 15 and 20% respectively if the channels had been properly cleaned and maintained. The channels were about 1000 and 1500 feet long and a healthy man wielding a mamoty should be able to shave about 1" of the soil plus all the grass crowns from the bottom and sides of these channels at a rate of about 50 feet/hour and also build banks where they had been deteriorated by animals back to designed levels. This would cost 20 hours of labor on the 1000 feet channel. Rural labor in off peak seasons costs about Rs. 1/hour and consequently proper cleaning and maintenance of this channel would cost about Rs. 20 per cleaning. This cleaning would have to be repeated about 4 times per year to keep the channel in good, high delivery condition and consequently the annual cost of cleaning and maintenance would be about Rs. 80. Assuming that this cleaning and maintenance increased delivery to the farmers fields by 0.1 cusec for 100 days/year, the total delivery increase to the farmers fields would be 20 acre feet per year and the cost of the water should be about <u>Rs. 4 per acre foot</u>. As is the case in most other countries, (e.g. Johnson et al. 1978)[14] cleaning and maintenance of the field channels is the best investment for obtaining increased water supplies for farmers fields.

3. Compaction of Soil in Beds and Banks of Field Channels

High rates of infiltration in the gravelly Red Brown Earth soils and in the Red-Yellow Latosols are problems in many parts of the irrigation distribution system. Recent studies at CSU show that permeabilities of soils of similar textures can be reduced to 1% of their normal values by compaction at the proper moisture content. Cost of such compaction at Sri Lankan rural labor rates should be about one rupee per 5 lineal feet of a channel that will carry up to 1.0 cusec of water. This would cost about Rs. 200 per 1000 feet field channel and data to date indicate the effect should last through at least one season. Assuming a savings of 0.2 cusecs for 100 days or 40 acre feet of water for a cost of Rs. 200 the cost of this saved water would be about Rs. 5.2/acre foot delivered at the farmer's field. However, this figure is strictly an estimate and trials should be conducted on Sri Lankan field channels to determine the actual costs and benefits.

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[14] Sam Johnson, W. D. Kemper, and Max K. Lowdermilk, 1978. Solutions to Water Management Problems of the Indus Basin. Submitted to the Water Resources Bulletin.

E. Irrigation Efficiency

1. Delivery Efficiency

The Irrigation Department assumes a delivery efficiency from the sluices to the outlet from the field channel of 70%. The 30% loss is supposed to occur from the canals (which are maintained by the Irrigation Department) and the "field channels" (which are maintained by the farmers). The field channels, including outlet structures were built by the Irrigation Department and the 1948 Irrigation Ordinance gives the Irrigation Department the authority and responsibility to withhold water from a field channel until the farmers have it in good condition. As discussed in the next section, this authority is not being used to achieve adequate field channel cleaning and maintenance. Consequently, the field channels are generally in poor condition and despite their relatively short length (about 2,000 feet) are losing considerable water. After following six of these channels to their destination and comparing them to channels on which measurements were taken in Pakistan, I estimate that an average of about 75% of the water entering the field channels is getting to the farmers outlet and that 75% of the water reaching his outlet is reaching his field. Based on these limited observations overall efficiencies in the delivery system are estimated as follows:

Portion of the Delivery System	$\frac{\text{Loss}}{\text{Inflow}}$	$\frac{\text{Delivery}}{\text{Inflow}}$
Canals (maintained by Irrigation Department)	.20	.80
Field Channels (maintained by Farmers)	.25	.75
Private Channels (construction and maintenance by Farmers)	.25	.75

The overall delivery efficiency is the product of the three Delivery/Inflow figures which is 0.45, or 45%. In other words, on the basis of these limited observations--at this time of year when farmers needs for water are considerably below their peak, a little less than half of the water released from the sluices appears to be reaching the farmers field. At peak season the farmers would do a better job of cleaning and maintenance, but the flows would also increase resulting in more spillage and leakage from these watercourses. Consequently, a figure of 50% delivery efficiency is a reasonable first estimate for the canal-field channel-private channel delivery system.

Actual measurements of loss are needed and some may be in process. The Irrigation Department has measured flow in the canals and field channels on many occasions. However, they generally use channel cross sections and current meters, which are not sufficiently accurate to obtain the differential flows from which loss measurements can be calculated accurately on short sections of watercourses.

Measurements which may be taken this year include the Kaudullah project, for which the British are sending occasional consultants, to help local engineers monitor flows in the project to evaluate deliveries and losses. The UNDP project to renovate the Mahavilachchiya, Mahakanadarawa, Pavtikulum, Vavunikulum and Padaviya project distribution systems should also produce some relevant data. However, the engineers planning these projects and doing the work are primarily civil engineers who tend to concentrate on the canals. If they do not obtain some good sets of data, some specific measurements of losses in field and private channels should be obtained in several of the irrigation schemes.

2. Application Efficiency

The high permeability and low water holding capacities of these soils make the achievement of high application efficiencies difficult.

There is little if any data on upland crops, although research is underway to obtain such data by Mr. Lewis at Jaffna, Mr. Fernando, at Vanathivillu and the Agricultural Research Group at Maha Illupalluma. Dr. Joshua also plans application efficiency studies at the USAID funded Farm Water Management Project at Kalawewe.

Upland Crops

In the early stages of growing chilli peppers (which are a major crop) the transplanted plants are often hand watered twice a day, from pouring buckets constructed of palmetto leaves or sheet metal. For the next 10 days they are watered once a day. These daily waterings involve less than 0.1 acre inches of water per acre and probably approach 100% efficiency. After this initial irrigation these pepper plants are irrigated in furrows similar to other vegetable crops, with the irrigator generally filling short furrows in succession and applying only about an inch of water. This process is commonly repeated about every four days. It reduces the possibilities of leaving so much water in the soil that aeration will be a problem, and probably achieves a high level of irrigation efficiency. In these upland farms the main loss is probably in the tiny distribution channel, often only carrying one or two tenths of a cusec--a distance of a hundred yards on a highly permeable soil.

There is a tendency for this careful type of irrigation to be practiced on most upland crops -- probably because upland irrigation has in most cases been associated with limited water supplies and in many cases the farmers were paying to have this water pumped from hand dug wells. Those traditional upland farmers knew the cost and value of water and have passed this on to their descendants who have selectively colonized upland irrigation schemes.

Paddy Rice Areas

The contrast between application efficiencies on the upland areas and the paddy rice areas is striking. In these paddy rice areas water is poured into the general area of the rice crop to the maximum extent available. Unlike the upland crops, rice is not damaged by standing water and the water controls weeds. In many countries the paddys are carefully puddled to reduce the loss of water down through the soil. The puddling process in Sri Lanka is generally a cursory matter and the structure of the soil is really not changed as much as it could be to reduce water loss. Lack of puddling and high infiltration rates soon fills the profile of the Low Humic Gleys with water and when the watertable reaches the surface, loss from these low lands is reduced to acceptable levels. However, farmers who try to extend their paddy rice fields up into the Red Brown Earth apply as much as 20 or 30 feet of water per season to these fields during a four month paddy season. One can argue that not all this percolating water is lost since it helps maintain the high water table in the lower paddys. In fact measurements have indicated water coming up from the groundwater in the lower paddys. However, the major portion of this water is not used in transpiration by the crops and is part of the loss and return flow discussed in Section V. If this water, flowing out of a paddy area is collected in a tank down stream for re-use during the later part of the season, or is stored for re-use the next season, this overirrigation of the upper rice paddies is not a loss. However, if the drainage water from the irrigation project is not reused or if the high water tables are reducing yields on adjacent upland crops, paddy rice cultivation on the Red Brown Earths is a major and unmitigated drain on the water supplies acting to drastically lower the average application efficiencies of the project and reduce crop production.

The Irrigation Department recognizes this fact and is planning the new projects so that paddy lands will be restricted to the Low Humic Gley soils.

reports if the head of the division is on tour. Flow of engineers to Nigeria and other countries continues with 8 to 10 fold increases in salary as the draw. The Engineering Universities graduate about 300 Civil Engineers per year, and at present there are enough of these to fill the beginning slots in the Irrigation Department. However, the overseas demand is for engineers who have proven themselves with a few years of successful experience. These people are in short supply and it will be difficult to keep on the accelerated schedule proposed for the Mahaweli Project without bringing in fairly large numbers of expatriate engineers. The Government recognizes this fact and has publicly announced that they will bring in Indian Engineers to fill this gap because they "can get 5 or 6 Indian Engineers for the price of one Western Engineer." A quiet campaign has also been mounted to attract some of the Sri Lankans who are overseas to come home to help for a few years with the "war to complete the Mahaweli and get the country moving again." "Benefits" have been provided to engineers which have almost doubled their effective salary.

Despite these measures to "bring the boys back home" and keep them here it is still probable that considerable expatriate help will be needed if actual completion of the Mahaweli is to come ~~even~~ within a couple of years of the six-year target date.

Agricultural Engineers who normally play a major role in irrigation are not included as strongly as they could be in the Irrigation Department. One possible reason for this is that the Agricultural Engineer curriculum at the University at Perediniya is a general agriculture course with a "six-month specilization in Engineering." This is not sufficient time to give the students the fluid mechanics, strength of materials and similar courses which qualify them to be "real engineers" in the eyes of the Civil Engineers who are the administrators in the Irrigation Department and other agencies. These Agricultural Engineers are also at a disadvantage when they go on for graduate training because most Agricultural Engineering Departments in overseas universities will either not accept them, or will require that they take about one extra year to pick up these basic engineering courses.

The Agricultural Engineering profession in Sri Lanka would be greatly benefitted if the undergraduate curriculum at Perediniya were expanded to provide this solid background which would provide the enrollees with additional capabilities and respect at home and an open channel into the advanced degree stream in other countries.

The University at Perediniya could play a major role in training persons such as the Water Management Specialists suggested for the Irrigation Department in Section IX. However, to do this they would probably need expatriate help for a couple of semesters to develop and teach a course which would cover the subject matter needed. There is one well trained man in water management at the University (Dr. Kandiah) but he is already extended almost to the limit. Training of others is contemplated under the USAID advanced training project and should be supported.

If the government is serious about completing the Mahaweli projects in six years it is practically impossible to train engineers and get them to the experienced and useful stage before the project will be completed from a major structures point of view. However, even if the government comes close to that schedule on the major works, it is probable that work on the minor structures and field channels will extend for several more years. Consequently, Agriculture Engineers trained (including field training) could be on line in time to help with this job (Mahaweli). The Irrigation Department, the Mahaweli Board and the University should be contacted to evaluate the need, the potential for solution and the resources that would be required to put together a training program that would fill the need.

XI. ALTERNATIVES TO IRRIGATION FOR INCREASING CROP PRODUCTION

Fertilizer is an obvious answer, but the government's current subsidy of almost 75% on fertilizer (and credit available for the other 25%) is about as far as you can go!

Another challenging possibility is the nonirrigated portions, which will still make up over 70% of the dry zone. This land receives between 50 and 75" of rain with potential evapotranspiration at about 72" per year. At present the majority of this (about 5 million acres) is in jungle with some chena (slash, burn, cultivate and move on) cultivation. The jungle trees stay green, survive droughts and continue to grow. However, most of them are not commercially valuable timber. The extremely high rate of interest (15 to 20%) on capital in Sri Lanka and the tendency toward socialistic policies prevent private investors from investing in long term investments such as timber plantations. However, the growing world's need for wood and wood products and the escalating prices should make such plantations a good investment for the government.

Expanded investment (similar to the existing teak and eucalyptus plantations) in the future should be able to utilize many of the unemployed and should provide the government with a "future looking image" as well as being a good investment.

Other possibilities for deep rooted commercially valuable crops, which can survive a drought occasionally should be identified and evaluated, particularly on the Low Humic Gley soils, where underground water generally persists through the dry seasons.

Since the government's land use policies prevent the formation of commercial private plantations of sufficient size to do research, the government will generally need to fund and carry out all the research needed to identify adapted varieties, or breed varieties which can make use of this resource.

XII. SPECIALIZED STUDIES REQUIRED

A. The extremely high infiltration rates and potential for high value crops (e.g., citrus and grapes) and limited water supplies for the Red-Yellow Latosols suggest the need for an irrigation system that could eliminate distribution losses. When invited to Pakistan by CSU two years ago to evaluate a similar situation, Dr. Jack Keller16/ from Utah State University suggested a "hose pull trickle system" rather than a traditional sprinkler or trickle system. This recommendation was based on an economic analysis and the low cost of labor. Basically the system involves a set of hoses that can be moved two or three times a day and thereby irrigate a large number of trees with a minimum capital investment. It is suggested that such a system be tried at Vanathivillu and possibly at Jaffna.

B. The apparent underestimate of the return flow from irrigation systems should be checked out immediately in at least one existing project. This would involve a hydrologic balance study with several rain gages, evaporation pan(s) and gaging of the inflow and outflow of the irrigation project, plus some estimates of areas covered by bare, dry soil during the season. If actual return flows are much higher than currently assumed the area planned for irrigation should be expanded.

C. High infiltration rates and consequent high losses of water from irrigation channels suggest a need for immediate evaluation of compaction (and other promising procedures) for reducing infiltration rates in the Red-Yellow Latosols and in the gravelly layer of the Red-Brown Earths.

D. The probability that large amounts of water are leaving specific high infiltration reaches of irrigation channels and the value of the water lost argue for support of the Irrigation Department in their effort to characterize losses from their systems. They indicate that their primary need on this project would be equipment.

E. The probability that cement will be in short supply during the accelerated Mahaweli project is high. With the large structures requiring the cement, alternative linings for water channels should be identified. One such lining is a plaster consisting of clay, sand and raw latex. Dr. Kandiah has data

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16/Keller is a leading international consultant on sprinkler and trickle irrigation.

on the water stability and strength of this material which indicates its probable suitability. Surprisingly, the price is competitive with cement. This and any other local materials that show promise of satisfying this need for low cost lining materials for water channels should be evaluated.

A small grant to Dr. Kandiah at the University at Peredíniya for a laboratory research program and ensuring co-operation between him and the Mahaweli Water Management Research Study should be a productive investment.

F. The Mahaweli Water Management Research Project at Kala Wewa, with Dr. Joshua as Director and Mr. Knierem of Chemonics as adviser, is planned to provide answers to most of the other questions pertinent to water management. It should be fully supported and expanded if the need and opportunity for expansion occur.

XIII. SUGGESTED SCOPE FOR THE IRRIGATION SUBSECTOR REVIEW

Inasmuch as Tom Wickham will be coming to Sri Lanka for the specific purpose of helping put together a scope for this review no attempt will be made to develop a complete scope but specific items which appeared during my brief contacts will be outlined.

A. The discrepancy between the 20% figures assumed for return flow, and a return flow including runoff from rains of somewhere between 60 and 70%, as calculated for average years using hydrologic balance considerations, should be looked into more thoroughly. There appears to be possibilities that the amount of land, that can be irrigated in the strings of successive irrigation projects in the river basins, is considerably greater than has been planned for. A thorough discussion of a hydrologic balance considered in the irrigation systems with the planners in the Irrigation Department and the Mahawehli Board should help to either rationalize these differences or point out the need for monitoring and research to determine the hydrologic facts.

B. The current absence of farmer organizations to help manage the water after it enters the field channel and the deficiency in funds for maintenance and personnel to monitor the distribution system should be discussed in detail with both the Irrigation Department officials and with the farmers and existing training institutions in Sri Lanka to determine what organizational training and implementation steps should be taken to assure the proper cleaning and maintenance of the distribution system which will reduce the water losses. In this regard the renovation of the five irrigation systems planned by the UNDP should be examined to determine what data is being taken prior to and following the renovation. If help is needed to determine the benefits and evaluate levels of effort in this extensive project it should be considered as a possibility for USAID funded research.

C. The extent of ground waters available for irrigation should be determined more precisely. There appear to be a considerable number of reasonably good aquifers forming an arc around the top of the island where both a sandstone and fragmented limestone strata exist. In some areas these are salinized but there may be possibilities for developing recharge basins where these aquifers surface. Water that falls during seasons when it would otherwise be lost as runoff might be used to push these saline waters out to sea and reclaim these aquifers so that they could be used for the storage capacity which is so important in providing water at the proper time to the soils which have low water holding capacity. A study conducted by some Israeli advisors some years ago on the aquifer in the area of Vanathivillu should be reviewed. The only copy of that study which I could find was at the Groundwater Resources Board and when I found it there wasn't time left to read it.

Another study that should be reviewed was conducted about five years ago by a USAID TDY up in the Jaffna Peninsula to evaluate the hydrologic system there with special emphasis on the salt water intrusion that is beginning to take place. Copies of that study are available in the USAID office.

D. A constructively critical look should be taken into the extent to which real data has been collected to make some of the decisions with regard to water management. I was not able to find much real data but am not sure whether this is because such data was never taken or because disorganization has resulted in the loss or temporary misplacement of some of this data. Data on losses from the irrigation distribution systems in Sri Lanka are a case in point. When asked what they were assuming on this for their findings some officials said they were assuming 30% loss. They indicated that this figure had been decided by a committee within the Irrigation Department. Members of the committee, which make the decision, indicated that it was a qualitative figure based on "judgment." There was also a discrepancy noted by one of the committee members that about half of the people referred to 30% as the amount of water that would have to be added in addition to the irrigation requirements in order to provide the irrigation requirements at the field while the other half considered the 30% of the water was lost in the distribution system. The fact that these two interpretations have not been rationalized among the committee was evidence of some qualitative aspects of the data that has gone into the planning of the new projects.

If it is found that data is lacking or that there is some question with regard to data obtained, the team conducting this irrigation review should actually go out with the Sri Lanka officials and take a few measurements from representative areas to get at least a few check points in this system.

The facts of life in Sri Lanka seem to be that the government employees obtain salaries that are so low that most of them have to spend a considerable amount of their time in figuring out how to make ends meet or to run commercial enterprises on the side which will provide their families with the necessities of life. Consequently, less actually gets done than is planned.

E. The training provided to both civil and agricultural engineers in water management would be evaluated to determine how well prepared they are for playing an effective role in managing the water management resource. This analysis should include an evaluation of the field training which they obtain. In Pakistan we found that when the agricultural engineers had real field training so that they knew how to analyze field situations and had confidence in their ability to design and supervise construction, they became much more enthusiastic about getting out into the fields than the normal engineers who had graduated without having this real field training. There are some indications that this same situation and lack of field training and experience exists in Sri Lanka with the engineers relegating most of the field work and analysis to the technical assistants.

Training obtained by these technical assistants should also be evaluated. The few that I met in Sri Lanka had more apparent self-confidence than the engineers that were supervising them. Here again there may be an analogy to Pakistan where the subengineers were given more field training in their two year course than the engineers were given in their six year course, and as a result the subengineers were often more effective in the field aspects of water management and more eager to go to the field than were the degree holding engineers.

An analysis of this training should include discussions with officials at the University at Perediniya of the reasons for their program whereby students take a general agriculture curriculum for the first 3 1/2 years of their university training and then spend only one-half year in studying the subject matter in which they are to specialize. In at least some curriculums this leaves the graduate without several courses that are considered essential in their disciplines in the universities in other countries. For instance, in agricultural engineering this curricula does not give the students classes in fluid mechanics or strength of materials and basically leaves them unqualified to go on to graduate training at other universities where these courses are prerequisites of the water management and farm machinery courses. There appear to be a couple of routes for remedying this situation. One would be to change the university's general approach to require more specialized courses and less of the general agriculture. Chuck Anholt said that some of the university staff were rather strongly convinced that their current procedure is the proper way to train their students and it may be impossible to change their minds. If so, it should be clearly brought to their attention that another year of specialized training such as they are giving for their master of philosophy degree will be necessary to prepare these men to compete in the field which they are entering or to go on to advanced degree training in other countries.

In discussing the field training aspect of this it should be recognized that a primary constraint on field training is a lack of transportation at these institutions and another probable constraint is that the people teaching the courses have little or no field experience themselves. These possibilities should be evaluated along with the possibilities for removing those constraints.

F. Some actual organizational charts including the names, training and years of experience of the personnel involved should be reviewed. This will allow a quantitative assessment of the depth of personnel in the water management and irrigation sector and help in assessing their need for outside assistance.

G. Someone (preferably someone who speaks Singhalese or Tamil) should find an opportunity to get into the country and talk to at least several farmers regarding their current relationships and the relationships they would like to have with the Irrigation Department. If the person does not speak the local languages he should go with someone other than a member of the Irrigation Department on at least part of these visits. Objectives of these discussions with farmers should include:

1. The determination of what information, if any, they have received from the Agriculture and Irrigation Departments regarding management of their water;

2. The degree to which the irrigation ordinance rules are enforced;

3. Problems that exist among farmers and between farmers and irrigation personnel;

4. Whether the farmers feel that a more authoritarian system on the part of the Irrigation Department would bring about improvement in their system or whether they feel that more organization among themselves as farmers could achieve this objective;

5. Whether the farmers perceive the magnitude of the losses which they are sustaining from their watercourses and whether they would be willing to invest some of their time, and perhaps capital, in preventing that loss;

6. Whether they feel that the Irrigation Department or the Agricultural Department would be the most effective agency in bringing information to them on how to measure and prevent their losses, and how to decide, more quantitatively, how much water they should apply to their different crops and what crops will be best to grow on their land to most effectively use their land and water resource to maximize their economic return; and

7. Some assessment should be made on the potential in the dry zones for holding more of the water that falls in the groundwater and preventing it from running off. Effects of this should be evaluated on the hydrologic balance in an area and the possibilities for increasing the production of deep rooted plants and of keeping wells productive and increasing their productivity through the following dry seasons. Increased absorption of the water could be achieved by cultivation to loosen the upper layers of soil and increase the infiltration, maintenance of mulches on the surface, by skip listing or pitting or by contoured terracing of this land to hold more of the water in place. Such a hydrologic analysis should include measures or estimates of the water holding capacity of the gravelly and decomposing rock layers, how much the water level changes from wet to dry season in the existing wells, and the pumping rate from these wells so that an idea can be obtained of the permeability of these layers. This coupled with the slope of the water table could give an indication of the amount of water flowing and how fast it is leaving the area. This analysis should, if possible, include a list of the plants growing on the island which seem to be able to use these deeper waters. This list of crops should include crops which have medium root depth but can reach a harvestable stage based on the water available to them.

H. Several projects should be contacted to determine the data obtained and approaches being used to evaluate water management in the island. These should include:

1. The water management project being conducted by the Agricultural Department with the advice and counsel of the IRRI team.

2. The Water Management Research Project being conducted by Dr. Joshua of the Irrigation Department in cooperation with the Mahawehli Project and being advised by Mr. Knierem.

3. The Agricultural Department studies at Maha Illupaluma and the studies being conducted by Mr. Lewis and other personnel of the Irrigation and Agricultural Departments in the Jaffna Peninsula and the studies being conducted at Vanathivillu Research Station on the Red-Yellow Latosol.

Discussions with farmers in these areas would be well worthwhile. For example the evaluation of the water management and economic feasibility of the little one-acre plots serviced by wells on the Red-Yellow Latosols of the Vanathivillu area should be evaluated to determine whether that program should be accelerated and perhaps whether there are arguments for allowing the farmers who show initiative and good production capability to expand their holdings by buying additional acreage or leasing acreage from those who are failing and wish to leave the scheme.

Reports previously written on Irrigation in Sri Lanka, such as those by Robert Chambers and Gilbert Corey (available in the USAID Office), should be reviewed.