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9. ABSTRACT

The objectives of this program are to develop knowledge of how best to conserve and use rain water; design and construct effective irrigation systems; prevent surface flooding, high water tables, and salt in groundwater; and integrate those water use factors into a productive cropping system consistent with farm size and available farming practices in the heavy clay soils of the Mekong Delta and in the Indus Basin, Pakistan. Several field studies were well underway in the Mekong Delta when the project there was terminated with the fall of the S. Vietnamese government on April 30, 1975. With support of the U.S. AID mission for Pakistan, several large-scale research and demonstrations field studies covering a wide range of on-farm water management practices have been undertaken at several locations in Pakistan. These include (1) continuation of field studies with WAPDA at the Mona Reclamation Experimental Project; (2) continuation of field studies with IRDP at Shadab and Lar; (3) undertaking of watercourse surveys, including physical and socioeconomic aspects; (4) completion of a report on water management alternatives for Pakistan; (5) completion of studies on alternatives for organizing farmers to improve on-farm water management; and (6) beginning development of training materials pertinent to on-farm water management.

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Nov. 1, 1974 to Oct. 31, 1975

Submitted to
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December 31, 1975

Colorado State University
Fort Collins, Colorado 80523

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A. Annual Report Summary Sheet

Project Title: Water Management Research in Arid and Sub-Humid Lands of Less Developed Countries

Contract Number: AID/ta-c-1100

Principal Investigators: Gaylord V. Skogerboe and W. Doral Kemper

Contractor: Colorado State University

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

Contract Period (as amended): April 1, 1974 to March 31, 1977

Reporting Period: November 1, 1974 to October 31, 1975

Total Expenditures and Obligations Through Previous Contract Year:	565,712 April 1, 1974 to March 31, 1975
Total Expenditures and Obligations for Current Contract Year:	567,019 April 1, 1975 to March 31, 1976

Narrative Summary

At the beginning of this report period, the project in Vietnam had just completed its first annual field review. Dr. Sidney A. Bowers, in collaboration with the Faculty of Agriculture at Cantho University, did undertake a number of field studies. These efforts, combined with the support of the U.S. AID Mission in Vietnam, had this program well underway at the time of its termination on April 21, 1975.

The support of the U.S. AID Mission for Pakistan has also proved invaluable in undertaking meaningful large-scale research and demonstration field studies covering a wide range of on-farm water management practices at various locations in Pakistan. The AID Mission is finalizing a proposed Water Management Loan Program with the Government of Pakistan in cooperation with the CSU Field Party. In addition, the World Bank has negotiated a contract with the Water and Power Development Authority of Pakistan to conduct a country-wide watercourse survey, which would precede a water management loan program. CSU is also active in this program because of its importance in providing the data base for undertaking the loan program.

Among the most significant accomplishments during this report year are: (1) continuation of field studies with WAPDA at the Mona Reclamation Experimental Project; (2) continuation of field studies with IRDP at Shadab and Lar; (3) undertaking of watercourse surveys, including physical and socio-economic aspects; (4) completion of a report on water management alternatives for Pakistan; (5) completion of studies regarding alternatives for organizing farmers in order to improve on-farm water management; and (6) initiating efforts to develop training materials pertinent to on-farm water management. Significant progress has been made towards problem identification, demonstrating and development of technological alternatives, and identifying processes for implementing such technological solutions.

Annual Progress Report
WATER MANAGEMENT RESEARCH PROJECT

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.

2. Vietnam

The prolonged war in the Mekong Delta, together with the migration of people to the cities and subsequent decrease in cultivated land, reduced food production to a level insufficient to feed the nations increasing population. In part, this deficiency was offset by importing high yielding rice varieties and commercial fertilizers; the remainder through importation of U.S. rice and feed grains.

The U.S. government, concerned over insufficient production, initiated several studies on the future technological-agricultural development of the Delta. It was perceived that to reach self-sufficiency greater technological development, particularly in regards to water control, was required.

The Delta comprises 5.5 million hectares, 3.9 million in Vietnam and 1.6 million in Cambodia. Because of soil acidity, toxicities, periodic salt water intrusion, etc., approximately 40 percent of this area is totally or partially unproductive. Despite these constraints, from a climatic and physiographic viewpoint, the Delta is ideally suited for agricultural development and year-round crop production. With technical

development this area could again become the most productive rice area in Southeast Asia.

Historically, crop production in the Delta consisted primarily of one rice crop per year. It was believed that the establishment of water control, including both structures and management techniques, would promote both crop diversification and multiple cropping. This in turn was expected to improve the economy of the concerned nations, the area, and the individual farmers.

The Mekong Delta Soils Project was established to secure the basic data necessary for the transition from the historic monocropped rice culture to a diversified year-round, multiple cropping system. To this end, the Mekong Project was established at the University of Cantho, Cantho, Vietnam because the area was representative of the Delta and the supporting facilities of the university were available. This cooperative project involved the University of Cantho, Colorado State University working under Contract AID/ta-c-1100, the Office of Regional Economic Development from Bangkok, Technical Assistance/ Agriculture from Washington, D.C., and USAID/Vietnam from Saigon. Data generated was to be forwarded to the Mekong River Committee for use in planning future development.

The Project was initiated June 12, 1973 with the arrival of the Colorado State University advisor. Research was immediately initiated on assigned project objectives. Simultaneously, the development of research facilities, ordering of research equipment, selection of participant trainees, etc., was started. The complete first year accomplishments were reported at the project annual review meeting held in Cantho, October 1-2, 1974 and in the Colorado State University Water Management Research Project 1974 Annual Report. The most notable accomplishments were the assembling of a viable research staff and the construction of an operational eight hectare experimental site with water control capabilities.

This report contains a resume of project events from November 1, 1974 to April 21, 1975. On this latter date, the project was terminated by order of the USAID/Vietnam Mission Director. On April 23, 1975 the Project Advisor was evacuated from Vietnam. One week later, April 30, 1975, the Government of Vietnam surrendered to the Viet Cong and North Vietnamese.

3. 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 for the Water Management Research Project

To increase food production in the arid and sub-humid lands of the less developed countries through the improvement of water management practices and the integration of these with other good management and cultural procedures with appropriate consideration given to increasing employment in the rural sector and utilizing local resources.

2. General Objective for the Project - Management of Heavy Clay Delta Soils for Multiple Cropping Under Water Control

To supply the Advisory Board of the Mekong Delta Soils Project with that research data necessary for planning the future development of the water and land resources of the Delta. The specific areas for which research is most urgently needed are listed below. It is intended that information generated by this project will be applicable to other tropical deltas throughout the world.

3. Specific Objectives of the Water Management Research Project

1. Development of knowledge and data on how best to conserve and utilize water falling on the land as rain and the most efficient means of supplementing needed soil moisture by limited amounts of irrigation water.

2. Development of knowledge and data that can be used for the economic design and construction of water conveyance and delivery systems including structures for control and measurement of irrigation water, especially on the farm.

3. Development of surface and subsurface water removal systems to minimize the hazards resulting from surface flooding, high water tables and salt in the groundwater.

4. Identification of important factors to be considered in land preparation and leveling of the various irrigated soils in the major climatic zones and the relationship of these factors to water management, erosion, water infiltration, and good land use and cropping practices.

5. Development and adaption of methods of water application, including time and amounts, which are suitable and efficient for different soils of varying physical properties (water-holding capacities, intake rates, etc.) with major crops.

6. Integration of these water use factors into a productive cropping system consistent with farm size and available farming practices.

7. Where water quality, soil salinity and exchangeable sodium are problems, means will be developed for increasing crop production by using amendments and management practices which will improve water and soil properties and by using salt-tolerant crops.

8. The identification of institutional and policy factors (legal, social, economic, religious, manpower, credit education, etc.) which influence efficient distribution and management of water on the farm level.

4. Specific Objectives of Project - Management of Heavy Clay Delta Soils for Multiple Cropping Under Water Control

1. To study the physical and chemical characteristics of the soils in the lower Mekong Delta as related to crop diversification and multiple cropping and to study the water requirements of various crops. (1,5)*

2. To improve the structure and permeability of the heavy clay Delta soils by application of various cultural practices. (4,5)*

3. To determine the most effective forms of water control including the methods of irrigation. (2,3,4,5,8)*

4. To develop cropping systems suited to the soil conditions of the Delta under controlled water management. (3,4,6,7,8)*

D. Continued Relevance of the Objectives

Our research findings, surveys in Pakistan and Vietnam, 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. Survey of the resource positions of farmers in Pakistan, Vietnam and several other developing countries show that the average farmer is unable to make a large capital investment in technology. Consequently, variants of our water management technology package should be developed which will be labor intensive and within the means of the small farmers. This will not necessitate change in our

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*The objectives listed above are specifically assigned by the project "Memorandum of Understanding"; that document which defines the project purpose and implementation. The objectives, in general, do not directly correspond to the CSU Contract objectives listed in the proposed "Plan of Work" for March 28, 1974 to March 27, 1975. Behind each of the above objectives is listed, as closely as possible, the number of the most closely related "Work Plan Objectives".

overall objectives, but will require our continuing attention to ensure that the technology which we help produce can be used to increase productive work opportunities, as well as produce more food.

In principle, the assigned objectives for the Mekong Delta Soils Project are still relevant and necessary for future Delta development. However, due to the termination of the American AID program in Vietnam, their present attainment by Colorado State University is impossible.

Another new factor which bears consideration in development of technology packages for developing countries is the rapidly increasing price of hydrocarbon energy. In countries such as Pakistan and Vietnam, which have little hydrocarbon energy, the increasing cost of gasoline powered mechanization and nitrogen fertilizer production appear to be increasing the probability that animal power and legume production must be a permanent part of the crop production picture. Consequently, our water management technology packages should have variants which are adapted to these low energy input situations.

E. Accomplishments During the Reporting Year (Nov. 1, 1974 to Oct. 31, 1975)

1. General

At the beginning of this report period, the project in Vietnam had just completed its first annual field review. Dr. Sidney A. Bowers, in collaboration with the Faculty of Agriculture at Cantho University, did undertake a number of field studies which are reported below. These efforts, combined with the support of the U.S. AID Mission in Vietnam, had this program well underway at the time of it's termination on April 21, 1975.

The support of the U.S. AID Mission for Pakistan has also proved invaluable in undertaking meaningful large-scale research and demonstration field studies covering a wide range of on-farm water management practices at various locations in Pakistan. Considerable research is being accomplished as evidenced by the citations below and the appendix material. The U.S. AID Mission for Pakistan is finalizing a proposed Water Management Loan Program with the Government of Pakistan in cooperation with the CSU Field Party. In addition, the World Bank has negotiated a contract with the Water and Power Development Authority of Pakistan to conduct a country-wide watercourse survey, which would precede a water management loan program. CSU is also active in this program because of it's importance in providing the data base for undertaking the loan program.

The campus research program has become more sharply focused upon support studies for the field programs. Increasing emphasis has been placed upon integrating the results from the various disciplines. The results of these efforts have been paying off during this report year, with even more progress expected in the future.

2. Vietnam

Included below are achievements in personnel and contract support, equipment acquisition, development of research facilities, a report on participant trainees, and a summary of research status and achievements.

Development of personnel and contract support. The new PIO/T for CY75 increased the project piaster funding, increased the allowable local project personnel, and extended USAID's support of the advisor.

Project funding was increased from VN$19 million for CY74 to VN$39 million in CY75. This increase allowed monthly project expenditures of VN$3.3 million ($4,400 US).

While all project positions from the previous year were retained, the increased funding allowed additional staff positions as follows: 1 statistican with MS degree; 1 research assistant, B.S. degree; 3 laboratory assistants, junior college level; 1 vehicle driver; 1 mechanic; 1 additional secretary; 1 guard; and 5 additional laborers. Permission was also granted to hire temporary laborers as required.

This new PIO/T assigned to the project two excellent Scout 1/4 ton trucks with maintenance and gasoline supplied. Except for the use of APO facilities, all USAID privileges were granted the advisor including USAID housing in Cantho and guest house facilities in Saigon.

As a result of action initiated by the Defense Attaches Office, all USAID contractors lost their APO privileges.

Procurement of Equipment. Some previously ordered equipment was delivered to the project. This included all soil physics orders such as the ceramic plate moisture extraction equipment, "Tempe" cells, penetrometers, tensiometers, balances, conductivity bridges, sieves, shakers, drying ovens, equipment for soil mechanical analysis, core samplers, soil probes, etc. Also, a Beckman model B spectrophotometer and numerous textbooks were received. Additional micrometeorological equipment was ordered for evapotranspiration studies.

Other equipment was purchased or fabricated locally with project piasters. This included a 9HP diesel engine for the pumping station, a 12HP diesel 2 wheel Kubota tractor for

plot work (See Figure 27, Appendix 1), floating cage wheels to allow use of the tractor in rice paddies, and various hand and power tools.

The locally fabricated equipment consisted of three class A evaporation pans (Figure 13, Appendix 1), stilling wells, six 1 m^3 hydraulic lysimeters, 2 additional double ring infiltrometers, various rain gauges, and completion of a rotary dry sieve for aggregate size distribution analysis.

Research facilities. Improvements on the experimental site included completion of the pumping station (Figures 3-6, Appendix 1), completion of fencing, additional land leveling, construction of additional irrigation canals, sealing head gates against leakage, and installation of six 1 m^3 lysimeters.

VN$25 million was granted for paving of site roads, construction of additional irrigation canals, etc. Although the contract was awarded, the contractor was lost in the fall of Da Nang and unable to initiate construction.

Construction of project buildings, valued at VN$55 million, was initiated in January, 1975. These buildings consisted of an administration building with a conference room, secretarial rooms, directors office, etc.; a combination office and library building; a laboratory building consisting of a soils lab, crops lab, constant temperature room, and calculating room; a storage building with facilities for seed storage, machinery storage, etc. All buildings were nearing completion at the time of project termination. Two apartments for the project director and project advisor were also nearing completion. (See Figures 28-34, Appendix 1, showing earlier phases of building construction.)

Besides the permanent buildings, a temporary, functioning, soils laboratory was established on the Cai Rang campus with facilities for both soil chemical and physical analysis.

Participant and other trainees. The project "Memorandum of Understanding" provided for participant training at Colorado State University. After completion of formal course work, participants were to return to the project in Vietnam to finish their thesis problem.

Three participants arrived at Colorado State University in December 1973 for two years training in irrigation engineering, soil chemistry, and plant breeding. In January 1975 the project advisor was informed that the obligated funds were insufficient for support through two years of study. Consequently, after consultation with RED officials in Bangkok, an additional $13,600 was provided for completion of their studies.

The fall of the South Vietnamese Government presented both personal and project problems for the Vietnamese participants. Two of the participants have wives and children remaining in Vietnam. In addition, support funds are available only for the duration of their studies. The Water Management Research Project in cooperation with the Agronomy Department, is presently searching for means to allow the participants to finish their research prior to termination of funding.

During the year, a PIO/P was written to allow one additional project participant to attend CSU. Unfortunately, this participant was unable to leave Vietnam prior to the American evacuation.

Other additional project staff members underwent training during this reporting period. Mr. Vo-Tong Xuan, the project work leader, went on educational leave to the University of Kyoto in November 1974. He returned in April 1975 with a Doctor of Agriculture Degree.

Miss Nguyen Thi Ngoc Cuc, the research assistant in charge of all project analytical work, spent eight weeks training in the soil laboratory of the Institute of Agricultural Research in Saigon.

Summary of research and work in support of assigned project objectives. At the time of project termination (April 21, 1975) the end of the dry season was approaching. Most research experiments were incomplete; plot harvests had either not been initiated or not completed. In addition, most research data was recorded in Vietnamese; English translations were not immediately available.

Despite the evacuation it appeared that several weeks were available for compilation and translation of available data and completion of experiments. The American evacuation was looked on only as a precautionary action. Funds were provided to finance the project through those additional weeks required to complete the experiments. Plans were made to forward all results and translations to Colorado State University as soon as they were available. The project advisor was evacuated on April 23, 1975; Saigon and the Government of Vietnam fell on April 30, 1975. Obviously, there was insufficient time and means to collect, prepare, and mail the data. The summary of "work in progress" listed below and described in certain appendices is based primarily on recollection and what little experimental data was immediately available.

3. Pakistan

Among the most significant accomplishments during this report year are: (1) continuation of field studies with WAPDA at the Mona Reclamation Experimental Project; (2) continuation of field studies with IRDP at Shadab and Lar; (3) undertaking of watercourse surveys, including physical and socio-economic aspects; (4) completion of a report on water management alternatives for Pakistan; (5) completion of studies regarding alternatives for organizing farmers in order to improve on-farm water management; and (6) initiating efforts to develop training materials pertinent to on-farm water maangement. Significant progress has been made towards problem identification, demonstrating and development of technological alternatives, and identifying processes for implementing such technological solutions.

The following four personnel have served during this entire report period: Dr. W. Doral Kemper (Agricultural Engineering and Agronomy), who has served as the Chief-of-Party; Dr. Wayne Clyma (Agricultural Engineering); Dr. C.J. deMooy (Agronomy); and Dr. Alan C. Early (Agricultural Engineering). Dr. Jerry B. Eckert (Economics) served until June, 1975, when he returned to campus, and was replaced by Dr. Sam H. Johnson III (Economics) who arrived in October, 1975. Dr. John O. Reuss (Agronomy) arrived in September, 1975 as an addition to the Field Party. Immediately following this report period, Dr. Sidney A. Bowers (Agronomy), who had previously served as Chief-of-Party of the Mekong Delta Soils Project at Cantho, Vietnam, arrived in Pakistan as an additional member of the Field Party.

Besides the research programs with WAPDA and IRDP, the CSU Field Party is working with the major agricultural research centers in Pakistan on very significant research pertaining to wheat, rice, cotton and corn. Besides other GOP institutions, the CSU Field Party has joint efforts with the University of Agriculture at Lyallpur and the University of Islamabad.

The extremely low yields of the Indus Basin are tragic in view of the need for food in the subcontinent and the monumental effort and genius that has gone into development of the world's greatest irrigation scheme. In this great basin, blessed with an abundance of deep alluvial soil, the limited supply of water is the primary constraint on number of acres cultivated and often on crop yields. Construction of new storage reservoirs has provided additional water for irrigation at a cost of about Rs. 170/acre foot at the reservoir. Over 2/3 of this water is lost from the delivery system, so the cost of this water when it reaches the farms exceeds Rs. 500/acre foot. Recent studies (Eckert, et. al., 1975) indicate that the value of this water to the farmer is about Rs. 350/acre foot which forces the conclusion

that farm water management and associated cultural practices must be improved so water has a higher value and efficiency of the delivery systems must be improved if investments in these great dams and delivery systems are to be recovered.

The SCARP tubewell program currently pumps water at a cost of about Rs. 50 per acre foot at the well and about half of this water reaches the fields (Clyma, et. al., 1975) so its cost at the field is about Rs. 100/acre foot. Consequently, tubewell water is generally a good investment for the farmer and for the country.

For decades it has been assumed by most planners in Pakistan that only about 10 percent of the water was lost as it passed through the watercourses between the canals and the fields, and consequently there was little to be gained from efforts to improve these watercourses. This original assumption of only 10 percent loss was apparently a result of lack of measurements by the foreign consultants. Extensive measurements by the CSU team and their cooperators show that almost half of the water leaving the canals does not reach the fields. Consequently, there is a potential for increasing water delivery to the farms by nearly 100 percent rather than just 11 percent. This fact, first greeted as heresy by most of Pakistan's engineers and planners, is rapidly being accepted as representatives of the various Pakistani agencies have worked with us in seminars and field studies (e.g. July 24 and 25 Watercourse Loss Seminar and Field Day, attended by over 20 personnel from WAPDA, 6 from the Irrigation Research Institute, 4 from Harza Engineering, 3 from the Integrated Rural Development Program) and are provided with Cutthroat flumes (designed at CSU and produced by Pakistani fabricators) and instructed in this and other methods for accurately measuring watercourse losses.

USAID/Islamabad, recognizing this apparent potential for improvement at an early date when the areas sampled were limited, requested a broad survey to evaluate the extent of water losses, and identify socio-economic factors which would hinder or facilitate the group action necessary to achieve watercourse improvements. This study covering about 40 watercourses in the most important agricultural areas of Pakistan was organized and conducted by Lowdermilk and Early in cooperation with WAPDA. Meanwhile, some of the older World Bank personnel who had used the old assumptions in their planning, questioned the data. However, successive teams of World Bank experts have objectively evaluated the CSU data and on the basis of those evaluations have proposed a major watercourse survey in which 20 teams of surveyors will study the water losses and other management factors on 60 watercourses to re-evaluate the planned SCARP programs and determine how much of the new program should be devoted to improving watercourses and irrigation efficiency. WAPDA

will be their cooperators in this study. The survey teams recruited, trained by Lowdermilk and Early and now gaining experience under Early's direction in the USAID-WAPDA survey, will become the trainers and team leaders for the World Bank-WAPDA study.

Having obtained a good measure of the potential for water management improvement in several of the main agricultural regions and having aroused sufficient interest in watercourse losses and irrigation efficiency in other agencies and directed it to ensure that the total potential for improvement in the whole basin will be determined, the CSU effort will now be focused on methods for achieving the potential improvement. This effort will include development and adaption of methods to the resources and capabilities of the Pakistani farmers.

During the past two years over 30,000 feet of test sections of the types of brick and concrete lining adapted to local construction capabilities have been installed. Their costs were determined and delivery efficiencies of these test sections are being tested and measures of their longevity are being obtained. Despite explosive increases in the costs of brick and cement, benefits still appear to exceed costs (i.e., see Eckert, et. al., 1975) on many of these types of lining when they are used on the main channel of the watercourse.

Further tests of lower cost methods of decreasing watercourse losses are underway. These include:

1. Soil cement (cinva-ram type bricks)
   a. treated with sodium silicate to increase their water stability
   b. plastered on water facing side with sand-cement plaster
2. Reconstructed and compacted watercourse banks
3. Formation of compacted earth cores in the banks.

Each of these methods are achieving major reductions in water loss at relatively low capital costs and some appear to furnish returns of the order of an acre foot of water delivered at the field for from 3 to 30 hours of labor. Considering the cost of rural labor to be about Rs. 1/hour, this is by far the least expensive water in Pakistan. Considering the value of water even at its pumping cost of Rs. 100/acre foot delivered at the field, it is apparent that these methods of improving watercourses are highly productive work opportunities for rural labor.

About half the losses of water from watercourses were found to be in the vicinity (within 30 feet) of the watercourse junctions. Constant borrowing of soil to make dams and subsequent erosion of this soil downstream commonly

results in broadened watercourses with narrow leaky banks in the vicinity of junctions. The solution to this problem is pakka control structures which do not involve borrowing and erosion of soil during each closure and opening of a channel. However, the steel slide gates commonly used in other countries are extremely expensive in Pakistan, costing over Rs. 500 per gate.

Eight types of control structures have been built and tested. Criteria for selection include:

1. low cost
2. minimum leakage, and
3. components are not so useful for other purposes that they are stolen.

At present the most promising control structures are reinforced concrete panels with carefully cast round orifices and lids which can be built for costs around Rs. 50. The reduction in cost compared to steel gates is due primarily to the fact that cement is manufactured in the country, but steel must be imported. These concrete gates are sealed with either a sponge rubber gasket, or with mud in a groove designed for this purpose. The control panels are installed at 45 degree angles with the lids on top. Installation costs are about the same as for the steel slide gates (around Rs. 100 each). These and the other control structures are being tested for: farmer acceptance, how fast farmers learn to use them properly, leakage rates, durability of materials, etc.

Loss rates of water were found to double or triple as height of water rises a few inches in watercourses due to extremely high porosity and permeability of the upper portion of the banks, and eventually to overtopping. Increases in height of water in the watercourse are due primarily to accumulations of silt in the channel and to vegetative growth which obstructs the flow.

An informal organization of the farmers, advised by an extension agent (who in turn is instructed by an agricultural engineer) has been successful in keeping a watercourse branch clean and in good repair by spending about one man hour per 50 feet of watercourse once a month. The water saved, compared to the more common systems of cleaning 2 or 3 times per year is about 0.2 cusecs per thousand feet in a branch filled for about 24 hours each week, which amounts to a return of 1.6 acre feet of water for the expenditure of 20 hours of labor. Farmers appear to recognize the benefits derived and have not required official urging to clean assigned sections. They are occasionally otherwise busy on the assigned cleaning day, but make this up within the following week.

Poor stands are a primary constraint on kharif cotton, and maize yields. It has been demonstrated that planting on beds adjacent to furrows and proper timing of irrigation to moisten and soften the crust by capillary wetting allows cotton to emerge after the soil has been crusted by rains.

Maize grown under basin irrigation, with differences in elevation of only about 2 inches between the highest and lowest areas within the plots, was found to have stands and yields/plant almost 100 percent better on the high and intermediate levels than on the low areas. During the current year, maize grown on beds between furrows was found to have better stands and yields. Even when the maize on the beds was intentionally flooded with up to 12 inches of water there was not an apparent reduction in yield on the bedded plots and the yields were the best of several treatments. This may be due to the surprisingly fast recession of water from the surface of the beds, which even under the application of 12 inches of water were not covered for more than 24 hours.

Wheat yields were found to be insensitive to lack of irrigation in the latter part of the season when the soil profile was brought to field capacity and one irrigation was applied about 3 weeks after planting. Total water needed for wheat production under this type of water management regime was only about 14 inches, or less than 60 percent of that applied to the average wheat field in the Northern Punjab.

4. Objective #1. The development of knowledge and data on how to best conserve and utilize water falling on land as rain and the most efficient means of supplementing needed soil moisture

a. Soil Physical Properties

Aggregate size distribution. To facilitate the study of soil physical properties near Cantho, the rotary sieve was completed and tested. The sieve functioned perfectly with reproducible results.

b. Soils Laboratory

Upon delivery of the various soil laboratory equipment, a temporary soils lab was set up at the Cai Rang campus of the University of Cantho. This laboratory had the capability of determining most pertinent soil physical and chemical measurements including moisture extraction curves, soil mechanical analysis, bulk densities, cation exchange capacities, pH, percent base saturation, soluable cations, percent carbon, etc. The technician in charge had a B.S. degree in analytical chemistry and had recently received training in soil physical and chemical analysis.

c. Development and Installation of Hydraulic Lysimeters

Six 1 m^3 hydraulic lysimeters of the general design reported in the 1974 annual report were fabricated. However, due to a hysteresis-like effect in the prototype model, a slight modification in design was necessary. Analysis of the calibration curves suggested that air had not been completely removed from the truck inner tube. The problem was corrected by vulcanizing a second valve stem on the upper side of the tube directly opposite to the original valve stem. De-aired water was then forced into the tube by pressure rather than vacuum; the hysteresis loop was completely eliminated.

The six lysimeters were installed in the experimental site. Two were planted to corn, two planted to mung bean, and two were placed in the weather station site to be later covered with grass. Since the lysimeters were planted during the second week of April, 1975, no evapotranspiration data was available at the time of evacuation. Figures 11-12, (Appendix 1) show field installation of the lysimeters. For construction details see the 1974 annual report.

d. Water Requirement Study of Paddy Rice

This experiment was a repeat of the dry season paddy rice study reported in 1974. Exact experimental details are reported in the 1974 annual report.

Briefly, the procedure consists of measuring water level exchanges in three tanks installed in the paddy. Losses from Tank A, a tank without bottom and planted with rice, were attributed to percolation, evaporation, and transpiration. Loss from Tank B, a tank with bottom and planted to rice, were attributed to evaporation only. Tank C, a narrow tank, was placed between rice rows and shaded by them. Arithmetic differences in water loss allowed individual estimates of evaporation, transpiration, and percolation. Figures 14-15 (Appendix 1) show the field installation of the tanks.

An oral report at the time of leaving indicated the trends were very similar to those reported in 1974. Evapotranspiration was in excess of 7 mm/day throughout most of the experiment.

e. Effect of Within-Field Elevation Differences on Cotton Stands and Yields in Pakistan

In order to better understand the effect of poorly leveled fields on crop productivity, the effect of elevation differences on stands and yields of cotton within 15 fields in the Mona Reclamation Experimental Project area is being investigated.

Two plots, each twenty-foot square, were located so as to include the highest land within the field in one plot and the lowest land within the other. A middle elevation plot of the same size was selected between the high and low elevation areas. The low and middle elevation plots respectively, averaged 4.6 and 2.2 inches lower than the high elevation plots. Thus, about 4.6 more inches of water were applied to the low elevation areas than the high areas.

The number of stalks within each plot area was counted, and the cotton harvested from each plot at each picking date was weighed and recorded. Preliminary analysis indicates a definite and major yield effect due to elevation differences in the filed. Average yield from the low elevation plots is only about one-half of that from the high and middle elevation plots. There is also an apparent reduction in stands on the low-lying plots, but this difference is less consistent than the yield difference. (See Appendix 2.)

f. Training -- Soil Moisture Determination Using Touch and Feel Method

Practical field determination of soil moisture content is a technique that can be very useful to the agriculturalist who applys the irrigation water and the engineer who evaluates irrigation application efficiencies. One method of such field determination has been labeled in Pakistan as the "Touch and Feel" (TAF) approach and is an adaptation of the method presented by J.L.Merriam. This approach is not meant to replace field samplings and laboratory techniques, but is intended to supplement these techniques when a practical quick estimate is needed. (See Appendix 3.)

g. Training -- Field Gravimetric Soil Moisture Determinations Using Sun Drying

For the field worker, an electrical outlet and oven is not always available to dry a sample for the gravimetric method of soil moisture determination. An alternative procedure for drying the samples is to use the sun's energy, which is so abundantly available in Pakistan.

The procedure developed calls for the use of plastic sheets, or the same plastic bags in which the samples are stored, as the container to be exposed to the sun after the first weighing of the sample. The procedure of this step is to spread the sample out and break any clods present for maximum surface exposure to the sun and hence to minimize the required exposure time. Since less surface exposure is obtained with the bag procedure than the sheet procedure, the bag procedure will require a longer exposure time for sun drying. The bag procedure has the advantages of requiring fewer containers in the field, where simplicity

is a major consideration and of providing the sample from being lost to a sudden gust of wind or to accidental lifting of the plastic sheets. (See Appendix 4.)

h. Training -- Soil Moisture Sampling and Calculation Using a King Tube Sampler

The King Tube sampler can be a useful tool to the water management specialist in Pakistan. The tube, if properly constructed, and when correctly utilized, can provide volumetric samples of soil to calculate dry bulk density, as well as the soil moisture percentages. However, the extremes in soil moisture condition limit this procedure. In very dry soils, some of the sample is often left in the hole and the dry bulk density is biased too low. In very wet soil conditions, some of the sample is often left inside the tube, also biasing the determination downward from the true value. (See Appendix 5.)

i. Influence of Initial Seed Moisture Content on Germination and Emergence of Maize

Stand establishment has been identified as a major problem in the production of maize and other kharif crops of the Punjab. High daily temperatures, low seedbed moisture and soil crusting are recognized as contributing factors to poor stands.

A series of laboratory studies were conducted at Colorado State University, Fort Collins, Colorado, to determine the effect of initial seed moisture on the germination of cotton, maize, and sorghum. During the summer, a series of greenhouse studies were undertaken to determine the influence of initial seed moisture content on the emergence of maize and sorghum when planted in soils of varying moisture content. (See Appendix 6.)

j. Effect of Excess Magnesium on Corn Growth

Excess magnesium (Mg) in solutions and soils has long been known to result in reduced plant growth. There have been two main explanations advanced to account for this reduced plant growth. The first theory is that Mg simply has a "toxic effect" (Gauch and Wadleigh, 1944). A toxic effect, as defined by Leon Bernstein (1974), results in specifically recognizable toxicity symptoms. Plant toxicity symptoms of Mg in plants have not been described in the literature. The second main theory of depression of growth by Mg is that a Ca-deficiency is induced by partial exclusion of calcium (Ca) from plants by Mg (Hayward and Wadleigh, 1949). Other explanations advanced to account for growth depression by Mg are a "general plant nutrient imbalance" brought about by excess Mg and, in part, a "high pH" effect.

Several reports in the literature indicate that whenever Mg exceeds Ca in nutrient and soil solutions, plant growth depression takes place (Ca/Mg < 1). Magnesium exceeds Ca in more than half of about 1500 groundwaters analyzed by the Land Reclamation Directorate at Lahore. This poses a potentially serious problem in using these groundwaters for irrigation of crops, especially for high bicarbonate waters that precipitate Ca during concentration in the evapotranspiration process.

This report constitutes the results of a preliminary study to evaluate the effects of Mg on corn growth. Objectives of the study included comparing growth depressing effects of a neutral Mg-salt ($MgSO_4$) with a more alkaline $Mg(HCO_3)_2$ and with a low salt and high salt waters containing more Ca than Mg. Single Mg-salt solutions were used to determine whether or not recognizable Mg-toxicity symptoms could be detected. (See Appendix 7.)

k. Demonstration Guideline for Meteorological Observations

A small meteorological station to make observations of rainfall and evaporation can be a useful tool for scheduling irrigation applications in conjunction with detailed crop and soil moisture observations. This installation is also useful to document climatological events in relation to crop growth stages. The purpose of this guideline is to provide detailed instructions for field workers to measure evaporation and rainfall daily.

Observations must be made daily at the same time so that measurements reflect an exact 24-hour period. The preferable time for observation is 0800 hours to make our observations comparable to those made by other agencies taking readings at other locations. (See Appendix 8.)

l. Guideline for Automatic Rabi Drill Calibration

Prior to seeding experimental and demonstration plots, the automatic rabi drill (ARD) requires calibration. This is due to the difference in texture and granular structure of the various fertilizers available and due to the fact that this is not a precision planter precalibrated at the factory. For these reasons, procedures have been developed that require three replications in order to draw any conclusions regarding the seed rate per acre that will result from a given dial setting. Also, the trial-and-error procedure of successive approximations is used to attain the desired settings for experimental purposes. (See Appendix 9.)

5. Objective #2. The development of knowledge and data that can be used for the economic design and construction of water conveyance and delivery systems including structures for control and measurement of irrigation water

a. Watercourse Losses as Related to Composition and Condition of Banks

Watercourse seepage deprives many Pakistani farmers of 20 to 40 percent of their allocated water. It was determined that 70 to 80 percent of the seepage occurs in the upper portions of the canal banks. This high permeable zone was related to greater plant growth, organic matter, and the associated insect and rodent population.

Seepage rates were measured for various treatments applied to watercourses constructed in loam and loamy sand soils. While compaction alone reduces seepage, it is evident the well compacted earth banks, reconstructed from "clean" soil, reduces seepage to negligible levels. Estimated bank reconstruction for 1000 feet of a 4 cusec channel, which flows 50 days per year, shows a savings of 20 acre ft. at a cost of 20 Rs/acre ft. This is less expensive than water from private tubewells. (See Appendix 10).

b. Comparison of Watercourse Losses Measured by Flume and Ponding Methods

Reports from the Mona Reclamation Experimental Project and CSU Water Management team on water losses in watercourses have indicated losses much greater than those previously assumed in planning SCARP development programs in the Indus Basin Irrigation System. The large differences have caused many individuals to raise the following questions:

1. Are the measured losses representative of other areas in the Indus Basin?
2. Are the methods used for measuring the losses adequately precise or biased in any matter?
3. If these new measurements are accurate, what is the reason for such losses?

To help answer these questions, Mr. Mohiuddin Khan and Mr. M. Badruddin, Chief Engineers in WAPDA, organized a meeting of personnel from WAPDA, Harza Engineering and Colorado State University and invited personnel from the Irrigation Department and Integrated Rural Development Program, at which water losses could be discussed in detail.

This meeting consisted of a three hour session on July 24, 1975 at which Director Ashraf of the Mona Experimental Research Project and Drs. Clyma and Kemper of CSU described the losses which have been measured, the methods used for measurement, and their limitations. Personnel from the other agencies asked questions and described their own experiences with measuring

watercourse losses. In summary the following water transmission efficiencies and irrigation application efficiencies have been measured over the last three years by MREP, IRDP and CSU personnel on over 30 watercourses in the Lahore, Mona, Mian Channu, Lyallpur and Multan areas.

Water transmission efficiencies are expressed as the amount of water flowing through the nuccas into the field divided by the amount of water flowing through the mogha and are usually multiplied by one hundred so they can be expressed as a percentage. Measured transmission efficiencies have ranged from 15 to 95 percent with the average about 60 percent. The losses are due primarily to leakage through the banks resulting from rodent holes, insect holes, old root holes, inadequate filling of old nuccas, erosion and borrowing of soil at junctions which leads to narrow leaky banks and to water used in wetting and filling the watercourse. The biological activity is concentrated in the upper portion of the banks and measurements have shown that these upper positions have much higher permeability. Factors such as silting or growth of vegetation in the channel, which force the operating level of water in the watercourse up to these porous sections of the banks cause large increases in water loss.

Irrigation application efficiencies are defined as the amount of water which the soil can hold in the plant root zone divided by the amount delivered through the nucca to the field. When the amount delivered to the field is less than what could be held by the soil the application efficiency is considered 100 percent. Measured application efficiencies have ranged from 0 to 100 percent with an average between 30 and 40 percent. During December 15 through February 15, average evapotranspiration periods (e.g. March 15 - April 15 and September 15 - October 15) soil holding capacity often exceeds the amount of water applied. However, even during these months over-irrigation occurs on some fields. Further details of these measurements may be obtained by writing to CSU, P.O. Box 1028, Islamabad.

The next session of this meeting was convened on the Mohlenwal Khurd watercourse in the Shadab area near Lahore on July 25, 1975. There was no water in the canals near Lahore so Mr. Moh'd Hussain who owns an electric powered tubewell and land in that area was asked for permission to make measurements on his watercourse.

Losses measured on the 1,245 feet watercourse using flumes were 0.24 cusecs. Losses measured on the 4 sections of this watercourse using the ponding method (and evaluating recession rate at water levels which on the average were equal to the operational level) totalled .33 cusecs. Greater loss using the ponding method was due, at least in part, to levels of water in the lower ends of the sections exceeding the operational levels, and the high rates of loss that occurred as water levels increased. The greater losses resulting from

this unequal level of water in these ponding sections would have been reduced to a practically negligible level if the sections had been reduced to 50 or even 100 feet in length.

Both methods, when used carefully, provide good estimates of watercourse loss. However, it is apparent that the loss rate is highly dependent on the level of water in the watercourse. When the water level dropped an inch below the current operational level, losses could be reduced to half their current values. These results emphasize the potential of frequent cleaning of watercourses to reduce water losses.

These loss rates are percentagewise, higher than the average measured by the Mona, IRDP and CSU water management teams. The greater loss was probably due in part to more than the average amount of tall grass in this watercourse. (See Appendix 11.)

c. Watercourse Losses

A study of Pakistan's watercourses reveals considerable water loss due to improper design, operation, and maintenance. Specifically, such losses result from root and rodent holes, excessively wide cross sections, insufficient freeboard causing spillage, reduced thickness of watercourse banks due to farming encroachments, excessive vegetation within the watercourse causing additional seepage and evapotranspiration, leaky nakkas, channel storage due to below grade watercourses, and other factors.

Watercourse losses were evaluated from six different locations over varying time periods. Inflow-outflow measurements utilizing Cutthroat flumes were used to determine water loss. Delivery efficiency and loss rates were calculated. In addition, three Mona watercourses were selected for detailed study before, during, and after watercourse improvement. The overall results showed that excessive losses, significantly greater than previously assumed, occur on both SCARP and non-SCARP watercourses. Where tubewells supplemented the canal water, increased spillage occurred.

It is imperative that Pakistan develop watercourse rehabilitation programs. The first rehabilitation priority should be to reduce losses in high water table areas followed by watercourse improvement for tubewell supplemented areas. As new SCARP projects are implemented rehabilitation programs should be initiated to provide the increased water benefits to every farmer in the watercourse. Similarly, watercourse improvements must be applied to previously implemented SCARP projects to reduce water losses and the waste of electricity used in pumping.

Information is insufficient for developing a watercourse improvement program in private tubewell areas. However, in such areas, tubewell supplemented watercourses should receive high priority for improvement.

In unsupplemented watercourses the first priority should be to provide an additional water supply. Then, depending on the water available in the watercourse and the level of farmer maintenance, a program of selected watercourse improve ments should be provided. Where watercourse improvement programs are not possible farmers should be educated on losses incurred through poor operation and maintenance and instructed in remedial procedures.

Regular routine maintenance, inspection for elimination of leaks, and cleaning and reinforcement of banks would be a beneficial program. Particular specifications for each watercourse need be provided depending upon flow rates, cross sections, freeboard, slope, elevation and requirements for effective operation. Under these suggested programs substantial increases in delivery of water to farmers fields can be achieved. (See Appendix 12.)

d. Where Water Goes in a Watercourse

Previous water loss studies were made under conditions where steady water flow could be approximated. Such studies did not account for losses in filling the channel dead storage nor the high infiltration during the early periods of water flow. This study was conducted over a 15 hour period when all water entering or leaving the watercourse branch was measured.

The summation of these measurements showed that only 41 percent of the water entering the watercourse branch reached the fields. This delivery percentage is considerably less than earlier estimates because measurements accounted for that water rapidly soaked up by the watercourse during the initial wetting stage and for the continual infiltration of dead storage water during the intervals when water was switched between various sections of the watercourse. Considerable savings could result by scheduling water delivery from successive nuccas along the watercourse rather than switching back and forth between sections.

Most physical work in irrigation is through building bunds at the diversion points. Much of the work could be eliminated by building non-erodible pucca junctions. This would reduce land loss due to excavation and crop damage due to leakage. (See Appendix 13.)

e. Watercourse Junctions and Control Structures

Due to weekly borrowing of soil at junctions to make dams, and consequent erosion of part of this soil downstream, junction areas become very low, the banks become narrow and 45 percent of the loss in a watercourse was found to be within 30 feet of the junctions on this watercourse. Consequently, filling the junction areas and building watercourse banks in these areas back to their proper level will reduce watercourse losses appreciably. (See Appendix 14.) However, this water savings will be only temporary unless some means is provided of replacing the borrowed soil, or controlling the water without using large amounts of soil in the dams. Either a regular maintenance program including earth moved to these junctions from the field at regular intervals, must be instituted or pakka control structures must be installed.

Prices of steel slide type control structures are over Rs 500 each in Pakistan because steel is imported. Concrete control structures (square panels with round holes and lids) were developed by Hart et al and are now manufactured commercially, which cost only about Rs 50 and seal adequately with a sponge rubber gasket or with mud in a groove designed for this purpose. These control structures cost only a few rupees each to install in rectangular pakka watercourses, but cost about Rs 100 to install in earthen watercourses. Even at this price (Rs 150/structure) it can be shown that they will pay for themselves in labor savings within 3 years and that the water saved is "free". (See Appendix 15.)

f. Manual Construction of an Experimental Watercourse at Phullerwan Farm

A 400 foot earthen, trapezoidal watercourse was manually constructed (2.5 cfs at 1 fps). Due to the inadequacy of foot compaction, major leaks developed upon filling with water; on the second filling all major leaks except through animal holes, ceased.

Using the ponding method, seepage losses varied from 0.039-0.032 cfs/1000 ft. The cost of material and labor are given. Excluding the control structures, the watercourse cost was 0.81 Rs/ft. (See Appendix 16.)

g. Watercourse Leaks

On December 27, 1974, the watercourse serving Tubewell 91 at Mona was surveyed and found to have 120 leaks through the banks in 8000 feet and an additional 40 leaks at improperly closed junctions. The tubewell was on during this time. Twelve days later this same watercourse was surveyed and found to have only 20 leaks through the banks when the tubewell was off. In general the operating level of the

watercourse had dropped about 3 or 4 inches and consequently it was concluded that 100 of the 120 leaks through the banks had their entrance in the area on the banks between the operating levels when the tubewell was on and when it was off.

The general recommendation that may be extracted from seepage calculations is that any observable leak should be stopped on main and branch watercourses even if up to one-half hour must be expended on excavating through the bank following the hole, and compacting earth back into the excavation to fill the hole.

Seepage faces are commonly observed as wet zones along the outside of banks. Measurements of infiltration rates through such seepage faces have been from 5 to 10 times infiltration rates into adjacent soils in flooded basins. These seepage rates through banks are commonly 1 to 4"/hour. Assume a seepage face 6" high and along a watercourse, loosing water at a rate of 2"/hour per foot of such seepage face. Removal of the porous bank and replacing it with fresh compacted soil can generally be accomplished at a rate of about two feet of bank per hour, and such treatment will generally reduce the infiltration rate to less than 1/3 of its former value. Consequently, an hour of work can save about one gallon of water per hour. On main watercourses, the value of the water saved by repairing and compacting the banks to eliminate seepage faces will be about Rs.1/hour of labor spent. In other words, the cost of the water saved will be about 0.07 hours/0.02 acre foot per year, or 3.4 hours of labor per acre foot of water saved.

On branch watercourses the cost of saving water by compacting banks to reduce seepage losses will be of the order of 25 man hours/acre foot of water if the effect lasts for a year. This indicates that bank improvement will be worthwhile even on sub branches where water flows only 6 hours per week, in which case the saved water would cost about Rs.100/acre foot.

On the basis of such calculations it is concluded that because of the low cost of labor in developing countries there are highly profitable returns to labor used in the improvement of watercourses. These efforts can bring water to the farmers at a labor cost of 1 to 100 Rs/acre foot of water, whereas new storage dams and pumping from ground water result in costs of water at the field varying from Rs.100 to Rs.500.

These opportunities for improving their water supplies should be brought to the attention of farmers. Farmers are spending much more for water by running jalars, building and operating their own wells or buying water from private tubewell operators, than they would spend to obtain similar amount of water through watercourse improvement.

To educate farmers to these opportunities will require special training of extension personnel, and the development of measurement and demonstration techniques. (See Appendix 17.)

h. Compaction of Earth Cores in Watercourse Banks

Compaction of earth cores in watercourse banks required about 0.1 man hour per foot of watercourse and reduced water losses to 23 percent of their former value. Savings of water on this watercourse as a result of this compaction effort were estimated at about 1 acre foot per 3 man hours invested. This is the least expensive water in Pakistan with benefits exceeding costs by a factor of 30. (See Appendix 18.)

i. Pucca Nucca Losses on Watercourse D of Tubewell 78

Water loss through the eleven improved outlets of watercourse D were measured. The type of nucca, the measurement method, and the loss is given for each outlet.

The total loss (.054 cfs) was less than 1 percent of the total watercourse flow (5.5 cfs); 70 percent of this loss came from one mud sealed panel nucca. Admissible nucca water loss for a watercourse should be determined before the nucca design is selected. The loss of 1-5 percent of the total flow should be allowable. (See Appendix 19.)

j. Development of Checks and Gates for Pakistan and and other LDC's

Since leaky nakkas cause a significant portion of the watercourse losses, considerable effort has been spent in testing and adaptation of new nakka designs.

The desirable nakka characteristics are enumerated. Discussion and suitability evaluations are presented for various type nakkas including the pipe, circular-opening panel, panel-and-pipe, sewer pipe, rectangular concrete, rectangular opening steel panel, sock, siphon, and rectangular slide gate. Of these, the pipe, circular opening panel, and panel-and-pipe nakkas were singled out as having real potential. The flow capacities and characteristics were developed and discussed for the more favorable nakka designs.

An evaluation is given on the cost of nakka and check installations. Included are both labor and material cost. In general, nakka choices based only on first costs are in the following order: (1) rectangular concrete, (2) sock, (3) sewer pipe, (4) pipe, (5) panel-and-pipe, (6) panel with brick-lined channel. (See Appendix 20.)

k. Training -- The Installation and Use of Cutthroat Flumes for Water Measurement

A considerable amount of work has been done on the development of water measuring devices including flumes, weirs, and flow meters. The latest in the series is the Cutthroat flume. The Cutthroat flume has certain beneficial operating characteristics including: water measurement is satisfactory under both free and submerged flow conditions and head loss through the flume is low, even less than the long-used Parshall flume. In summary, it gives satisfactory accuracy for water flow measurement in the flat gradient channels of Pakistan. Furthermore, it is easy to construct because of the flat bottom required. Due to the above mentioned advantages, the Cutthroat flume should be widely accepted and used by all who are involved in water management work in the flat-gradient channels of Pakistan. (See Appendix 21.)

l. Training -- Measuring Tubewell Discharges by the Purdue Coordinate Method

A carpenters square or folding rule can be used to estimate discharge rates from Pakistan's tubewells where the discharge pipe is horizontal. By placing one side of the square on the discharge pipe of known diameter (D") the water fall (Y") can be determined for a one foot horizontal distance (X") measured from the pipe end. Discharge is then calculated from the theoretical equation

$$Q(cfs) = .0063D^2 X\sqrt{1/Y}$$

Since theoretical values vary from the actual, discharge from various pipe diameters should be measured with a Sparling meter and discharge graphs prepared. (See Appendix 22.)

m. Training -- Differential Leveling for Benchmark Survey of the Watercourse

Differential leveling is the process of finding the differences in elevation of any two points. It usually requires several setups of the instrument along a general line between the two points. Each setup requires a rod reading on a point of previously determined elevation and a rod reading on a point of unknown elevation. A benchmark survey is conducted to provide a widely spaced series of points (pucca nakkas, culverts, bridges, etc.) of known elevation from which a topographic survey is conducted at a later date. (See Appendix 23.)

n. Training -- Field and Watercourse Orientation Mapping Using Plane Table and Peep-Sight Alidade

The plane table and alidade are frequently used instruments where layout maps are needed of irregular field and watercourse orientations. This offers the advantages of preparing the map while the surveying is done and permits checking the watercourse and field layout as shown on the map with the actual layout. Also, where the design of, for example, a farm pond is completed as soon as a map has been prepared, the design can be completed and staked all in one operation. No return trip to an office to prepare the map, make the design, and then another trip to the field to stake the dam, pond, and spillway is necessary. The principal disadvantage of using the plane table and alidade is the extra field time necessary. When bad weather occurs, no work is possible. (See Appendix 24.)

o. Training -- Profile Leveling of Watercourse Main and Major Branches

Profile leveling is the process of determining the elevation of the ground surface at a series of points at measured intervals along a drainage ditch, terrace, waterway, road, or for any other purpose where it is necessary to consider changes in elevation of the ground surface.

It is necessary to tape or otherwise measure the horizontal distances for a profile. Vertical distances along a profile would have no meaning without the corresponding horizontal distances between changes in elevation.

Stakes or chaining pins are usually set along the fixed line for a profile survey. These stakes are usually set before the survey is made. Stakes are placed at fixed distances along survey, i.e., 25 meters (feet), 50 meters (feet) or 100 meters (feet) depending upon the detail required for the survey. In addition, stakes are set at points where the line changes direction and at every full station. For the profile survey of the watercourse main and major branches, chaining pins should be used to mark the stations at a 25 foot distance interval. (See Appendix 25.)

p. Training -- Topographic Mapping Using Grid Method and Level

Maps are essential to the best farm planning. In addition, maps are frequently the basis for engineering design of farm layouts and soil and water conservation structures and facilities. Pakistan is in dire need of maps of a scale (1:5000 or less) adequate for farm planning and engineering design. No matter where you will be employed, you will not likely find an adequate map to assist you in properly applying your engineering knowledge.

A map which shows horizontal distances, horizontal angles, and elevations is called a topographic map. The addition of elevation to a map results in the map showing topography or relief of the land surface. The contour map is the simplest method of showing elevation on an otherwise two dimensional sheet of paper. (See Appendix 26.)

6. Objective 3. Development of surface and subsurface water removal systems to minimize the hazards resulting from surface flooding, high water tables, and salt in the groundwater

a. Wells for Skimming Fresh Water from Aquifers with Saline Water at Greater Depth

In the aquifers of the Indus River Basin relatively fresh groundwater overlies more saline water. To exploit this water, CSU initiated a skimming well research program.

A review of the basic flow principles in aquifers containing both fresh and saline water shows the feasibility of fresh water withdrawal from the zone above the saline water. Based on Interface Theory, CSU laboratory investigations showed there is a critical discharge rate beyond which interfaces between dissimilar liquids becomes unstable resulting in withdrawal of the lower liquid. This critical discharge is low for well penetration near an undisturbed interface. The practical conclusions are that well penetration should be 30 percent of the fresh water thickness in isotropic aquifers and no more than 60 percent in aquifers where the horizontal permeability >> vertical permeability. Investigation of the discharge relationship to interface elevation beneath the well showed that for the same elevation the discharge and critical discharge was greater for anisotropic than for isotropic aquifers.

Examples are given on use of these developed relationships for well design and operating criteria. All studies indicate low well discharge is required to prevent upconing saline water intrusion. Relationships predicting the dissolved concentration as a function of time and flow rate were developed by considering the problem as one of flow from a single non-homogeneous liquid. The results show that even where salinity increases gradually with depth, lower discharges result in significantly lower concentrations.

Field test results support the developed theory. A tubewell, at Mona, whose discharge was too saline (2300 ppm, SAR 14) for use was restored to acceptable salinity levels (800 ppm, SAR 3.6) by reducing the pumping depth (105' to 45') and discharge rate (0.9 cusecs to 0.3 cusecs). Additional field experimentation is in progress. In the same area two pumps and 16 observation wells were constructed. The pumping rates will be progressively increased while monitoring the

salinity distribution in the well. The discharge rate and discharge salt content will also be monitored. (See Appendix 27.)

b. Water Supply for Irrigation on Andros Island, Bahamas

Andros Island has a substantial fresh groundwater supply overlying saline water. Over the years, a dynamic equilibrium has developed between the annual recharge (12") resulting from rainfall, and that discharged into the sea. Significant use of this recharge amount would result in a reduction of stored groundwater and establishment of a new equilibrium.

In the inspected area, wells are placed one per acre and pumped at 500 gpm for one hour per irrigation. Because of restricted permeabilities, wells must be drilled deeper than 22 ft. For wells of one ft. radius, using the above pumping rate, and assuming a 0.2 porosity, calculations show a maximum cone elevation beneath the well of 6 ft. Pumping creates a regional rise in the fresh-saline water interface. In a new dynamic equilibrium, the interface should be maintained at least 8-10 ft. beneath the well. If the minimum practical well depth is 27 ft., then the regional interface should be maintained at 35 feet.

This maximum safe interface elevation is used in calculations of the maximum safe increase in consumptive water use. Estimated irrigated crop consumptive use exceeds the natural vegetation evapotranspiration by 17 inches; this deficit requires pumping of groundwater. The maximum safe increase in consumptive use is a function of the ratio of irrigated land to total land (Ai/At) overlying a fresh water lense. Equations expressing the relation are derived and results presented graphically for both radial and one-dimensional groundwater flow. The maximum safe consumptive use increase is greatest when the developed land ratio is small. A 17-inch increase in consumptive use can be safely tolerated when the developed land ratio (Ai/At) is 0.10-0.18. These derived relations can also be used for crop selection and adjustment of cropping intensities so as not to exceed a particular consumptive use limit. (See Appendix 28.)

c. Field Test of Skimming Wells

Field testing of skimming wells was initiated early in 1975 following the completion of a shallow tubewell and dug well at the Phularwan Farm in Pakistan. The well depth was determined according to previous theoretical results and the measured fresh-water thickness of about 90 feet at the test site. The interface between the fresh water and the more saline water beneath is monitored through the use of

modified observation wells. Well discharge capacity has not been as large as we had hoped for an effective test of theoretical results, and a deeper well is tentatively planned. The results to date have shown a maximum upconing of about 8 feet at a distance of 18 feet from the pumped tubewell. This upconing is in response to a total withdrawal of 1.65×10^5 feet^3 of good quality water. Calculations of the volume displaced by the rise in the interface indicate that a large fraction of the pumped volume is accounted for by the upconed interface. This fact means that a great deal more pumping is required to result in the maximum stable interface required to test the theoretical results. While our results to date do not lend themselves to comparison with theory, their practical implications are important because they show that interface upconing is minimal when the well does not penetrate too deeply and discharge rates are low. A farm well only a few hundred feet from the test site, but deeper with a larger discharge, produced water of an unuseable quality. This well was modified to more closely approximate the optimal skimming well conditions, and has been performing quite satisfactorily. Project personnel have been asked by GOP officials and by individual farms to investigate the feasibility of modifying other wells in a similar manner. (See Appendix 29.)

7. Objective 4. Identification of important factors to be considered in land preparation and leveling of the various irrigated soils in the major climatic zones and the relationship of these factors to water management, erosion, water infiltration and good land use and cropping practices.

a. The Influence of Puddling, Water Level, and Straw Return on Soil Physical Properties, Paddy Rice Yields, and Yield of a Following Upland Crop.

Data reported in a 1974 drum experiment showed paddy rice yields from a nonpuddled, nonflooded (but saturated) soil were reduced but slightly as compared to yield on conventional flooded, puddled treatments. It thus appeared that on heavy soils, with slight percolation and herbicidal weed control, puddling and flooding operations might profitably be eliminated.

This experiment was a logical field extension. The experiment design was a 2^3 factorial with treatments of puddled vs nonpuddled, flooded vs nonflooded, straw return vs no straw return. The intent was to measure the influence of each factor on crop yields and on various physical properties including infiltration.

At the time of evacuation the rice yield was completed, the straw returned, and plots planted to green beans. In addition, following the rice harvest, infiltration was

measured on each of the 24 plots. Although samples were taken for bulk density and aggregate size distribution, these determinations were not completed.

Statistical analysis of paddy rice showed no significant differences due to puddling or flooding treatments, or their interaction. Average yields due to puddling and non-puddling were respectively 4.58 and 4.34 mt/ha. Average yields for flooded and nonflooded treatments were 4.72 and 4.20 mt/ha. These results agreed with the trends from the 1974 drum experiment. No treatment-related trends were observed in infiltration.

Detailed data are found in Appendix 30. Figures 16 to 20 (Appendix 1) show the field experiment.

b. Determination of the Optimum Moisture Content for Plowing Heavy Clay Soils

Plowing clay soils when too wet often causes compaction and puddling. If plowed too dry, the power requirements are great and the soil turns up in massive hard blocks which resist breakdown. Even when plowed at less extreme moisture contents, the soil must be harrowed within short intervals or the clods dry and make proper seedbed preparation difficult. The moisture range between too wet and too dry is frequently narrow and the transition from one to the other may be rapid.

To determine the optimum soil moisture content for plowing and the allowable delay in harrowing, a split block field experiment was initiated. Treatments consisted of three different moisture contents and three different times for harrowing. Differing moisture contents were established by saturating different plots at three day intervals and plowing when the last plot saturated approached field capacity. Harrowing times were 0, 6, and 12 hours after plowing.

All plots, in each of three replications, were plowed lengthwise with a disk plow. At the designated times, they were harrowed across their width with a Kubota rotary tractor (Figure 27, Appendix 1). Immediately after plowing and harrowing, all main and sub plots were sampled to determine soil moisture contents, clod densities, and aggregate size distribution. After drying, infiltration curves were to be run on each plot. The experiment was run on April 15, 1975; data acquisition and analysis was not complete at the time of evacuation. Figures 25-26 (Appendix 1) show the experiment in progress.

c. Maximizing the Yielding Ability of a 75 Day Rice Variety

A rice variety selected by Kien Phuong farmers reportedly matured in 75 days; normally, high yielding varieties

require 120 days for maturity and approximately 180 days for many local varieties.

A factorial fertility experiment was initiated to determine the fertility requirements for maximum yielding. The fertility treatments were as follows:

kg N/ha:	0,50,100	(Urea)
kg P_2O_5/ha:	0,40,80	(TSP)
kg k_2O/ha:	0,30	(KCL)

The factorial combination of the above resulted in 18 different treatments each replicated three times. Planting was by direct seeding. Following the harvest, all plots were planted with exactly the same treatments. The second planting was one month old at the time of evacuation.

Data from the first planting had not been analyzed nor compiled prior to the evacuation. However, an oral report indicated the following:

1. The variety matured in 77 days from the time of direct seeding.

2. The highest yields, in excess of 4mt/ha, were secured with the 100-80-0 treatment; the seeding rate is not known.

3. All non-phosphorous treatments in the second planting were stunted and showed much less growth than phosphorous treated plots. These growth differences are evident in Figure 10 (Appendix 1). By implication it appears that phosphorous is required for maximum paddy rice production in the Delta.

d. Dry Season Production of Grain Sorghum on the Floating Rice Lands

Similar to the experiment of 1974, a split plot supplementary irrigation-fertility experiment was initiated on the floating rice lands of Hue Duc District in An Giang province. Because of a water shortage (due to lack of distribution systems) these lands normally remain fallow during the dry season. Thus, the purpose of this experiment was to determine if grain sorghum could be produced on the residual soil moisture following rice harvest, and what fertilizer treatments are required for maximum production. Fertilizer treatments were as follows:

kg N/ha:	0,50,75,100	(Urea)
kg P_2O_5/ha:	0,50,75	(TSP)
kg K_2O/ha:	0,50	(KCL)

Supplemental irrigation: 0,15 cm (at boots).

The above treatments in factorial combination resulted in 48 individual treatments. While the soil surface was still saturated, Hegari seed was dropped beneath the straw mulch, in rows 50 cm apart. Two weeks after emergence, fertilizers were broadcast on the surface and sprinkled with 1 cm of water. Plants were thinned 3 weeks after emergence to 10 cm spacing. There was no spraying for insect control.

Harvest was in progress at the time of evacuation; thus yield data was not available. Field observations indicated a response to nitrogen and supplemental irrigation. Visually, there were no differences between the 75 kg N/ha and the 100 kg N/ha treatments. In addition, there was no visual response to phosphorous. There were no indications of insect damage.

Figures 35-38 (Appendix 1) show differences due to nitrogen, etc.

e. Variety Trials and Screening

Numerous variety trials were in progress at the time of evacuation. These included mung beans, soybeans, corn, sorghum, upland rice, paddy rice, and dwarf wheat varieties. Virtually no data was available on these trials except on corn.

Observation on sorghum, corn and upland rice seemed to indicate sensitivity to aluminum toxicity; all resulted in poor stand. Similarly, all wheat varieties did poorly; it is not known if this was due to aluminum toxicity or other factors. Soybeans and mung beans did well; particularly, Indonesian soybean varieties.

A wet season corn variety trial was planted on October 1, 1974. The trial was a selection by the Rockefeller/ Bangkok organization of 19 different varieties and was replicated four times.

The corn was planted on raised beds 1.5 m wide and 6m long. The row spacing was 60 cm, while the plant spacing was thinned to 30 cm.

Seventeen days after planting, an exceptionally heavy rain occurred (103.5mm), which was followed two days later by 33 mm of rain. Due to the high clay content (60-65%), this soil is poorly drained. Consequently, the root zone remained saturated several days. Varieties whose stands were least affected by the prolonged saturation were: Local Check, Phil DMR 2, and Cupricio Flint Comp DMR. Varieties most affected were Phil DMR 6, Synthetic 99, and Phil DMR 5.

Stands were poor on all plots. Therefore, yields were not based on whole rows, but instead were calculated on any available 1/2 row thinned to 30 cm between plants. Thus, these yields do not allow a valid statistical analysis, but may serve as an indicator of relative yielding capacity.

The highest yielding three varieties were Synthetic 99 (10:32mt/ha), Elt 3407 (9.9mt/ha) and Syn P_{200} x Kisan (9.31 mt/ha). The three lowest yielding varieties were Phil DMR 6 (4.59 mt/ha), Phil DMR-2 (6.18 mt/ha), and Hunis Comp. (6.36 mt/ha). Based on both the apparent ability to yield and withstand prolonged saturation, it appears the Local Check is the most desirable variety (8.98 mt/ha). More detailed data is shown in Appendix 31.

f. Irrigation Practices for Traditional and Precision Leveled Fields in Pakistan

Programs for optimum water use in Pakistan require a knowledge of the farmer irrigation practices. Irrigation practices were studied, for both supplemental and unsupplemental water supplies, at Mona, Shadab, Mien Channu, Multan, and Lyallpur.

Results showed that, in general the median water application in supplemental areas (3" $\leq$ 4") exceeded that of the unsupplemented (2" $\leq$ 3"). One factor influencing this difference is size of the irrigation unit. The median size of the unsupplemented unit was 0.2 $\leq$ 0.3 acres while the supplemented was 0.4 $\leq$ 0.5 acres. The affect of unit area on depth of irrigation is apparently related to interaction between infiltration rate and time required for complete coverage.

The median application efficiency for SCARP areas was 20-30 percent indicating a tendency to overirrigate. In non-SCARP areas application efficiencies were much higher with underirrigation predominating. Three examples on the effects of seasonal irrigation practices on wheat were discussed. In the SCARP area (application efficiency - 25 percent) there was a tendency to overirrigate and to irrigate too frequently early in the season and too little during the period of peak water use. On a private tubewell supplemented farm the seasonal application efficiency was 55 percent with a greater number of irrigations and greater total water applied. On the unsupplemented farm the application efficiency reached 90 percent with negligible deep percolation. The data implied excellent management practices but plant stress could have resulted if one irrigation were missed.

As irrigation unit size increases the absolute difference in elevation between lowest and highest points increases. With increasing size, field leveling becomes more difficult.

Previous studies showed unleveled fields caused greater irrigation applications. Evaluation of fields after leveling showed water savings of 1/3 to 1/2 as compared to traditional fields. Improvements were noted in stand, growth, fertilizer efficiency, etc. These factors suggest that farmers with short water supplies should reduce their irrigation unit size and precisely level their fields. (See Appendix 32.)

g. Improved Water and Land Use Management Through Precision Land Leveling

Farmers in Pakistan use the level basin system of irrigation and expend considerable effort in attempting to maintain the level of their fields. Measurements of individual fields in Pakistan have shown that frequently the fields are not level and much wastage of water results caused by excess water application and other management factors. An analysis of these factors is given from observations of the hydraulics of water application to level basins. Data from irrigation of leveled borders are presented to show the improvement in control of the amount of water applications. The procedure of land use improvement through precision land leveling is described. The saving in water will improve yields on existing cultivated land, permit increasing the area under cultivation, and reduce salinity and waterlogging. (See Appendix 33.)

8. Objective #5. Development and adaptation of methods of water application which are suitable and efficient for soils of varying physical properties (water-holding capacities, intake rates, etc.) with major crops.

a. Influence of Method of Irrigation, Straw Application and Planting Method on Soybean Emergence

In recent years, soybean production in the Mekong Delta has greatly increased. However, due to the heavy clay soils, poor emergence is a constraint on production. Therefore, to determine those techniques which might improve emergence, a split plot field experiment was initiated with treatments as follows:

Main plot treatments: flooding, sprinkling, and furrow irrigation.

Sub plot treatments: surface applied straw, incorporated straw, and no straw application.

Sub-sub plot treatments: punch planting (seed not covered); one covered seed per hill; two covered seeds per hill.

Emergence was quite high on all treatments due to the better tahn usual seedbed preparation (one plowing and three rototillings). There were no detectable differences due to irrigation method or straw applications. There was a small but highly significant difference (0.01 level) due to planting method as shown below:

Average Emergence Due to Planting Method*

Punch planting	One seed/hill	Two seeds/hill
95.26_a	97.81_a	102.15_b

*120 = 100% emergence

The results indicate that good emergence on these heavy soils is obtainable with good seedbed preparation and that emergence could be improved by planting two seeds per hill.

Evacuation was ordered before the beans were ready for harvest. More detailed data is available in Appendix 34. Figure 21-22 (Appendix 1) show phases of the field experiment.

b. Influence of Irrigation Methods on Emergence and Yield of Upland Rice and Corn

Randomized complete block designs were utilized to determine the influence of flooding, sprinkling, and furrow irrigation on emergence and yield. With both crops, emergence was poor due not to irrigation method but apparently aluminum toxicity. All plots were plowed under shortly after emergence ceased. No analysis of data was attempted.

Based on numerous observations, it appears that aluminum toxicity and the associated low pH will prove a major constraint to upland crop production in the Delta.

c. Recommendations for Trickle and Sprinkler Irrigation in Pakistan

This field trip study was to investigate the practicality of using trickle or sprinkle irrigation for better on-farm water management in various sandy land problem areas and certain fringe areas where water is either saline or extremely scarce.

Of the systems considered, the hose-fed basin and hose-fed sprinkler concepts are recommended because of their relatively low cost, reasonable labor requirement, Pakistan's capability to manufacture components, low system energy requirements, interchangeability of systems, applicable to practically any soil type and topography, high application efficiency, uniform applications, simple repair and maintenance, suitability for high salinity water, etc.

Recommended areas for installation included the green belt area near Karachi, limited water areas near Quetta, northern and western portions of the Thal Desert where adequate ground water exists, and fringe areas around irrigated lands where water supplies are limited. Prior to installation, studies should be initiated on outlet selections, procedures for laying supply tubes to basins, basin size, soil effects, and flexibility and durability of Pakistan produced components. In addition, a study should be made of special environmental problems such as damage by people, rodents, insects and birds, management and labor problems, and extreme climatic factors.

Initially, a single 10 acre site should be set up to test equipment, management and labor ideas, water movement and growth studies, and demonstration of required techniques. This site should be located near Islamabad where visitation is convenient for public officials and other concerned parties. Recommended crops for this site are almonds, pecans, apricots, peaches and strawberries. To assure success, one high level researcher should be assigned to this project.

After one year, if the project appears viable, two additional demonstration sites should be selected. (See Appendix 35.)

d. Effects of Delaying the First Irrigation on the Development of Yield Components in Semi Dwarf Wheat

This preliminary study was to test the effect of varying delays in the first irrigation on Chenab-70 wheat. First irrigations were delayed 14, 21, 28, 35, 49, and 63 days after planting. All treatments received a total of 4 irrigations of 3 inches each.

Results showed a significant reduction in headed tillers for first irrigations more than 21 days after planting. A delay of greater than 49 days reduced the spikelets per head. Similarly, grains per spikelet were significantly reduced after a 49 day delay. The length of delay had no influence on the weight per 1000 grains. Delays of more than 21 days significantly reduced relative grain yield. If delayed until the 35th day, gross incomes could drop to 63.3 percent of its unstressed level.

In practical cropping the most important variable is moisture management between 21-35 days after planting. Due to a linear decline in tillers, yields declined 2.6 percent per day during this two week period. (See Appendix 36.)

e. Water and Fertilizer Interactions in Wheat Production

This study, Water and Fertilizer Interactions in Wheat Production, was designed to estimate the response of Chenab-70 wheat to irrigation and fertilizer and determine the optimum economical input combinations. The design was an incomplete factorial replicated three times. Irrigation treatments consisted of 1, 2, 3, 4, 5, and 6 three inch irrigations distributed optimally to meet crop needs. Nitrogen treatments were 0, 50, 100, 150, and 200 lbs N/acre; split plots received 50 and 150 lbs P/acre. Using multiple regression techniques the estimated response equation was derived.

Responses to applied nutrients were substantial. Economic optimization required both high nitrogen and phosphorous levels. Response to irrigation treatments was not dramatic since rainfall and the preplant irrigation supplied 62 percent of the "consumptive use" requirement; with one post plant irrigation 83 percent of consumptive use was provided. Since the response to water was rather flat, little contribution could be expected from additional irrigations. However, at high irrigation and nitrogen levels yields were depressed due to lodging and rust.

Some recommendations from this study follow. For maximum yields avoid plant moisture stress during two critical periods; 21-35 days after sowing and during the early boot stage. Assuming a preplant irrigation, if a farmer can only give one irrigation, it should be 21 days after sowing. If two are given the second should be at early boot to avoid stress during the flowering period. When nitrogen applications are heavy, do not apply more than four postplant irrigations (approx. 52 cm) if rust and lodging are to be avoided. When fields are poorly fertilized, five to six irrigations are possible if the water price is lower than its true country value. A generalized practical fertilizer recommendation is that with two, three, or four properly timed irrigations up to 125 lbs. N/acre can be applied. Two bags of urea and one of DAP per acre will be very profitable to the farmer; on phosphorous poor soils an additional bag of DAP or TSP can be profitably applied. (See Appendix 37.)

f. Water Management and Nitrogen Fertilizer Movement and Utilization in Soils

The low average yields of kharif crops in the Indus Basin are not indicative of the potential of this region for crop production. Even yields obtained at research stations under reasonably high fertilizer applications are often lower than those obtained under carefully controlled water management in other locations with similar climates. The large

difference between the highest yields obtained and the average yields of farmers and experiment station plots where reasonable amounts of fertilizer have been applied under adequate irrigation indicates that some of the management practices are restricting yields. The possibility that water applied as irrigation, particularly in conjunction with heavy rainstorms that often occur during the monsoon season, may be leaching part of the mobile nitrates from the plant root zones, should be considered in this regard. Nitrate is one of the most essential and the most costly input in the high crop production picture and it becomes a highly mobile component of the soil system soon after its incorporation in the soil. Consequently preliminary assessment of what may be happening to nitrate in the soils of the Indus Basin was considered worthwhile.

9. Objective #6. Integration of these water use factors into productive cropping systems consistent with farm size and available farming practices

a. Water Requirements of a Small Irrigation System Planted to Rice

Through a cooperative agreement with 17 Catholic farmers at Cai Son, Kien Giang province, an irrigation system was built to supply water to 20 hectares of paddy rice.

The system consisted of a raised earthen irrigation canal with concrete turnouts, a 9 hp diesel engine with inclined axial flow pump, distribution box, etc. The pumping station, located on the canal bank, was completely brick enclosed with engine mounted on a concrete pad. The depth of pump submergence was sufficient to insure adequate water supplies regardless of the tide.

The project was designed to measure water delivered to each field throughout the year. Plans were to determine the water required for soil preparation and for production during the various stages of plant growth. In addition, a socio-economic survey was written to determine the impact of the system on the lives of the families involved.

Construction of the system was completed just prior to the evacuation; data collection had not yet started.

b. Progress Report for the Mona Reclamation Experimental Project

Funding and its Effect on Progress

One of the principal efforts during 1975 was arranging funding of the watercourse improvement project and the water management program at the Mona Reclamation Experimental

Project. Due to large increases in material costs, the initial grant of 2,000,000 Rupees for the watercourse study was substantially spent by December 1974, 6 months ahead of schedule. In anticipation of this exhaustion of funds, in May 1974, a letter was sent to the USAID Mission suggesting that other funding programs should be developed. Again in June 1947 the anticipated need for additional funding for further studies at the Mona Reclamation Experimental project was sent to the USAID Mission. In the ensuing months three successive proposals to provide funding at Mona for continuing studies in water management were drafted and discussed with the Mission and rejected for various reasons. Agreement as to the format for the application and the procedure to be used for funding was not reached within the Mission until December 1974. The proposal was rewritten three more times as funds thought to be available proved unavailable. The proposal was finally signed in April and funds became available about the end of May 1975. In the period from December 1974 to May 1975 most aspects of the water management research program at Mona were drastically curtailed or discontinued because no funds were available. It was obvious by October that funds would be late in coming and the program was substantially altered from November through June of 1975 because of the funding delay.

This delay in funding resulted in delay of programs and failure to develop and execute programs during critical periods. Watercourse construction at tubewell 78 was terminated after only a portion of one particular branch was completed. As a result, farmers had to accept inadequate water supplies because of a partially completed watercourse. The most advantageous period for construction of watercourses was during the rabi season because of the reduced demand for water and this period of construction was lost. In addition, major programs of research planned for the rabi season and part of the early kharif season could not be developed.

The land levelling program was severely curtailed by delay in funding.

After funds became available in May, a number of programs and improvements previously planned were initiated or continued.

Section D. (Earthen, Contractor Constructed Watercourse)

The "compacted earth" watercourse known as branch D on which construction was started by contractors was evaluated. This watercourse was approximately 4,000 feet long and it was not operating for 5 months resulting in substantial loss of water and crops to the farmers for this section of the watercourse. Construction of the watercourse was not

according to specifications in that the prescribed compaction was not provided. In addition, design was not carefully controlled and major sections of the watercourse are too high above ground. Drop and check structures were installed to regulate the water surface elevation and check structures were also developed to prevent excessive erosion. Various types of nuccas have been developed for delivering water to branches from the main branch as developed by Drs. Kemper and Hart and these have been installed to deliver water to all the minor branches taking water from this main branch.

The general condition of this watercourse was poor and becoming worse because of erosion from monsoon rains, damage by animals crossing the watercourse, and erosion on the inside banks in several stretches. Grass was growing profusely in some sections and was restricting flow, and causing some overtopping at stretches where inadequate supervision of the contractor had resulted in no compaction of the pad and subsequent slumping of the banks. The loss rates on this watercourse which ranged from 0.06 to 0.23 cusecs per thousand feet when it was first filled had increased to an average of over 0.4 cusecs per thousand feet (part of this was due to failure to completely close nakkas).

At this time the Mona extension group was asked to help organize the farmers to improve, maintain and clean this watercourse. Dr. William Hart and Mr. Tom Trout and other members of the field party inspected this branch with the Mona hydrology and extension staff and developed recommendations for maintaining this branch. These included:

a. No cuts to take water out of the main channel
b. No trimming of the banks to enlarge fields
c. Discontinuing use of the watercourse banks as a feeding station for herds of buffalo
d. Reduction of crossing points for animals to points where culverts could be installed
e. Sodding of points where extreme erosion was taking place
f. Building up points where the banks had deteriorated to little or no freeboard
g. A regular cleaning and maintenance program.

The Mona extension personnel called a meeting of the farmers and encouraged them to organize an informal association to help maintain their watercourse. The requests of the farmers for additional culverts and pakka nakkas were listed and a second meeting was scheduled. It was determined that most of the farmers' requests were reasonable and could be met. An attitude of cooperation was evident in the second meeting as the extension personnel discussed the "technical" recommendations. The farmers had "elected" their "users' association" officers and decided to clean and maintain the watercourse every two weeks. The Mona extension

personnel monitored the time spent on these cleanings and it appears to take the farmers about two hours to clean one hundred feet--doing some bank patching as they clean. After the first cleaning and careful closure of the nakkas, water losses were again down to an average of less than 0.2 cusecs/1000 feet. Later it was decided that cleaning once a month kept the watercourse in reasonably good condition with adequate freeboard. Cleaning once a month instead of the common two or three times a year appears to save an average of almost 0.2 cusecs of water per thousand feet. Since this branch is filled for about 24 hours/week the yearly water savings are about 20 acre feet of water per thousand feet of watercourse for an expenditure of about 240 hours of labor, or a cost for the water of about 12 hours of labor per acre foot. This is one of the least expensive sources of water in Pakistan.

The initial reaction to the earthen watercourse was quite negative because of the components of improper design and improper construction. However, as workable pakka nakkas have been installed and the farmers have taken a personal interest in the watercourse, it has improved and now delivers water to farmers on that branch of the watercourse with an acceptable degree of loss. Farmers appear to recognize the benefits derived from their labors and have not required official urging to clean their assigned sections. They are occasionally busy on the assigned cleaning day, but take care of their responsibility during the following week. Experience on this branch demonstrated the need for structures at outlets for sub branches, more careful design of check and drop structures, more careful management of the grade and elevation of the channel as well as provision for maintenance of the watercourse.

Branch I (Earthen, Farmer Improved Watercourse)

The farmers on branch I were approached by the Agricultural Engineers of the Mona Project with the proposition that the project would provide concrete control structures if the farmers would construct the watercourse channel and banks to the proper dimensions. This branch is between two branches which have been lined with brick and concrete at no expense to the farmers. Consequently, it was not too surprising when the farmers refused this proposition. At this point the Mona extension personnel were again asked to assist. They have worked with these farmers for several years. They told the farmers that concrete and brick lined test sections were all built, that the improved construction would reduce the crop damage from seepage in the upper section, would increase their water supply and that the pakka control structures would save them much work and last for many years. The farmers formed an informal users' association and agreed to the original proposition.

Losses were measured on branch I and the steady state losses were about 40 percent. A careful water budget of all water delivered to the nuccas compared to water supply at the head of the branch indicated that losses were near 60 percent. This is considered an extremely high loss rate since average distance from the head of this watercourse to the fields is only about 1,600 feet. A major factor in these high losses was delivery of nearly 5 cusecs of water at the head of the branch by the pucca main watercourse compared to a previous 2 to 3 when the main watercourse was not improved. Branch I had not been adequately enlarged to handle the increased flow rate.

Farmers did cooperate in rebuilding of the banks, and installation of pucca control structures for this branch of the watercourse. This program is continuing and losses at the present have been reduced from over 0.8 cusecs per thousand feet of watercourse to about 0.4 cusecs/1000 feet. Costs were approximately 2 Rupees per foot* of channel for the pucca control structures and .5 Rupees per foot of labor was supplied by the farmers. Siphons have been introduced on this branch of the watercourse to encourage farmers not to make kutcha nuccas on this main branch. They are encouraged to take their water to their fields from the sub-branches of the watercourses or to use siphons (provided for this purpose) when water must be taken from the main branch. At present only 2 kutcha nuccas have been cut in the improved section of the watercourse and since the identity of the culprit is apparent, it will be simple for the extension agent and users' association to focus an "education program" on this individual.

Reconstruction of Branch I watercourse was as follows: The existing channel was excavated to the desired grade and the existing banks were not removed, but were merely augmented to achieve the proper elevation and cross section. As a result, water still finds its way through old holes and losses are still substantial on this branch of the watercourse. The reduction in losses has been substantial and the benefit/cost ratio of the watercourse improvement is about 10 according to present computations.

A number of procedures for further reducing these losses will be initiated with time as the farmers continue to maintain and improve this section of the watercourse on their own initiative and with our assistance.

One of these procedures for reducing leakage which has been tested on a 72 foot test section of this watercourse is the compaction of an earth core in the watercourse banks. The inside portion of the banks above operating water was peeled off with kassies or shovels and a narrow trench

*Amortized for a 15 year life at 15 percent interest.

(about 2.5" wide) was pounded lengthwise in the bank using a hand compactor weighing about 15 pounds. This trench averaged about 5" deep and soil was compacted below this trench at least 5". The trench was then filled and compacted and the top of the bank replaced. The resulting compacted core, about 2 1/2" wide and extending from just above the water level to about 10" below the water level, reduced water losses of this section from 0.48 to 0.11 cusecs/1000 feet. The labor required in building this core was about 0.1 man hour per foot of watercourse. Assuming the reduction in loss lasts for a year on this watercourse, 100 man hours of labor/1000 feet will save 30 acre feet of water. This appears to be one of the most promising methods of decreasing leakage from old watercourses.

Optimum Management for Crop Production

Optimum management programs for wheat during rabi 1974-75 and maize during kharif 75 have been conducted on precision levelled fields at tubewell 78 and at tubewell 122 in the Mona project. The results of these experiments are the means of providing demonstrations to the farmer of improved cropping practices and improved water management in order to increase yields on the improved watercourses. The results of these experiments also provide documentary data for the potential yield levels for this area and the reduction in the water use that can be achieved through improved farm water management. The results of these experiments are reported in separate sections but major improvements in the yield and reduced water use has been achieved.

Seasonal Irrigation Practices

Another study initiated for kharif 1975 was a study of seasonal irrigation practices for tubewell 78. In this study four farms were selected for tubewell 78 and the amounts of water applied to each field on each farm has been observed during the entire kharif season. These data are under analysis and the study is anticipated to continue for the rabi season. In addition, the associated cultural practices and input data are also being obtained for these farms.

Some general observations of the seasonal irrigation practices for these farms were that:

1. The farm located at the head of the watercourse utilizes water on a demand basis. Water is only infrequently used during the allotted turn and instead the farmer opens a nucca a small distance and utilizes almost a continuous flow to irrigate all the fields on his particular farm on a convenience

or demand basis. Since the observer is at the farm only during the scheduled irrigation, the number of irrigations observed on this farm are only a small percentage of the total number actually applied. The cooperation of this farmer in making the measurements of the unscheduled irrigations was not obtained. The major conclusion is that water is not limiting on this particular farm.

2. Farm number 2 includes the 9 acres of precision levelled land in the "optimum management" plots. Comparisons will be made of the distribution and allocation and total use of water for the levelled and unlevelled areas and the inputs and outputs that are achieved for the different areas. In addition careful measurements of the application efficiency and delivery efficiency to the levelled and unlevelled areas will be provided.

3. Farm number 3 is located at the tail of the watercourse and is served by Branch D, the earthen improved section. Major changes observed on this farm are the increase in rice acreages achieved during kharif 1975 probably in response to the farmers' realization that his water supply has doubled as a result of the improved watercourse and because the combination of this extra water and abnormally high rainfall during the past two years have raised the water table at the tail of the watercourse near the drain. Maize and cotton fields planted for kharif 1975 were destroyed due to heavy rains, inundation and a high water table. Lack of water is not a factor limiting crop production on this farm. Only about 50 percent of the available supply is actually utilized on the farm. However, the farmer could plant additional fields to crops adapted to the increased water supply.

4. Farm number 4 is located near the tail of Branch I which is the farmer improved watercourse. Data from this study will give before and after delivery efficiencies and application efficiencies for this improved section. In addition, seasonal irrigation delivery efficiencies and application efficiency will be provided. Another general observation is that on this farm near the tail of the watercourse, the farmers actually utilize less than 50 percent of the land area available in crops and the resulting poor utilization of water can be attributed in part to this lower cropping intensity.

These farmers need assistance in planning their cropping program in order to more fully utilize their water supplies. An analysis of the period by period water supply, water demand, and water utilization rates for these farms is in progress.

A program of precision land levelling and advisory assistance to the farmers for fertilizer, seed, and irrigation practices has been developed and is in progress on the watercourse serving tubewell 78. A major component of this program is to provide assistance to farmers and increase their cropping intensities and yields to effectively utilize the increased water supply available on the improved watercourses. A number of acres have already been levelled and farmers agreements obtained to follow recommended cropping and irrigation practices. A goal has been set of 100 acres to be completed for the rabi season 1975-76. Mona project extension personnel will provide assistance to the farmers in obtaining: good quality seed, adequate quantities of fertilizer along with the recommended dosages for different levels of production, a rabi drill, assistance in planning his cropping pattern and water management assistance to apply the proper amounts and timing of irrigation water. The objective is to raise the level of production on these farmer's fields to near 50 maunds per acre with the advisory assistance. In addition, by providing a more careful control of timing and amounts of water, the quantities used to produce this crop is expected to be reduced by half.

A socio-economic survey of watercourses serving Tubewells 78 and 122 at the Mona Reclamation Experimental Project was conducted. The general objectives of this survey were to evaluate the perceptions of the farmers concerning the benefits and problems related to the improvement of channels on these watercourses and to seek problems that have developed because of these improvements. The farmers have taken the attitude that these watercourses were Government watercourses because the financing and execution of improvements had been done at Government expense without appreciable interactions with the farmers either in the planning or execution of the improvements. The farmers were generally perceptive of the advantages of these watercourses and were impressed by the increased supply of water that has been made available. However since they perceived them to be Government watercourses they did not generally feel responsible for maintenance of these watercourses. Informal users associations have been organized on two branches of the watercourse and these users associations have initiated programs of maintenance and cleaning in order that they might obtain full and continued benefits from the improved watercourses.

A conclusion of the survey was that there were definite disadvantages to the improvement of the watercourses without involving the farmers. Experience at other watercourses at Mona and in the Water Management Scheme with the Integrated Rural Development Program have indicated that there are difficulties in obtaining farmer cooperation while making improvements. The contractor built watercourses were generally built quickly at Mona but this advantage is offset by the disadvantage of farmers not doing part of the work themselves and their tendency to decline responsibility for maintenance cooperation. Since these watercourses were built as urgently needed test sections for research purposes, the lack of farmer input can be justified. However, the farmer reactions suggest that the time and effort spent by extension agents to gain farmer cooperation and input on improvements to watercourses is a prerequisite to farmers participation in construction and assuming responsibility for maintaining the watercourses.

Pilot Watercourse Improvement Program

Cooperation of the farmers on branch D with the guidance of the technical and extension staffs achieved cleaning, maintenance and water savings at a resonable cost of expended labor (about 13 hours/acre foot of water).

The extension staff was able to motivate the farmers on branch I to do the earth work (requiring about 0.5 man hours/foot) to improve their own branch watercourse to the proper dimensions as determined by the technical staff. The technical staff also installed concrete control structures at an average cost of about Rs.200/structure, or an overall cost of about Rs.5000 for 2500 feet of watercourse. The water savings and costs of improvement evaluated on this branch watercourse suggested expansion of this type of improvement project to a full watercourse.

The purpose of this pilot watercourse study would be to evaluate the extension and technical efforts needed to motivate and guide the farmers in this type of improvement project where farmers do the earth work and the Government supplies the technical guidance and pakka control structures. The total cost to the Government is estimated at about Rs.100 per acre served by the watercourse and the total labor expected from the farmers is about 25 man hours/acre of land served. The cost of the pakka structures is small enough that after watercourses have been improved which demonstrate the benefits, it should be possible to get farmers to pay the whole cost by direct subscription or through a loan program.

As part of the selection process, the following information was obtained on 15 watercourses on which farmers had a past history for being cooperative.

a. Numbers of farmers, tenants, and acreage owned or farmed,

b. Size of the watercourse and authorized supply of tubewell and canal water,

c. Cropping intensity,

d. Accessability to the Mona colony and to a pakka road.

On the basis of these data, watercourses 65, 56, 57, 79 and 62 were selected as the five best candidates. The information on these watercourses was checked, actual water supply was measured and watercourse losses were measured under steady flow conditions.

Information on measured water supplies indicated in Table 1.

At the watercourse serving tubewell 57, the mogha is submerged when the tubewell is running and only a small portion (0.4 cusecs) of the authorized supply (1.9 cusecs) was coming into the watercourse.

At the tubewell 79 the watercourse was in such poor shape in the area near the tubewell that when the tubewell came on the water overtopped the banks and caused washouts. The actual supply to this watercourse is nearly its authorized supply of 6.25 cusecs. However the maximum carrying capacity of the watercourse is less than 5 cusecs. It does appear that there is some submergence of the mogha and reduction of canal supply when the tubewell is on. Over 1 cusec of the water loss when the tubewell was on occurred within 100 feet of the tubewell.

At tubewell 56/L watercourse the mogha was obviously submerged when the tubewell was on and the measured canal supply was 0.40 cusecs compared to the authorized 2.75 cusecs. There was a loose brick in the box which divides the tubewell water between 56L and 56R which was situated to deflect more of the tubewell water to 56L watercourse. This brick was still there 10 days later. At that time the watercourse had been cleaned recently, the water level in the watercourse was lowered. The mogha flow was not measured, but it was estimated as about 1.2 cusecs.

At tubewell 62, there was no water in the distributory on the day when the flow measurements were made.

Table 1. Data Collected in the process of selecting the pilot watercourse.

Tube Well No. at the watercourse	Area (Acres)	Authorized Supply (Cusecs)		Measured Supply (Cusecs)		Distance (Miles to)		Average Loss Rate		General Soil Texture
		Canal	Tubewell	Canal	Tubewell	Colony	Pakka Rd.	Cusecs 1000 ft	Percent 1000 ft	
56/L	840	2.75	2.0	0.40	3.70	4.0	0	0.39	9.7	Clay loam
57	834	1.9	3.0	0.40	1.54	5.0	0	0.24	13.2	Clay
62	847	1.6	3.5		3.00	5.0	3.0	0.33	11.3	Loam
65/L	399	2.0	2.4	0.10	2.36	7.0	2.5	0.49	15.6	Loamy Sand
79	959	2.75	3.5	2.00	3.5	2.5	0.5	0.54	9.9	Clay loam

On the basis of the cooperative attitudes expressed by the farmers during the survey and the criteria listed below, the watercourse at tubewell 56/L was selected as the pilot watercourse.

It has the most cooperative farmers. It is most accessible (the pakka road runs through the commanded area). Its loss rate of 0.39 cusecs per 1000 feet is about the average. Its measured water supply rate per acre was low (4.1 cusecs for 840 acres).

At these moghas the measured canal supply was smaller than the allocated supply. This is partially due to the fact that addition of tubewell water to the watercourse has submerged the mogha and drastically reduced the canal water supply for this watercourse. In the case of the distributory at tubewell 65L, the water level in this tail end of the distributory is consistently about three inches below the design level. A total of 17 cusecs of watercourse was feeding 3780 acres for an average duty of 222 acres per cusec. Assuming that the average channel between the mogha and the field is 5000 feet long for the four large watercourses, and 4000 feet long for the tubewell 65 watercourse, leads to the conclusion that 8.8 of the 17 cusecs is lost from the watercourses, leaving only 8.2 cusecs to reach the fields, where the average duty becomes 460 acres per cusec. This supplies an average of only 1.5 feet of water per year to the cultivated lands included in these watercourses, which is far below the average planned for the SCARP area. This is partially due to the fact that most of these watercourses take off from the distributaries where the canal supply level is lower than the designed level.

On watercourse 56/L the cropping intensity appears to be realatively high and this fact must be reconciled with the relatively low water supply.

Changes of Responsibilities of Mona Personnel

WAPDA and the World Bank, partially through data from the Mona project, have recognized the need for a strong water management and watercourse improvement component in future programs. To place proper emphasis on the water management factor they have decided to conduct national surveys of watercourse losses and irrigation application efficiencies along with salinity, waterlogging, and other factors. To organize and conduct these surveys and develop the program in this subject area, Director Ashraf, the Technical Officer Mr. Qayyum, Senior Soil Scientist Dr. Haider and Senior Agronomist Mr. Rehmat Ali have been promoted to central office positions in WAPDA. Their assignment was based largely on the expertise in water management demonstrated in their studies and reports during the last few years.

We have asked that M.M. Ashraf, now Assistant General Manager (Planning) in WAPDA be given responsibility for the Mona project so he can help select satisfactory replacement personnel and give continued support to the Mona program. Apparently this is being done.

Resume of Mona Project Progress and Needs

In spite of funding delays and personnel changes the on-farm water management research program at Mona achieved many of its objectives during 1975. More help in supervision of the field personnel by Pakistani supervisors is needed to improve the efficiency of the program. Transport was not purchased due to delay of funds and lack of transport severely decreased efficiency and curtailed some programs. Vehicles have been ordered but unionized drivers prevent use of these vehicles for needed night and early morning work. Consequently some motorcycles have been ordered. Planning still needs improvement. Some improvement in these functions has occurred during the past year, but some deterioration has resulted because of changes in personnel. It is particularly essential that the hydrology section be given supervision by a person who has technical ability in water management.

While the Water Management and Watercourse Improvement Projects at Mona are among the most productive research projects in Pakistan, they are still only about 50% as efficient as they could be. More planning, better scheduling of transport and administrative support to avoid shortages of petrol, cement, etc., can do much to optimize the production of these research programs.

c. Progress Report for the Punjab Water Management Scheme of the Integrated Rural Development Program

A socio-economic study of a watercourse was conducted including a comparison of the problems as defined by physical measurements on the watercourse compared with the perceptions and definition of these problems as obtained from farmer interviews. A report presenting the results of the study has been prepared and is appended to the Annual Report. A major cleavage between two of the caste groups on the watercourse was identified and in the succeeding year this was the dominant factor leading to the farmers unwillingness to cooperate in water management improvements. The fact that the one group is apprehensive of the benefits that would be provided the other group through cooperation in water management improvement practices prevented the program from being implemented.

The individuals who were to take responsibility in the Pakistan Government for implementation of the scheme were assigned late last year. These individuals were obtained

from a number of organizations within the Agriculture Department and were not particularly trained or experienced in the area of on-farm water management. After their assignment to the program, there was a period when there was considerable internal inertia to implementation of any programs under the water management scheme because they were unconvinced of the importance of water management to farmers. As a result only limited progress was accomplished during the initial six months of their assignment. This to some degree represents the kinds of problems that will occur as additional personnel are assigned to implement the water management loan program unless a concentrated effort is expended in educating and interacting with the individuals that are to implement the program. This will be particularly true for individuals who are assigned from outside any of the on-going water management programs.

A survey was conducted of the Lar watercourse to determine concepts and social structure. A conclusion of the survey was that the farmers on this watercourse would probably be one of the most difficult groups in Pakistan to organize for water mangement improvement practices. However when an appropriately trained and properly experienced engineer was posted on the watercourse he was able to get them organized so that 2000 feet of lined watercourse was constructed and 50 acres of land were leveled. This individual was also able to get initial and unanimous agreement as to the location of the watercourse as well as a petition for removing and relocating the mogha.

During 1974 becuase of bureaucratic delays in the Integrated Rural Development Program and in the Auditor General's Office which approves these funds, the construction was stopped and for a period of approaching one year no further construction occurred after the initial approximately 2000 feet. Subsequent to this interval of time, again approaches were made to the farmers and provision of funds for construction were arranged and in the succeeding two months period another 3000 feet of watercourse has been improved. This watercourse is a pucca watercourse cost shared with the farmers. A tentative conclusion from this experience is that there are many factors which will contribute to major difficulties in the implementation of on-farm water management practices on a cooperative basis with farmers. These cleavages may result in an inability to organize and obtain agreement with the farmers. However, through proper interactions and encouragement of the farmers it is possible to organize even under very difficult circumstances. Farmers do perceive the advantages of improved on-farm water management practices and are responsive to these incentives.

General observations of the experiences of IRD engineers in the implementation of watercourse improvement suggest that a rather intensive program of training and supervision should be implemented before releasing such individuals for primary responsibility for these improvements. Most of these engineers do not have practical experience in designing watercourses and it is a complicated procedure to integrate all of the factors that must be considered in the design of the watercourse. The construction procedures commonly followed in Pakistan do not ensure adequate quality of the improvements and therefore it is necessary to supply these individuals with specific on-job training in supervising construction and maintaining the quality. There are also many factors that should be considered in obtaining agreement and the cooperation of the farmers. Practical techniques for obtaining farmer cooperation must also be developed or excessive delays and difficulties will be encountered. Even with all of these circumstances ideal the normal bureaucratic procedures that tend to evolve in the provision of funds and other facilities to implement the program will be a major deterent to farmers because of its interference with their water supply and resulting potential reduction in crop yields.

These experiences suggest that intensive training in design theory and implementation practices must be provided these engineers in order to ensure the adequacy of their designs and quality of their construction. They should also be provided supervision at a higher level which is capable of reviewing these designs and inspecting the construction process in order to maintain and ensure quality. This presumes the engineers will be involved in a Government sponsored program of technical assistance to farmers in improving their watercourse systems including lining and pucca improvements. Many of these watercourses need to be completely redesigned in order to deliver water at acceptable elevation and in a manner that results in maximum water supply to the area being served by the mogha. A high priority output of the CSU water management research program should be recommendations for a specific training program including course content and technical specifications, which will adequately prepare individuals for implementing watercourse improvement programs.

Due to bureaucratic delays in funding, unavailability of cement and cleavages between farmers, progress on the watercourses planned at Lar and Maraka has been slow. Three thousand feet of watercourse were built at Lar and 1000 feet at Maraka during the current year.

However a more comprehensive understanding of the problems that are encountered and the procedures that must be followed in order to implement watercourse improvements in Pakistan has been gained. In the remaining eight months

of the program duration, it is expected that more progress will be made in the actual provision of physical improvements in the field. The results of this experience should be an improvement in the understanding of the entire process.

Two employees of the Integrated Rural Development Program have just returned from Colorado State University where they completed academic requirements for an MS degree in agricultural engineering. These two students are in the process of implementing on-farm water management improvements on a watercourse in Pakistan as part of their thesis program to complete their degree requirements. These individuals have had excellent academic training as well as practical experience in Pakistan and they will now integrate these expereiences to attempt to implement a comprehensive program of watercourse improvement, precision land leveling and irrigation advisory assistance to the farmers of the watercourse. The watercourse has been selected, the farmers have agreed to cooperate in the program and the data collection process has been initiated. A major portion of the program will be completed during the Rabi season including a data collection program on attempts to schedule irrigation water and improve on-farm practices as well as improve a watercourse through farmer cooperation. In order to complete their MS degree requirements considerable factural data must be collected on the processes of obtaining farmer cooperation and the benefits and costs of the improvements on the watercourse. It is hoped that this particular effort will provide considerable data on the benefits and costs of improved on-farm water management practices in Pakistan.

There has been appreciable progress on the "research components" of the project which are discussed in detail in the technical sections of this report. In brief, watercourse losses in the Shadab and Lar areas were found to dissipate from 30 to 70 percent of the water delivered at the moghas. New watercourses with compacted banks were found to have losses only 10 to 30 percent of losses in old watercourses. The cost of water saved by building new watercourses, or new banks on old watercourses was determined and found to be far less expensive than the cost of buying tubewell water.

Agronomic studies showed that good fertilization and proper timing and amount of irrigation could more than double yields while using only about 50 percent as much water as was applied to adjacent fields. Loss of water from the soil was found to coincide closely with potential evapotranspiration estimated from evaporation pans during the rabi season - probably because the soil was almost constantly wet during this season.

d. Irrigation Scheduling for 1974/75 Wheat in the Punjab Province

Recent water shortages in Pakistan prompted numerous water saving efforts. One such effort was devising a computer program for scheduling irrigation of wheat in the Punjab. Program inputs consisted of daily calculations of Penman's potential evapotranspiration, consumptive use coefficients relating actual ET to PET as a function of days from planting, a soil moisture withdrawal factor relating rate of evapotranspiration to the availability of soil moisture, influence of soil texture on available soil moisture, rooting depths with time for various soil textures, and growing season and stage of crop growth.

Intensive testing is required to prove the reliability of this program. The extension of the methodology to other crops appears feasible if data is available for the necessary inputs. (See Appendix 38, which discusses this topic in the context of preventing waterlogging and salinity.)

e. Economics of Improved Soil and Water Management for Fodder Production in the Shadab

The Water Management Research Sections of the Integrated Rural Development Project (IRDP) and Colorado State University (CSU) in Pakistan are cooperating in a series of practical studies on farmers fields aimed at defining improved agronomic practices for all the major irrigated crops and to introduce the most profitable improvements to the farmer for his acceptance. The present paper deals with a first attempt to gain acceptance for improved practices in fodder productions.

Demonstration plots with fodder crops of maize and sorghum were laid out on private farmers' land in the Shadab Pilot Project near Lahore. Fertilizer and farm water management improvements were included in the trials. Local water supply problems minimized the water management inputs but fertilization almost doubled the production of fodder. The cost/benefit ratio of the suggested improvements for maize fodder was 100:647 and that for sorghum was 100:738. These values should carry sufficient weight to motivate the farmer into a change of practice once the new techniques have been introduced to him. (See Appendix 39.)

f. Need for On-Farm Water Management Training Program

The purpose of this discussion paper is to examine the need for trained personnel to work intensively with farmers to improve their on-farm water management systems and irrigation practices. Much of the effort devoted to water management research in Pakistan by Colorado State University (CSU) has focused attention on the poor condition of on-farm

watercourses and farmers' irrigation practices. USAID/CSU results indicate that the majority of the water losses occur not in the major distribution systems, but after the water passes the mogha and enters the watercourse. While considerable resources have been invested in improving major canal distribution systems and providing additional water storage, almost no resources have been invested in improving on-farm watercourses, land leveling, and training farmers to efficiently utilize their scarce resource of water. The forthcoming USAID-GOP "On Farm Water Management Loan" is designed to channel resources into the previously neglected on-farm watercourse level sector. However, unless specific steps are taken to train personnel to work at the on-farm level, the "Water Management Loan" will not produce the desired results.

The focus of this paper is on the training of the extension field workers who will be required to help implement the on-farm aspects of the USAID-GOP "Water Management Loan" and who will teach farmers how to maximize benefits gained from physical watercourse improvements. This extension worker can help the farmers to more effectively use the services offered by other technical departments such as the Precision Land Leveling Program (PLLP), the Agricultural Development Bank, or WAPDA (SCARP). He will remain at the farm level to advise and assist farmers individually and collectively to continue to improve their farming methods and maintain their watercourse system for increased farm production. (See Appendix 40.)

g. Development of Training Materials

Initial efforts have been undertaken to develop training materials for use in Pakistan; however, much of this material is, and will be, just as appropriate for training in any irrigated region of the world. The first basic step in improving water management for increasing crop production is one of problem identification; then, technological solutions can be developed to overcome system constraints. However, the real difficulty lies in, "How do we implement appropriate technologies?" Besides an entire host of institutional requirements for successful implementation, it is recognized that nothing can be implemented without well-trained host country personnel. Graduate study in the U.S.A. is only a small partial answer--the real solution lies in on-site training, both in the classroom and in the field, with the major emphasis to be placed on field experience.

To date, training materials have been developed regarding water measurement in watercourses and from tubewells, soil moisture determination in crop root zones, and surveying of watercourses and irrigated lands. (See

Appendices 3,4,5,21,22,23,24,25 and 26.) These materials are particularly useful in problem identification. This work will be continued.

The development of training materials becomes more and more important in Pakistan as we near the initial implementation phase for improved on-farm water management in Pakistan. There is a rapidly growing need for well-trained on-farm water management personnel in Pakistan.

10. Objective 7. Where water quality, soil salinity, and exchangeable sodium are problems, means will be developed for increasing crop production by using amendments and management practices which will improve water and soil properties and by using salt tolerant crops.

a. Farm Water Management Effects on Waterlogging and Salinity in Pakistan

Pakistan has given a high priority to solving the waterlogging and salinity problems in its irrigated lands. Such solutions must be based on the development of a water budget and its components for these irrigated areas.

Equations describing the general water balance of this area are presented along with assumptions upon which their derivations are based. Using data from the Mona Reclamation Experimental Project, a complete water balance is developed for project years 65-73 and for conditions preceeding project establishment.

Water balance analysis indicated that much water is wasted through watercourse losses and ineffective irrigation practices. While more refinement on the Mona water budget analysis is required the results suggest that waterlogging could be improved by reducing canal supplies to areas with good quality groundwater, improve farm water management to reduce losses of the present supply, and to increase pumpage as cropping intensity increases. This would result in a lowering of the water table and an increase in the annual recharge.

Similarly, a salt balance for each area must be achieved in Pakistan. The first prerequisite for a salt balance is a water balance. If the water balance is achieved and understood, proper management of its components can result in a salt balance. (See Appendix 41.)

b. Irrigation Scheduling for Waterlogging and Salinity Prevention

Over-irrigation in both quantity and frequency are important contributing factors to waterlogging and salinity.

Numerous field measurements in the Punjab of Pakistan have indicated the common occurrence of over-irrigation. A number of causes for this occurrence include fields that are not level, use of irrigation methods not adapted to the crop being grown, the application of water on fixed schedule determined by the warabundi and the farmer's attempt to compensate for an unknown future by applying available water now when future supplies remain uncertain.

Irrigation scheduling, the determination of when and how much water is needed by the plant and soil system, periodically throughout the cropping season, is a straight forward, simple approach to reducing the over-irrigation which leads to waterlogging and salinity. The methodology, input data requirements, and results of irrigation scheduling for the rabi wheat crop of 1974-75 are presented. The institutional arrangements necessary for implementing irrigation scheduling are discussed as are the relationships to other water management improvements possible in Pakistan. (See Appendix 42.)

11. Objective #8. Identification of institutional and policy factors (legal, social, economic, religious, manpower, credit, education, etc.) which influence efficient distribution, management and utilization of water on the farm level

a. Water Management Alternatives for Pakistan - A Tentative Program

Although the integrated irrigation system in the Indus Basin is the world's largest, it operates at only 30 percent efficiency, most loss occurs in the watercourses.

A proposal is presented for an effective water management program consisting of watercourse improvement, precision land leveling, and irrigation and irrigated cropping extension. The first two elements are discussed in relation to five different types of watercourses; I - normal watercourse (400 acres, 1 cfs/350 acre), II - heavier discharge watercourse (700 acre, mogha discharge = 2 cfs), III - heavier discharge watercourse (530 acre, mogha discharge = 2 cfs), IV - tubewell supplemented watercourse (operating at 65 percent capacity, V - tubewell supplemented watercourse (operating at 40 percent capacity).

Water saved through a farm management program can be evaluated according to its subsequent use; the most likely uses being more frequent irrigation of existing acreage and irrigation of new acreage. Based on anticipated future fertilizer application, semi-dwarf wheat response is plotted against number of applications. Using current wheat prices, the value of water saved through a management program averages Rs 356/acre ft.

Watercourse improvements are discussed and cost estimates and benefit-cost ratio presented for lining channels, type and design of lining, type of reconstruction and maintenance of earthen canals, and maintenance only for earthen channels. For main channel linings trapezoidal-concrete gives a higher benefit-cost ratio than the rectangular-brick construction; the highest ratio is for the type IV watercourse. For reconstruction of earthen watercourses, manual reconstruction gives a higher benefit-cost ratio than mechanical reconstruction. Manual reconstruction of a type IV watercourse with a three man maintenance crew allows the highest ratio (22.5). Simple maintenance alone, using a three man crew, saves 307.3 acre ft. of water on a type IV watercourse with a benefit-cost ratio of 20.3.

The benefits of precision land leveling are discussed and estimates made of the benefit-cost ratio. Again the highest benefit-cost ratio is for a type IV watercourse (3.23); the lowest ratio is for a type II watercourse (2.35).

The role of irrigation extension is dicussed as is the need to educate the farmer in plant-soil-water-nutrient relationships in order to utilize the advantages of watercourse improvement. Finally, the necessity and benefits of organizing water users associations are presented. (See CSU Water Management Research Project Technical Report No. 43.)

b. Institutionalizing Water User Organizations in Pakistan

The water laws of Pakistan have remained in a static state for a number of years. Law, like the society for which it is adopted to guide social conduct, should be dynamic and unconstraining. Unfortunately, there is no process in Pakistan nor in most other nations for a systematic review on the adequacy of the law. This report is an attempt to take one particular aspect of the law and examine it against the existing conditions and changing times.

The legal analyses of the status of local water user organizations in Pakistan and selected countries has led to the following conclusions.

1. Pakistan has no formalized pattern of local association or organization concentrating upon water use and conservation.

2. The laws and regulations for water use as well as the design and operation of the water delivery system do not encourage creation of cooperative efforts among water users at the farm level.

Three major reasons exist that compel the majority of water users to merely function in the system: a) the rigidity in rotation of canal water delivery, yet unpredictability in water delivery to the farmer; b) noninvolvement of the farmer in the decision-making process of canal delivery, subsequently leading to an inability to influence control over one of the most vital elements in agricultural production, or to adopt a planting and harvesting schedule in which the plant water requirements are timed to coincide with predicted water availability; and c) legal sanctions against water trading and selling inhibit the users from freely maximizing the supply within the watercourse area.

3. The Government of Pakistan has accorded high priority to the development of some structural type of local water user organization.

4. No insurmountable constraints are detectable in either legislative or customary water laws of Pakistan. In fact, research into old irrigation systems of other Islamic nations, and in particular the Moslem influence upon the irrigation communities of the once Moorish controlled portions of Spain, clearly indicate an established pattern of water user collaboration to control and manage the resource.

5. Several general laws of Pakistan can serve as the legal foundation for implementing the concept of water user associations; however, it is recommended that specific legislation be adopted to sanction their formation and provide adequate legal authority.

6. The formation of local water users associations would provide the institutional framework for improving irrigation efficiency and increasing agricultural production by:
   a) getting farmers directly involved in the local decision-making process;
   b) managing water delivered to the watercourse, thus improving timing and conveyance throughout the chak;
   c) solving some problems of small farmers and resolving disputes between users;
   d) serving as a vehicle and forum for disseminating information and assistance on improved water use and agricultural practices and technologies;
   e) constituting a legal contact point between the government and water users; and
   f) offering opportunities for increasing labor intensive agriculture.

7. A range of organizational schemes exist that serve to illustrate users involvement and programs in local water control and management and from which basic models can be developed acceptable to the needs of the Pakistani farmers and consistent with the policies and programs of the government.

8. The scheme of water user associations:

   a) must be an endogenous entity structured and tailored to coincide with the religious, social, political, economic and legal systems of Pakistan;
   b) should commence with a simple, nonsophisticated organizational arrangement having the attributes of flexibility and completeness to allow evolution and maturation as intra-watercourse demands and development take place; and
   c) can be designed for hierarchical evolution to achieve interwatercourse collaboration in water management, and undertake development on improvement programs of a greater magnitude or complexity than the "first level" entities.

9. Based upon an examination of local water organizations in five countries, it is concluded that effective water control and management is facilitated by having an expeditious institution for equitably resolving disputes (e.g. the Tribunal of Waters, Valencia, Spain).

10. The success of any agrarian program with objectives of enhancing the quality of rural life and meeting national food production requirements depends upon a strong water policy to increase delivery and application efficiency, encourage conjunctive use of surface and groundwaters and activate structured collaboration of local water users in improved water management. Such objectives and policies require an awareness of policy-makers and government officials of the conditions and constraints to change of the water users. Conversely, the image of government officials and personnel in relation to the water users must be improved by their demonstrating an appreciation and understanding of the problem.

Reexamining the basic proposition of improving on-farm water management in the Indus Basin, the following recommendations are offered to develop and institutionalize the concept of water users associations in Pakistan:

1. The institutionalization of water users associations requires a simultaneous effort at both the macro

and micro levels. It is recommended that a government agency be established or designated at the macro level with responsibility for developing and administering programs designed to assist the farmers, such as watercourse rehabilitation, land leveling, insuring dissemination of vital information on water availability and delivery schedules, improved practices and technologies and with authority to negotiate and contract with water users associations for implementation of such programs. The entity, in addition, should be the liaison between the micro level efforts of the associations and other provincial and national agencies with responsibilities and programs in water and related resources.

2. Induce the establishment of associations through governmental incentive programs, as opposed to penalty or enforcement techniques.

3. Permit a wide degree of variations in organizational scope of authority so as not to restrict or constrain future development (i.e., allow the organization to start from an embryo and mature as the needs arise).

4. Draft a charter stating policy and purpose of organization.

5. Include in the objectives the goal of improving efficiency in water delivery and use from ground and surface waters and prevention of excessive return flow.

6. Formulate rules and regulations for operation and maintenance of association works.

7. Allow the association to levy assessments for the operation and maintenance of the system as well as providing a portion of these assessments for a capital improvement fund, and empower the association to collect water charges such that individual and collective (community) responsibility can materialize, and perhaps even eliminate the propensity for corrupt practices.

8. Failure to pay assessments or for other material infractions should result in the loss or suspension of the right to receive water and voting privileges.

9. Draft bylaws for administrative functioning of the association.

10. Provide the association with jurisdiction over main and minor watercourses within the command area.

11. Prohibit associations from becoming involved in politics.

12. Establish internal organs of the association to permit greatest amount of farmer participation in decision making (an assembly of users), a managing body (executive organ) and body to resolve disputes quasi-juridical in nature. Ensure equitable representation of all members through graduated voting rights, rights which would extend not only to the operating landowners but also tenants.

13. Provide for obligations, rights, and liabilities of association members.

14. Create the recognition of the right of each member to share of his water and provide for the enforcement of such right consistent with the Islamic concept of equitable apportionment.

15. Provide means of enforcing charter provisions and rotating directorship.

16. Technically assist the association in delivering water to the shareholders in due time, place, and amount when water is needed by the plants.

17. Keep use of water by the association consistent with the ability of the Irrigation Department to deliver water, although it may be necessary to modify the customary practices of water use within the watercourse, i.e., shifting within the types of warabundi - pakki, kachi, rosewari, nakka by nakka, or reverse warabundi.

18. Defray or minimize, through cost sharing, the initial and subsequent costs of improving the use system.

19. Induce and/or assist cultivators in the installation of turnouts or gates at the nakka in place of the present practice of removing the dirt. The organization should provide a ditch rider who is the only employee (or his organizationally designated assistant) who can open and close the nakkas.

20. Consider, and where possible, induce the conjunctive use of ground and surface waters (e.g. give the association the authority to realign major and minor watercourses but within the constraint of water delivery through the mogha and tubewells where they exist).

21. Assist the members through financial and educational means (which in turn requires a training program for extension-type personnel) to learn of, provide for, and implement improved farming and irrigation practices.

22. Extension and training efforts must be directed not only to water users, but also the water purveyors.

23. Provide for an integrated hierarchial organization among user associations to accomplish various magnitudes of development.

24. Establish at the federation level, an independent juridical body, consisting of association presidents, to resolve water disputes within the federation command area.

25. Develop a line of communication to the provincial and national governments either through a hierarchy of associations or a new or existing governmental agency particularly concerned with rural affairs.

26. Permit the divisional canal officer and other nonirrigator types as impartial technical advisors to the association with no voting power.

27. Strengthen the authority in the Canal and Drainage Acts that presently exist regarding the rights and responsibilities of divisional canal officers to inspect delivery systems at the farm levels, i.e., from the mogha onward.

28. Examine the impact of land tenure practices and regulations upon proposed program of improved water management.

(See CSU Water Management Research Project Technical Report No. 36.)

c. Water Management Research in Arid and Sub-Humid Lands of the Less Developed Countries--Near East and South Asia

Water management problems of irrigated agriculture are discussed. The role of effective management planning and practice in achieving problem solutions is stressed. Preoccupation with delivery systems and the almost complete neglect of related cultural considerations, farm machinery, marketing systems, institutional administration, etc., has delayed the acceptance of the total management concept in most LDC's.

As part of total management, irrigation systems design must start with the farm subsystem and an understanding of the relationship between water and the various farm cultural and water management practices, the economics of cropping systems, market demands, the availability and cost of water, and crop water requirements. Upon these considerations are based the design of the farm irrigation layout which in turn determines the design of the water delivery subsystem. Management of such irrigation systems require satisfactory legal mechanisms for water delivery control.

The history and extent of Pakistan's irrigation system and system management are discussed with the conclusion that the irrigation management and farming practices require modernization of the production potential afforded by Pakistan's favorable climate and soils.

A description is included of the current major CSU activities in Pakistan including their role in the WAPDA Experimental Reclamation Project, the Integrated Rural Development Program, Water Management Loan, WAPDA's Watercourse Survey, increasing the emphsis on soil-plant-water research, and other activities.

An evaluation is given of the potential for increasing production and water management's contribution. Technological practices are suggested for the improvement of irrigation watermanagement. An evaluation is given of CSU's program evolvement and the thrust of the research program over the next few years in the areas of improved water management and economic and institutional analysis.

A successful CSU Water Management Research Project should lead to a national program of improved water management. This includes the development of a general methodology for preparing a water management strategy which integrates agronomic, engineering, economic, legal, and sociological methods of analyses. (See Appendix 43.)

d. Physical and Socio-Economic Dynamics of a Watercourse in Pakistan's Punjab

The purpose of this exploratory study was to identify and describe major physical and socio-economic constraints confronting farmers on one watercourse in their management and use of irrigation water for crop production. The general assumptions which undergird this study are: 1) farmers' constraints at the watercourse level constitute a complex system and can best be identified by a team approach; 2) farmers' responses to physical, legal, social, and economic constraints are rational and can be described; 3) in order to understand farm level irrigation conditions and practices, it is necessary to collect information from farmers about their individual and collective actions and opinions; and

4) water management improvements must be supplemented by many complementary inputs and services if they are to contribute to increased crop yields per acre.

This state-of-the-art study of farmers' problems and practices on one watercourse in Pakistan is presented as another attempt to understand farmers' irrigation problems. These problem identification studies are action oriented leading to problem solution. As an example, after the survey was completed, farmer cooperators were carefully selected for demonstration of maximum yield wheat plots. These trials were conducted to compare farmers traditional practices with improved water management and other cultural practices. On level fields, farmers' results with traditional 50 lbs. of nitrogen per acre and usual irrigation practices were compared with a treatment of high fertilization and irrigation applications according to soil moisture depletion. From 100 to 150 lbs. per acre of nitrate and from 37 to 75 lbs. per acre of P_2O_5 was used. The increment in yield due to increased fertility and improved irrigation applications averaged 24.5 maunds for Chenab 70 variety and 17.0 maunds for S.A 42 variety. These yield increases, which were double farmers' traditional yields, were accomplished with 25 to 50 percent less water than the farmers usually applied! Such actions leading to visible crop yield increases through improved water management practices and complementary inputs tend to speak loudeer to farmers than any of our reports.

The results of this study reflect the conditions for only one watercourse in Pakistan. However, the results are so startling in some instances and consistent with other published data in other instances that a number of recommendations seem necessary and worthwhile. These are:

1. Farmers in Pakistan must be provided with information and procedures for maintenance of the existing and improved system.

2. Farmers need to be provided with incentives to organize in order to improve water delivery by legal means, through institutional encouragement from the Irrigation and Agriculture Departments, and through assistance to farmers who have organized and made improvements. The same farmer organization should provide for regular, frequent (daily) maintenance of existing and improved watercourse systems.

3. An effective extension program must be developed to provide services to the farmer such as seeds, fertilizer, insecticides, and knowledge for improved crop production and proper use of irrigation water. This program must evaluate and

improve, through a practical field training program, the existing organizations for extension and broaden the concept of extension to include multimedia communication and innovative approaches to obtaining farmer confidence, cooperation and action.

(See Appendix 44 and CSU Water Management Research Project Technical Report No. 42.)

e. Physical, Economic, and Sociological Aspects of On-Farm Water Management on Sixteen Watercourses in the Punjab

The objective of this study is to identify and describe the major physical, economic, and sociological constraints faced by farmers in the watercourse system and demonstrate their relationship to low delivery efficiencies and poor crop yields in five cropping regions of the Punjab. This effort involves a comparison of irrigation efficiencies and behaviors between farms within watercourses and between farms in five agro-climatic zones. Selected physical, economic and sociological variables will be examined for their uses in: 1) the development of objective criteria for selection of watercourses for improvement programs; 2) analyzing problems of organizing farmers into water users associations; and 3) providing necessary information for training of on-farm extension advisory personnel.

The specific objectives of this research effort are listed below.

1. To evaluate and compare delivery efficiencies and farmers' application efficiencies in five major cropping regions of the Punjab.

2. To compare delivery efficiencies along with over- and under-irrigation patterns between farmers located at the head and tail positions of sample watercourses.

3. To search for sociological and economic factors which can be linked with differences in delivery and field application efficiencies and the propensity for farmers to collectively organize to promote their common interests in water delivery, control, and application.

4. To provide criteria which can be utilized for objective selection of those watercourses where farm and watercourse improvement activities will have the greatest likelihood of acceptance and payoff.

5. To provide a data base for subsequent development of guidelines for organization of farmers into water users associations--such associations are needed to provide watercourse supervision, improvements and maintenance.

6. To evaluate farmers' cultural practices, irrigation behaviors, and levels of farm management knowledge. This data base is viewed as important for improvement of farmer advisory programs and training of water management advisors.

7. To provide micro-level data about farmers' responses to constraints resulting from present water codes and regulations. This data can be utilized in suggesting changes which will provide incentives for more efficient distribution of water.

8. To evaluate various methodologies used in the present study for improved design of future studies.

9. To generate specific research hypotheses which can be examined in future water management studies.

(See Appendix 45.)

f. Watercourse Survey Handbook

This forthcoming publication will be number ten of a methodology series produced by the Colorado State University Water Management Research Project in Pakistan. It is designed to meet training needs of Pakistani's in conducting physical and socio-economic surveys of watercourses. This series is the natural outgrowth of needs in one country, but should have transfer value for other irrigated regions around the world.

The purpose of this statement about the handbook, which is now available in only draft form for testing in Pakistan, is to describe its contents. The handbook is now under revision for improvements as a result of recent experience in conducting sixteen watercourse studies.

This highly useful set of training materials and methods to be used in watercourse evaluations is timely because few if any materials have been brought together in a practical handbook for system analysis of on-farm irrigation water management. About 30 years of combined international work experience by the authors has taught them the importance of training. Until host country personnel are trained to conduct basic applied field research and implement findings on the basis of objective

empirical data, technical assistance programs are fruitless. There is no greater need today than to build-up host country human resources required for increased agricultural production through action research programs. Any research project which does not have this goal, to put it more strongly, can be viewed as anti-developmental. The wise statement of a Chinese sage in centuries past sums up our philosophy and approach in preparing this handbook and other training and implementation guides: "To give a man a fish is to help him eat for only a day; to teach a man to fish is to assist him to eat always." This approach to research is in glaring contrast to that often undertaken for preparing reports which simply collect dust in some official's office. This practical philosophy also is one which focuses solely on developing human capital for making accelerated agricultural production possible. As foreign technical assistance workers, it means multiplying ourselves by working ourselves out of a job with time. What greater challenge is there in international development today? (See Appendix 46.)

E. Dissemination and Utilization of Research Results

1. Background

Facilities were completed and had gotten underway on the project, "Management of Heavy Clay Delta Soils for Multiple Cropping Under Water Control," which was a part of the Mekong Delta Soils Project, when the project had to be terminated on April 21, 1975. At the end of this report period, research had been underway for three years on the Water Mangement Research Project/Pakistan. In the last two years, most of the U.S.AID/Washington funding has been converted from supporting largely campus activities to mostly supporting field activities. In addition, the remaining funds being expended for campus research activities have been used for projects which are more sharply focused upon supporting field programs.

2. Vietnam

The primary intent of the project was that research results be submitted to the Mekong River Committee for use in future developmental planning for the Delta. This was accomplished by way of the annual review meeting and report. However, results were also disseminated by inviting and encouraging visitation to the site, through personal communication, etc. Since the previous reporting period, visitors to the site included embassy personnel, USAID/Saigon and USAID/Washington officials, FAO officials from Rome, IRRI personnel including their director, Ford Foundation personnel from Bangkok and Saigon, Consul General and staff from Cantho, etc. In addition, the site was visited

by numerous farmers and farmer groups. Reference was also made to the project through various television and radio programs.

Despite the premature termination of the project, it should not be termed a failure. Essentially, the project was apolitical; its ultimate objective was to feed people by providing research data on which to base future technological development.

Although the US sponsorship has ended, they left behind an excellent equipped research facility capable of fulfilling the objectives originally intended. In addition, through its association with a University, it can serve in the training of much needed professional agriculturalists.

During the short life of the project, most time and effort was devoted to developing the facility; actual field experimentation, although strongly emphasized, had to assume a secondary importance until the means of conducting research were available. Thus, during this period the research could be considered as a problem identification.

Based on the experience of the past two years, it becomes apparent that the two major constraints on developing a year-round diversified multiple cropping system are water control, including drainage, and low pH with the associated problems of toxicity.

The problems of water control become obvious in trying to grow upland crops during a wet season of excessive rainfall and periodic flooding and in a dry season where distribution systems are entirely lacking. Not so obvious was the effect of low pH. Attempting to establish certain upland crops during the dry season, when pH decreases and toxicity problems increase, proved more serious and difficult than originally perceived. Establishment of dry season upland crops may well depend on both variety selection and breeding and the development of management techniques (liming, fertilization, etc.) designed to reduce the hazards of acidity. It is in the areas of water control and soil acidity that future research should be focused.

3. Pakistan

a. Presentation to the Pakistan Planning Commission

Among the significant developments during the past year in Pakistan was the inclusion of on-farm water management research as a major item in the next 5 year plan with 200,000,000 Rupees of funding proposed. Largely on the basis of formal verbal and printed presentations made to

the Planning Commission of the Central Government by Colorado State University and Mona Reclamation Experimental Project personnel early in 1975, the Planning Commission, which sets priorities for proposed projects for the Government of Pakistan, placed on-farm water management as one of the high priority areas for Pakistan's future development.

b. FAO Sponsored International Conference on Waterlogging and Salinity Held in October 1975 at Lahore

The organizers of this conference requested that the CSU Water Mangement team present papers to this conference and participate in development of its recommendations. Papers presented included:

1. "Improved Water and Land Use Management Through Precision Land Leveling" by Ali, Clyma and Early.

2. "Improvement and Maintenance of Earthen Watercourses to Reduce Waterlogging and Increase Water Supplies for Crop Production" by Kemper, Clyma and Ashraf.

3. "Crop Yields and Rate of Salinization of Soil as Affected by Irrigation Water Quality Over Three Years" by deMooy, Bhatti, Cheema, Gill, Khalid and Rafique, Schmehl and Franklin.

4. "Irrigation Scheduling for Waterlogging and Salinity Prevention" by Early

5. "Farm Water Management Effects on Waterlogging and Salinity in Pakistan" by Ashraf, Clyma and Ali.

These papers and recommendations of the panels will be published in the proceedings of that meeting. The recommendations will emphasize the importance of improvement of waterlogging and salinity tnrough proper on-farm water management practices. Among these recommendations are a program of watercourse improvement in SCARP areas and in future SCARP areas, and a program of assistance to farmers to improve and maintain watercourses and improve their irrigation practices. Land leveling also received a high priority recommendation. The full text of these recommendations are expected to be available soon and these will provide a good impetus to the improvement of on-farm water management in Pakistan.

c. CENTO Panel Meeting on Optimum Use of Water in Agriculture Held in Lyallpur March 3-5, 1975

The organizers of this meeting requested the team and each of the members individually to participate in this meeting. The following papers were presented and several other papers by our cooperators were on this program.

1. "Watercourse Losses" by Clyma, Ali and Ashraf.

2. "Irrigation Scheduling for 1974/75 Wheat in the Punjab Province" by Early.

3. "Consumptive Use of Irrigation Water by Major Crops in Pakistan" by deMooy, Bhatti, Cheema, Khalid and Schmehl.

4. "Consumptive Use of Water by Wheat Under Optimum Management Conditions" by Haider, Farooqi and deMooy.

5. "Interaction of Irrigation and Fertilizer Application to Semidwarf Wheat" by Qureshi and Eckert

6. "Effects of Delayed First Irrigation on Yield Components of Semidwarf Wheat" by Nur-Mod'd, Ibrahim and Eckert.

7. "Wells for Skimming Fresh Water from Aquifers with Saline Waters at Greater Depths" by McWhorter and Kemper.

8. "Water Management and Nitrogen Fertilizer Movement and Utilization in Soils" by Kemper, Clyma, Ali and Haider.

These papers will be published by CENTO in the proceedings of this meeting.

d. Water Management Seminar and Field Day Requested by WAPDA

In July, in response to a request from WAPDA a seminar and field day were presented in Lahore by CSU and Mona project personnel to other personnel of WAPDA, the Irrigation Department and Harza Engineering International (consultant to WAPDA). The purpose of this meeting was to discuss watercourse losses and their measurement and give WAPDA personnel a full opportunity to see the watercourse loss and irrigation efficiency results and raise any questions or disagreements they might have. Data were presented by Mona and CSU personnel. After these presentations a number of questions were discussed and opinions expressed concerning the relation of these findings to the continuing and planned programs of WAPDA. On the next day, a field tour was conducted at which watercourse losses on a watercourse in the Lahore area were measured. Attending personnel participated in the data collection process. The results of the study conducted on this field day are available in an included list of brief reports. A major result of the seminar and field day was that WAPDA has now placed improvement of watercourses as their number one priority

for attention after allocation of Tarbela between the provinces has been settled. A concensus is evolving in WAPDA that the long emphasized waterlogging and salinity problems are primarily consequences of poor on-farm water management practices and that the best solution of the problem lies in better on-farm management of water.

As a result of this seminar the team was asked to send members to the Sindh (November 18-21, 1975) to help WAPDA, Harza and associated personnel calibrate their equipment, check their measurement techniques and plan their program for evaluating watercourse losses.

e. Army Farm Operators Technical Seminar October 16, 1975

The General in charge of Army Farm Operations requested that Kemper present a paper and lead a discussion on the topic, "The Future of Agriculture in Pakistan in Relation to Availability of Water". This presentation and discussion lasted two hours and was delivered to twenty-four officers in charge of operating the 100,000 acres of land farmed by the army.

f. Punjab Water Management Field Day (IRDP) Held in March 1975

This field day was attended by about 250 farmers and various guests including the Punjab Minister of Agriculture who delivered a rousing speech based on notes and printed information provided by the CSU party. Farmers were told they could increase their cropping intensity by 50 percent using the water they now have available by improving their watercourses, applying less water to each field and that proper fertilizer added to this improved water control could more than double yields per acre.

Dr. Lowdermilk has been conducting extensive surveys in Pakistan and one of his standard questions is how deep do plant roots grow? The farmers generally estimate from 2 to 6 inches. Lowdermilk had told us of this misconception which is surprisingly widespread among the farmers, including those in the area where we were going to hold this field day. We suspected that this misconception was a factor in their practice of irrigating whenever the surface is visibly dry. Consequently on the field day a pit about 3 feet deep and 6 feet long was dug immediately adjacent to a wheat field. When the farmers came to this site on the field day, shovels full of earth were dug from under the wheat field at 3 foot depth and passed to the farmers so they could break the soil apart and see the roots. They were then told that these roots helped supply water to the plants and that they did not have to irrigate

until the soil down in this root region became dry. Lowdermilk, who had not known the program of the field day was surveying on a watercourse about 3 miles from the field day site and asking his regular questions. He was surprised to find that the farmers now believed that roots went down to 3 or 4 feet. He asked them why they believed roots went this deep and found that a few farmers from this watercourse had attended the field day. They apparently discussed this surprising new idea with their neighbors, and even dug a few holes to see if it was true in their fields. The extensive spread of this new concept, activated by a 5 minute demonstration indicates:

1. that farmers learn quickly from these simple participation demonstrations and we should develop and test more of them.

2. That field days can be a surprisingly effective method of spreading concepts which can improve water management and crop production.

The results of the agronomic and watercourse studies carried out at Shadab were summarized in a field day report in Urdu. Over 1000 copies of this report have been distributed.

Another report prepared with CSU assistance and based on our cooperative studies was titled "Water Losses in Watercourses". This thirty page report in English has been widely distributed to Agriculture Department personnel.

g. FAO Request for Participation in 5th Session of the Regional Commission on Land and Water Use in the Near East

The CSU team has been asked to participate in this meeting and prepare a report on our work in Pakistan.

h. Action Program for Water Saving and Wheat Production

As the winter wheat season planting began during the Fall of 1974, it became obvious that the irrigation water supply situation was critically short. River flows were at their lowest in 90 years, and no stored water was available at either Mangla or Tarbella Dams. This also reduced power generation capacity which was affecting electrically driven tubewells. As planting fell behind, the country became very concerned about possible short falls of substantial magnitude in wheat production.

In response to this emergency, Dr. Eckert drafted an Action Program for Water Saving and Wheat Production which provided detailed recommendations on planting and cultural techniques in a scarce water circumstance. The bulk of these

recommendations were drawn from cooperative experimentation done by the Cereals Section, Punjab Agricultural Research Institute and CSU under the overall Fertilizer-Water Response Function trials. Varietal and fertilizer recommendations for late plantings were provided by CIMMYT's resident wheat advisor, Dr. Armando Campos. Dr. Clyma contributed sections on water savings possible by better channel maintenance and on the importance of foregoing or correctly timing the annual closure for repairs. Dr. Early contributed a section on irrigation scheduling and provided monthly recommendation charts throughout the season. (See Appendix 47.)

This report was adopted in its entirety and was widely distributed by the Special Assistant (Agriculture) to the Prime Minister among extension and agricultural personnel throughout the irrigated areas. A series of emergency meetings of Provincial and National ministers and other decision makers dealt with implementation of the program. National radio and press appeals were made and the specific technical recommendations were released when appropriate throughout the season.

In a related development, based on costs and potential returns calculated from the fertility-water response data, the Prime Minister announced that the fertilizer price had been lowered by 12.5 percent for a six-week period designed to stimulate nitrogen top dressing of wheat while it could still be beneficial.

i. Developing Manufacturing Capability for Field Equipment

The CSU Field Party has been working with Mr. M.L. Gill of the Bethlehem Technical Foundation to develop a local capability for manufacturing certain frequently needed pieces of equipment for water management research. This company now makes Parshall and Cutthroat Flumes, King tubes for soil sampling, slotted tube samplers, hook gauges and other equipment. These items have been thoroughly tested in farm and research station environments and perform as well as similar items manufactured in the United States. Bethlehem Technical Foundation is currently preparing sales and promotional literature in order to offer their services to supply this equipment throughout the country. In addition, manufacturing capabilities are being developed in the Lahore and Multan areas with other small private firms.

j. Use of Cutthroat Flumes

The first Cutthroat flume was installed in Pakistan during November, 1973 as a result of efforts by Dr. Wayne Clyma. This flume, which was developed by CSU with AID

211(d) funding for use in flat gradient channels, is particularly adapted to conditions encountered in Pakistan. This flume has gained rapid acceptance and its popularity is expected to increase.

4. Campus

The campus research program presently underway is directly supportive of water management research in Pakistan. Much of this research program is generalizable to situations in other LDC's. For example, agronomic research regarding nutrition imbalances caused by salinity, seedling moisture dormancy, seedling emergence, and use of water by plants from a water table has general applicability.

The development of predictive techniques for designing skimming wells for withdrawing shallow fresh groundwater is a major development by Dr. David McWhorter in the Agricultural Engineering Department. In addition, Dr. McWhorter is supervising a field research program in Pakistan funded by CARE, which is a field evaluation of the predictive techniques developed on campus. The combined results of the campus and field research will yield practical guidelines for designing skimming wells in Pakistan. These technological results will be combined with economic and sociological on-going studies to develop a skimming well development "package" appropriate to improved on-farm water management.

Dr. George Radosevich, who is a lawyer specializing in natural resources and environmental law, has spent considerable time studying water user (farmer) organizations in the western United States and many countries in the world. His efforts have provided the necessary framework for initiating a program of organizing the farmers on any particular watercourse in Pakistan into a water users association. This is a highly important aspect of improving on-farm water management.

The studies by Dr. Max Lowdermilk and Dr. David Freeman of the Sociology Dept., in cooperation with the CSU Field Party, particularly Dr. Alan Early and Dr. Wayne Clyma, have become extremely important in identifying the problems and constraints faced by Pakistani farmers in their attempts to improve crop production.

There has been a serious attempt by the on-campus staff of the Water Management Research Project, with representatives from Agronomy, Agricultural Engineering, Economics and Sociology, to undertake studies that will be highly supportive of the Field Party efforts.

A graduate training program has been developed at CSU particularly suited to the needs of this project. First of all, promising individuals in the host country already

possessing a college degree in the appropriate discipline are identified by the CSU Field Party for advanced training. These individuals must already be employed in a host country government agency which is cooperating with CSU. Agreements are signed by the individual and the agency where he is employed to insure his return. Then, the individual comes to CSU for academic training. Arrangements with the CSU Graduate School allow the individual to return home after completing the necessary classwork in order to undertake the necessary research for completing a thesis. Upon completion of the research, CSU Field Party members can conduct the final examination in the host country. The primary emphasis is upon M.S. and M.A. students. At the present time, there are two Vietnamese M.S. students in Agronomy, three Pakistani Ph.D. students in Agronomy and one Vietnamese M.S. student in Agricultural Engineering. During the previous reporting year, one Pakistani completed his M.A. in Sociology and another Pakistani completed his Ph.D. in Economics. During this year, one Pakistani Ph.D. student in Agronomy returned home, along with two Pakistani M.S. students in Agricultural Engineering; in each case, they are now doing their research in Pakistan. Two more Pakistani Ph.D. students in Agronomy will return home in early 1976. All three Vietnamese students are scheduled to complete all work, including research, by late 1975 or early 1976.

5. Reports, Papers, Speeches and Seminars

Research findings are printed in several forms for distribution to various audiences. In addition to these annual reports, findings are published in our Water Management Research Report series, as technical journal articles, in our Field Report Series, as informal reports for limited distribution, and as theses. Much of the material has been included as appendices to this annual report. A comparison of previous annual reports of this Water Management Research Project with this annual report (appendices and listing of reports, papers and theses) show a continued definite trend from campus to field activities. This annual report includes some of our initial efforts in developing training materials for use in on-site field training. More and more emphasis is being given to the development of training materials, most of which will also be highly valuable as we expand our efforts to other countries.

6. Research Award

In response to a call for papers by CENTO (Central Treaty Organization) Dr. Jerry B. Eckert analyzed the 1973-74 results of the water and fertilizer production response trials being conducted collaboratively with research colleagues at the Punjab Agricultural Research Institute. The resulting paper was presented at the CENTO sponsored International Seminar on the Optimum Use of Water in Agriculture at Lyallpur

DR. SARDAR A. QURESHI
Cereal Botanist
Punjab Agricultural Research Institute
Lyallpur.

DR. JERRY B. ECKERT
Agricultural Economist
CSU Water Management Research Project.
Pakistan.

NOOR MOHAMMAD CHAUDHRY
Assistant Cereal Botanist
Punjab Agricultural Research Institute.
Lyallpur.

The men you see are agricultural scientists. Their joint research* has given us a new method to raise wheat production in conditions of water scarcity.

The millions of farmers who will benefit from their research may never know their benefactors, but we believe that the achievement of these researchers must be recognized.

For this brilliant research these scientists have won the 1974 Fertilizer Research Prize. This prize, to be awarded annually, has been instituted for the first time in Pakistan by Dawood Hercules, to promote research on fertilizers leading to increased economic and physical returns to the farmers.

DAWOOD HERCULES CHEMICALS LIMITED

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"Water & Fertilizer Interactions in Wheat Production." *Write to us for free copy.*

SV

in March, 1975. Entitled, Water-Fertilizer Interactions in Wheat Production, it was subsequently published in CENTO Scientific Paper No. 16. (See Appendix 37.)

In order to stimulate deeper, more practical research on fertilizer use, Dawood-Hecules, Inc., Pakistan's largest fertilizer manufacturer, initiated a nationwide contest for the best fertilizer research completed in 1974. Entries were received from most major Pakistani research institutions. The above paper was announced as the overall winner in June, 1975. The Rs. 5000 award will be divided equally between Dr. S.A. Qureshi, Noor Moh'd Chaudhry and Dr. Eckert, with the latter's share committed to purchase of recent reference materials in wheat agronomy for placement in the P.A.R.I. library.

F. Work Plan for the Coming Year*

1. Program Emphasis

As a result of the studies outlined above and reported in this complete annual report, several components for a practical on-farm water management implementation program have been defined. These include:

a. techniques to reduce losses from watercourses;
b. design criteria for precision land leveling;
c. land shaping, irrigation and fertilization practices which will double yields while reducing water applications 25 to 50 percent; and,
d. implementation procedures for gaining farmer acceptance and cooperation in united efforts to improve and maintain watercourses.

While these components can and should be improved, they appear to already have sufficient benefits to be accepted by the farmers and pay them a handsome return on their investment. The major focus of the Water Management Research Project during the coming months will be on a series of pilot watercourses where these components of the program will be delivered to the farmers and farmers' acceptance, adoption, and general benefits will be evaluated. Pakistani engineers, agriculturists, and extension personnel will be given implementation training and their performance will be evaluated. From these evaluations (and the solutions of practical problems encountered in the implementation) guidelines will

*The proposed work plan is the product of the CSU Field Party in Pakistan and on-campus personnel. However, a field evaluation of this contract will take place in Pakistan during January and February of 1976. The results of this field evaluation will be utilized to modify this proposed work plan for the time period April 1, 1976 to March 31, 1977.

be prepared for a watercourse and crop production improvement program tailored to the needs and resources of the Pakistani farmer.

These guidelines will be incorporated into the Water Management Loan program presently being planned by USAID and the Government of Pakistan.

2. Field Research

Colorado State University, in cooperation with the Mona Reclamation Experimental Project and the Agricultural University, Lyallpur, is in the process of developing recommendations for improvement programs for watercourses in Pakistan that can be translated into Urdu and made widely available to farmers in Pakistan. These proposed programs will be different largely in the amount of government support and supervision provided the farmers in the improvement of their watercourses. One publication is being prepared that gives several recommendations for a watercourse maintenance program that any organization of farmers on a watercourse can institute largely on their own incentive. The major emphasis will be on simple techniques for improving the maintenance of watercourses and with heavy emphasis on the benefits to be derived from such a regular maintenance program. The next level of assistance would be supervision provided from either the Extension Service or the Irrigation Department in which farmers would actually rebuild their watercourses utilizing several recommended techniques and then institute a maintenance program. The third component of this program, being tested as a pilot watercourse program, is the complete rebuilding of the main channels and branches with the installation of pucca control structures and then the institution of a maintenance program. Another major program will involve the complete renovation of watercourses and the rebuilding of either the pucca sections depending upon the particular circumstances of the watercourse as a part of a SCARP or a water management loan program. Other items included in this program would be a major assistance program from the government in supplying the farmers with technical assistance and financial incentives for organization and implementation of these improvements.

The information needed for these publications is: (1) the cost (rupees and labor);(2) the benefits (increased water supply and decreased seepage damage to crops) derived from various methods of watercourse improvement and maintenance; and (3) an evaluation of the personnel and training needed to "deliver" the improvement methods to the users and motivate the users to adopt the program.

This is the same information that is needed by USAID and the Government of Pakistan in developing their Water Management Improvement Program which is currently being proposed for Loan funding. This program, currently proposed for about 8 million dollars and an equivalent level of rupee funding would aid farmers in leveling their land and improving and maintaining their watercourses.

To date, we have evaluated watercourse cleaning and maintenance, new watercourse construction, augmenting banks to provide proper cross section, and compacting soil cores in watercourse banks. Low cost concrete control structures have also been developed. Each of these improvements has an apparently high benefits to cost ratio on the test sections or branch watercourses on which they were tested. However, farmer willingness to organize and do the work on our small test sections may be due to special positive relations between the extension agents involved and one or two influential farmers. The methods, their acceptance and the benefits derived require testing on full scale watercourses where problems of logistics and supervision can be met and solved.

Consequently, improvements are planned on a series of pilot watercourses under the Watercourse Improvement Project at Mona. The Extension Service will be enlisted in this project. We will evaluate how much of the technical information needed for watercourse improvement can be taught to field assistants, to agricultural assistants, and how much must be brought to the site by highly trained specialists in engineering, agronomy, etc. These pilot watercourses will also allow estimates of benefits/costs which will be closer to the actual expected in Pakistan than the data from the small scale research test sections.

These pilot watercourses will also allow the water management and crop production components of our team and their cooperators to field test their recommendations. This testing will also involve evaluating the degree to which the new recommendations can be taught to extension field assistants and delivered by field assistants to the farmers, or agricultural assistants to the farmers, or whether more highly trained specialists will be needed.

Printed materials to guide the extension personnel will be developed and evaluated. The actual functioning of water users associations compared with examples from other locations will be observed and recommendations will be developed for thier organization and operation.

This information will be put to use immediately as it is obtained to develop and later to refine the best possible development program for improving watercourses, water management and crop production in Pakistan.

3. Campus Research Support

The efforts in Pakistan will be supported on campus by a number of on-going efforts. The recent efforts of the Agronomy Dept. will be demonstrated in Pakistan beginning April, 1976. A Ph.D. student in Agronomy, Mr. Larry Nelson, will spend one year in Pakistan employing the results of campus laboratory research in field research and demonstrations under the supervision of CSU Field Party agronomists. In addition, both campus and field personnel will continue efforts in developing an agronomic practices "package" that can be implemented in Pakistan as part of the Water Management Loan Program.

Field studies on the skimming well project, which is partially funded by CARE, will be completed. This effort is under the direction of Dr. David B. McWhorter in Agricultural Engineering. The results of laboratory and field studies will need to be combined into a set of recommendations for both public and private tubewell development.

Dr. William E. Hart will complete his studies on nakkas for use in the watercourse improvement program. His laboratory efforts were tested in Pakistan during the summer of 1975 as part of his TDY assignment. More recent correspondence with the Field Party indicate very good results.

The economists will continue to evaluate the Pakistan results of water management and fertilizer field trials in Pakistan to determine the value of water for different crops. Studies will be continued to evaluate costs and benefits to farmers, particularly small farmers, for various improved water management practices.

The studies by Dr. George Radosevich regarding the institutionalizing of water user associations in Pakistan have been completed. Now, the emphasis will be placed upon testing various organizational arrangements among different watercourse users. This work will require an evaluation of field efforts, and the preparation of guidelines which will assist Pakistanis in their attempts to organize farmers.

The CSU Water Management Research Project has created considerable interest in on-farm water management in Pakistan. One of the significant outgrowths of this interest is the emphasis on developing more knowledge about the watercourses throughout Pakistan. The efforts by Alan Early and Wayne Clyma of the CSU Field Party in cooperation with Dr. Max Lowdermilk of the Sociology Department, as well as Dr. David Freeman of the same department, have been instrumental in providing essential information regarding farmer behavior and the water management constraints that he faces. The analysis of considerable field data will be completed during this

work plan period, with three reports being prepared. Upon completion of these reports, a short summary report will be prepared for U.S.AID which can be widely distributed throughout the world.

4. Future Goals

The CSU Water Management Research team should remain in Pakistan as long as the Government of Pakistan and USAID/Islamabad see a need for their services to help develop means to remove the physical and sociological constraints to improved water management and crop production and evaluate and refine the guidelines for the development program.

CSU may also serve a role with Pakistani institutions such as the University of Agriculture and the Agriculture and Irrigation departments in developing the essential technical training programs that will provide the required trained personnel for a nationwide water improvement program. This effort is outside the scope of the Water Management Research contract financed by TA/AGR, but is an expressed interest of USAID/Islamabad. A cooperative proposal from CSU and the University of Agriculture at Lyallpur to develop programs designed to give this specific training to the Department of Agriculture and Department of Irrigation personnel should be written and proposed to USAID/Islamabad for Mondale type grant funding. This project should be closely coordinated with the Water Management Improvement Program being developed by USAID/Islamabad for loan funding with the Government of Pakistan. For technical content, this training program could draw heavily upon the results from the pilot watercourse studies and other results of the Water Management Research Project.

The primary reason for centrally funded USAID research by Universities specializing in certain technical areas is the potential transferability of research from one developing country to another. To the extent that the findings in one developing country are transferrable to another, savings in time and expenditure can be achieved in the process of solving problems in the second and succeeding countries. The CSU Water Management Research Project is nearing the point where this thesis can and should be tested.

1. Efficient field methods have been developed for determining the potential for physical improvement. (Watercourse transmission efficiencies, water application efficiencies, salinity profiles of the aquifer, etc.)

2. Survey methods have been developed to gain information of adequate validity with minimum expenditure of time.

3. Specific techniques are being developed and tested in Pakistan which:
   a. decrease water losses from watercourses (i.e., compacted earth cores in watercourse banks, improved control structures for junctions, rebuilt and new watercourses, linings of various types) at reasonable cost;
   b. measure irrigation water adequately and evaluate crop consumptive use adequately to estimate over- and/or under-irrigation and give farmers advice on crop and water scheduling;
   c. allow use of farmers resources (labor, draft power, etc.) to improve his water transmission efficiency, his irrigation efficiency, crop stands and yields (by limited soil surface shaping); and,
   d. obtain water of optimum possible quality and amount from aquifers where salinity increases with depth, and so forth.

Within the coming years, most of the above techniques will have been adequately tested in Pakistan to ensure their usefulness for diagnosing and solving water management problems. These techniques should then be written for international use, and along with trained personnel, should be made available for use in other countries. Short term consulting assignments in other developing countries should be anticipated and welcomed by CSU Water Management personnel who have become "authorities" in vital subject areas of watercourse delivery efficiency, irrigation application efficiency, crop and water scheduling to optimize production on limited water supplies, water management surveys, etc.

APPENDIX 1

PHOTOGRAPHS
OF THE
MEKONG DELTA SOILS PROJECT

Figure 1. View of experimental site on Cai Khe Campus and surrounding area. Site is located in center of picture at the upper end of lake.

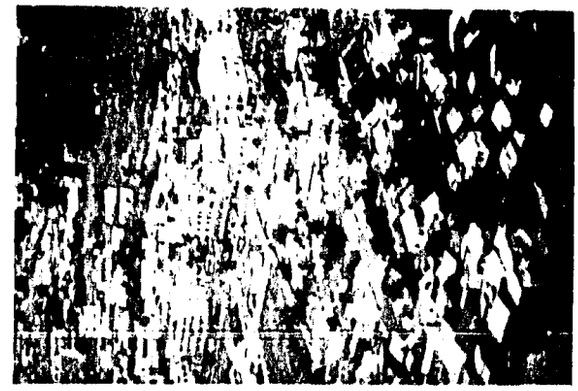

Figure 2. Part of city of Cantho. Project advisors residence (USAID Compound) located exactly in center of picture.

Figure 3. Pumping station located adjacent to lake.

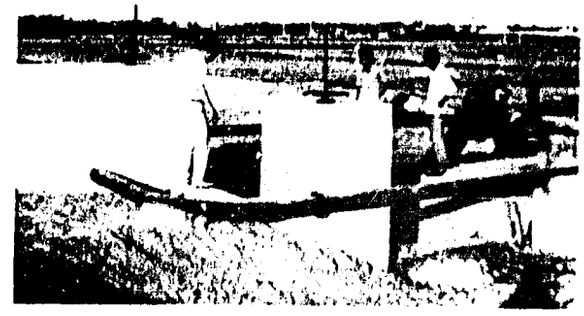

Figure 4. Pumping station showing gate structure for drainage, inclined axial flow pumps, pump engine, etc.

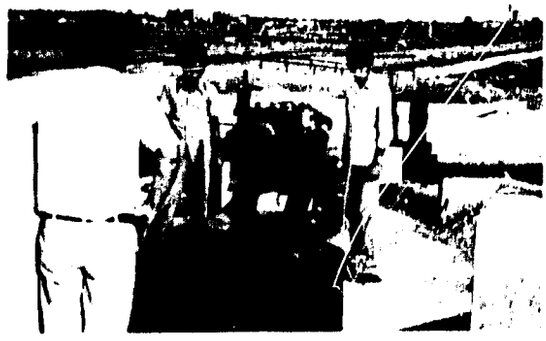

Figure 5. Pumping station showing pumps, diesel engine, valves, etc.

Figure 6. Pumping station in drainage operation. Seen is inclined pump draining 1/2 site.

Figure 7. Experimental site dike and fence.

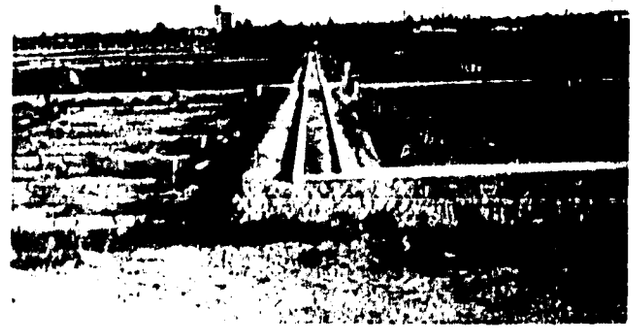

Figure 8. Main irrigation canal and laterals.

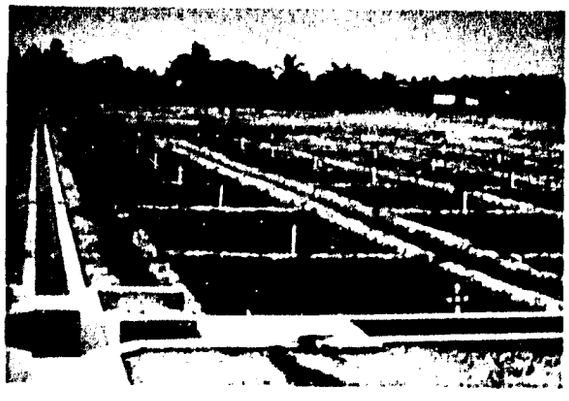

Figure 9. Main irrigation canal and laterals. Also shown is 75 day paddy rice-fertility trial.

Figure 10. Seventyfive day paddy rice-fertility trial. Center plots show phosphorus deficiency.

Figure 11. Hydraulic lysimeters during field installation.

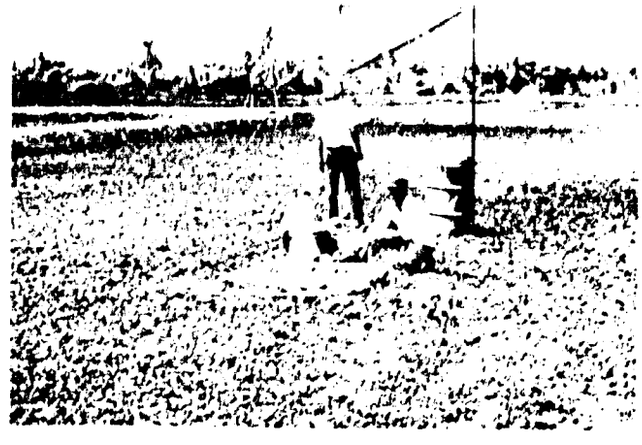

Figure 12. Calibration of lysimeters.

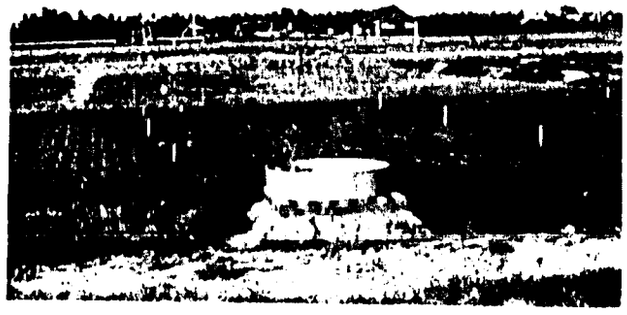

Figure 13. Class A evaporation pan installed adjacent to paddy rice-water requirement study. Pan was elevated because of periodic flooding prior to completion of dikes.

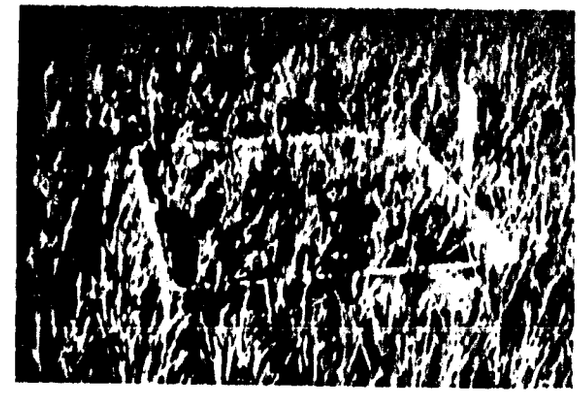

Figure 14. Tank B in paddy rice water requirement study.

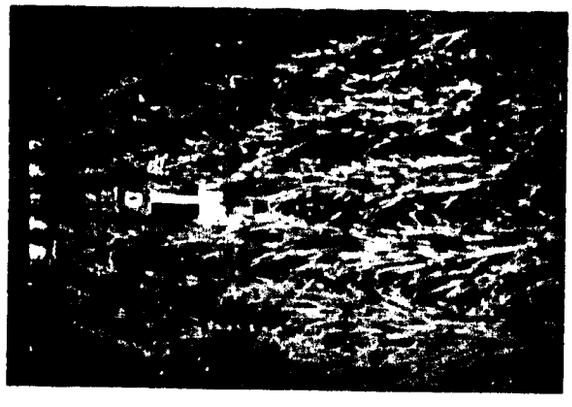

Figure 15. Tank C in paddy rice water requirement study.

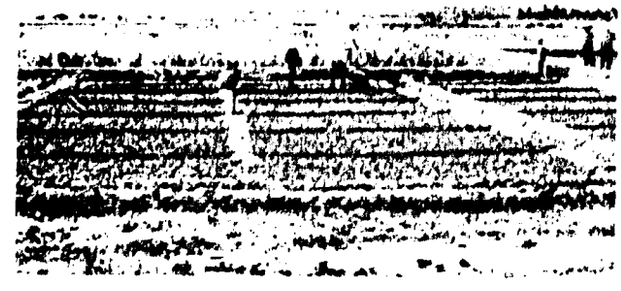

Figure 16. Planting green beans after paddy rice. Soil physical properties test.

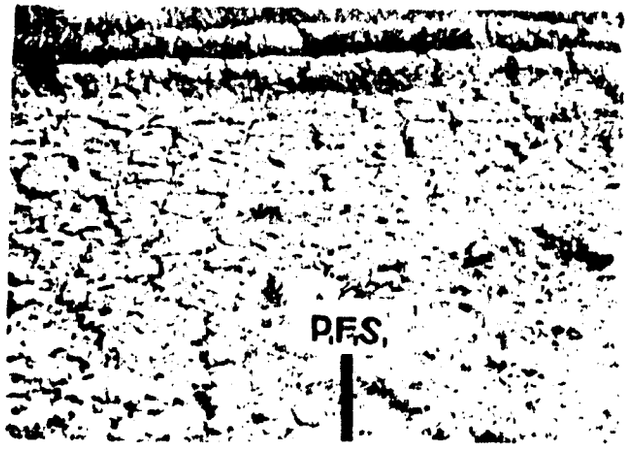

Figure 17. Cracking pattern on puddled soil.

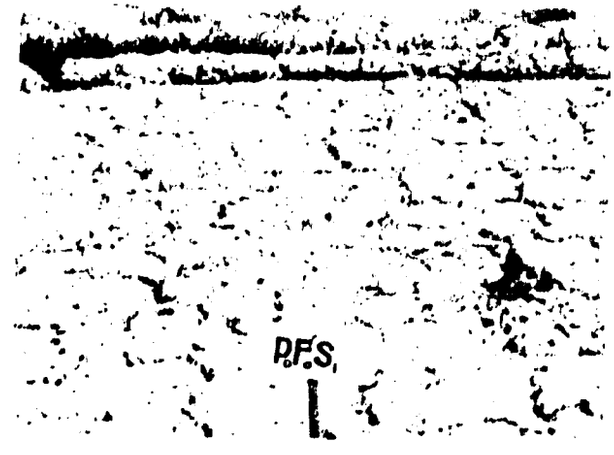

Figure 18. Cracking pattern on non-puddled soil.

Figure 19. Subsurface cracking.

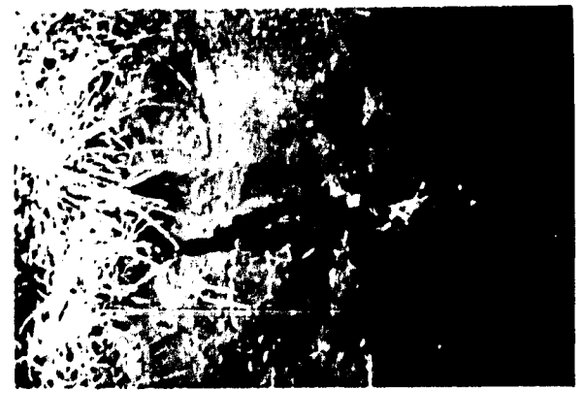

Figure 20. Subsurface cracking.

Figure 21. Soybean emergence experiment showing beds and treatments.

Figure 22. Soybean trial showing emerging seedlings.

Figure 23. Soybean variety trial.

Figure 24. Dwarf wheat variety trial.

Figure 25. Experiment on optimum moisture content for plowing.

Figure 26. Experiment on optimum moisture content for plowing.

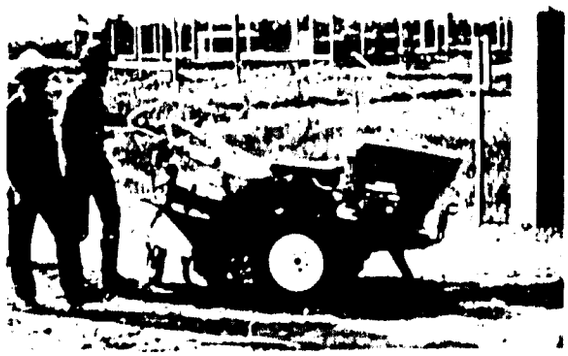

Figure 27. Locally purchased Kubota 12 HP diesel tractor.

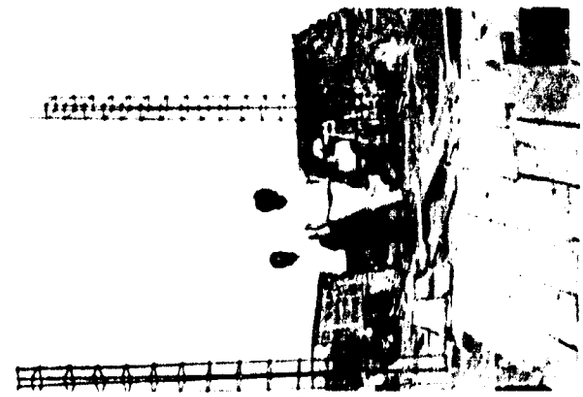

Figure 28. Initiation of building construction. Shown is Dr. Nguyen Viet Truong, Project Director and Dean of College of Agriculture; and project labor foreman.

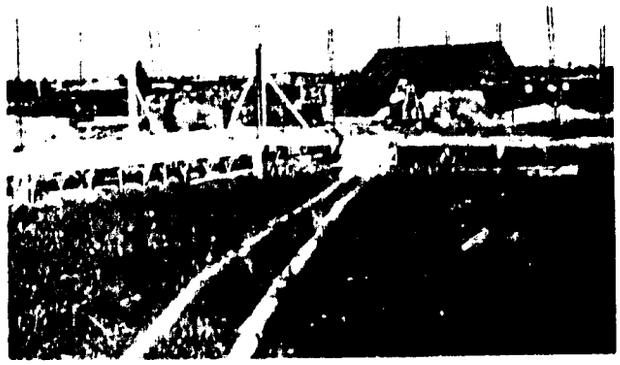

Figure 29. Building construction.

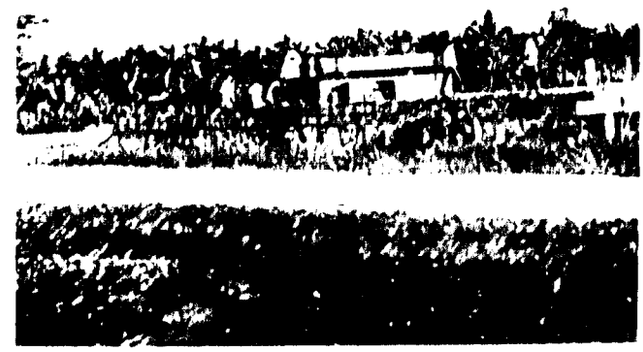

Figure 30. Building construction.

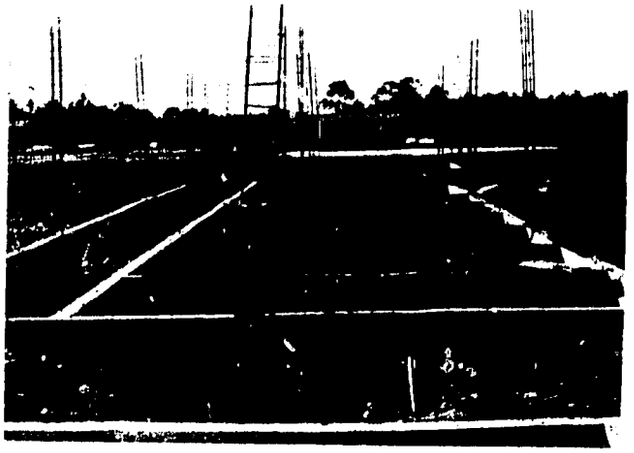

Figure 31. Building construction.

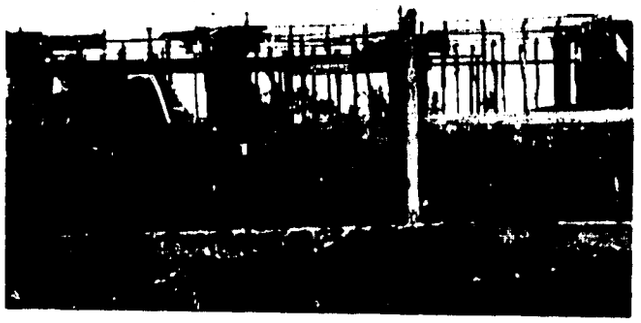

Figure 32. Construction of office and library building.

Figure 33. Construction of administration and office buildings.

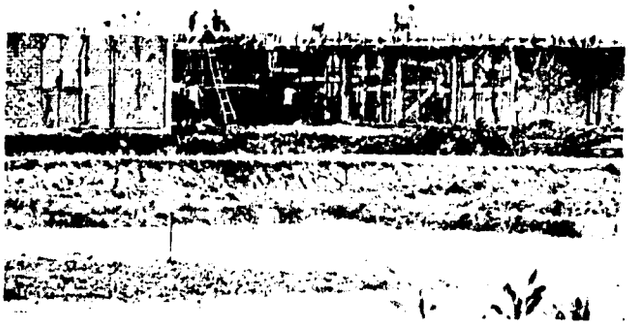

Figure 34. Construction of administrations, office and laboratory building.

Figure 35. Construction as viewed from site.

Figure 36. Off station sorghum-fertility-supplimental irrigation trial. Located on farmers field in floating rice area of An Giang Province.

Figure 37. Difference in plant height and color due to nitrogen deficiency.

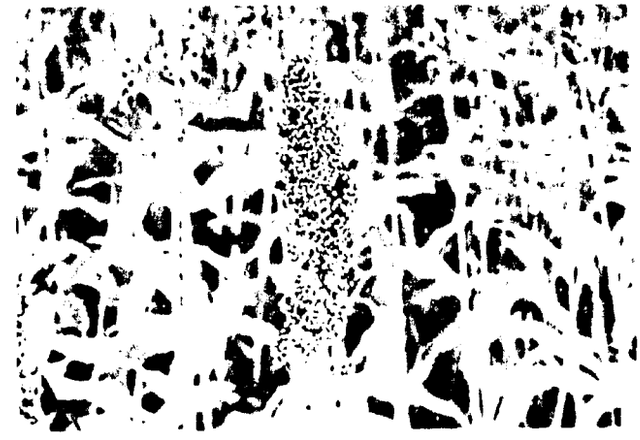

Figure 38. Typical nonirrigated Hegari grain sorghum head.

Figure 39. Farmers children in grain sorghum trial.

Figure 40. Portable weighing lysimeters developed for off-site work. Weighing done with strain gauge and bridge circuit.

Appendix 2

EFFECT OF WITHIN-FIELD ELEVATION DIFFERENCES ON COTTON STANDS AND YIELDS IN PAKISTAN

Mohsin Wahla & John Reuss

In order to better understand the effect of poorly leveled fields on crop productivity, the effect of elevation differences on stands and yields of cotton within 15 fields in the Mona Reclamation Experimental Project area is being investigated.

Fields were selected by Agricultural Extension workers during October 1975. Basis of selection was simply that the farmer was aware that a significant elevation difference existed within the field. Two plots, each twenty-foot square, were located so as to include the highest land within the field in one plot and the lowest land within the other. A middle elevation plot of the same size was selected between the high and low elevation areas. Extreme edges or dirt borrow areas were avoided and selection of the areas was made without regard to crop growth. In most cases elevation differences were determined by depth of water at the final irrigation. Where no irrigation was applied after plot selection, elevation differences were determined by means of a dumpy level.

The number of stalks within each plot area was counted, and the cotton harvested from each plot at each picking date was weighed and recorded. To date most of the plots have been picked three times. Data collected to date are summarized in Table 1.

The low and mid elevation plots respectively averaged 4.6 and 2.2 inches lower than the high elevation plots. Thus, about 4.6 more inches of water were applied to the low elevation areas than the high areas. Yield data collection is not yet complete but preliminary analysis indicates a definite and major yield difference due to elevation within the field. Yields are generally very low, but in all cases, the yields from the low elevation plots are below those of the high and mid elevation plots. Average yield from the low elevation plots is only about one-half of that from the high and middle elevation plots. The probability that this difference is due to chance is less than 0.005. There is an apparent reduction in stands on the low lying plots, but this difference is less consistent than the yield difference.

The data will be subjected to additional analysis after the data collection is completed. However, the effect of excess water on the lowest areas appears unmistakeable.

Apparently major yield depressions on significant portions of these fields are being caused by lack of adequate leveling.

Table 1

Effect of elevation difference within fields on cotton stands and yields (3 pickings).

Plot No.	Elevation difference High	Mid	Low	Stand High	Mid	Low	Yield High	Mid	Low
	-- inches* --			Stalks/400 Ft^2			lbs/acre		
1.	0	2.2	3.4	191	172	182	370	522	265
2.	0	3.1	4.7	120	108	82	291	443	269
3.	0	2.1	4.3	82	170	21	232	389	174
4.	0	2.0	4.0				291	160	58
5.	0	2.0	4.0				138	79	65
6.	0	1.0	3.0				450	291	196
7.	0	2.0	3.7	123	136	82	545	689	199
8.	0	2.5	4.0	38	34	28	302	384	98
9.	0	2.0	4.0	70	196	65	365	436	215
10.	0	3.2	6.0	77	76	41	545	806	178
11.	0	3.2	10.6	73	71	48	334	163	73
12.	0	1.5	4.0	96	78	29	291	204	87
13.	0	2.5	5.6	143	157	80	370	395	174
14.	0	1.5	4.0	180	87	80	482	552	225
15.	0	2.0	4.0	119	143	122	901	668	596
Means		2.19	4.58	109	118	72	390	345	191

*Elevation below highest point.

Appendix 3

SOIL MOISTURE DETERMINATION USING TOUCH AND FEEL METHOD[1]

Methodology Series Number Three

Alan Early and Wayne Clyma[2]

Practical field determination of soil moisture content is a technique that can be very useful to the agriculturalist who applies the irrigation water and the engineer who evaluates irrigation application efficiencies. One method of such field determination has been labeled in Pakistan as the "Touch and Feel" (TAF) approach and is an adaptation of the method presented by J. L. Merriam, (1960), (see footnote No. 1 below). This approach is not meant to replace field samplings and laboratory techniques, but is intended to supplement these techniques when a practical quick estimate is needed.

The attached table presents verbal descriptions of the appearance of the soil as it is tested. The basic approach is to first determine the texture of the soil. This is done by wetting a small handful of the soil and working it to a uniform consistency in the hand by squeezing and kneading it. A coarse soil when squeezed will leave moisture in the hand, the sample shows little cohesion and will not form a ribbon when squeezed between the thumb and forefinger.

A light soil leaves a wet outline on the hand when squeezed, shows some cohesion when manipulated, and will form only a very weak ribbon when squeezed between the thumb and forefinger. This very weak ribbon is never more than 1/4 to 1/2 inch in length.

A medium soil leaves a slighter wet outline on the hand when squeezed in the hand, shows definite cohesion, and will form a moderate ribbon up to one inch in length when squeezed between the thumb and forefinger.

A fine soil hardly leaves a moisture outline when squeezed in the hand, shows strong cohesion, and will

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[1]Adapted from "Field Method for Approximating Soil Moisture for Irrigation," by J. L. Merriam, TRANS. A.S.A.E., Vol. 3, No. 1, 1960.

[2]Agricultural Engineers, Colorado State University Water Management Research Project, Pakistan.

SOIL MOISTURE APPEARANCE CHART

Moisture Deficiency In/Ft	COARSE (Loamy Sand)	LIGHT (Sandy Loam)	MEDIUM (Loam)	FINE (Clay Loam)	Moisture Deficiency In/Ft
	(field capacity)	(field capacity)	(field capacity)	(field capacity)	
0.0	Leaves wet outline on hand when squeezed.	Leaves wet outline on hand; makes a short ribbon.	Leaves wet outline on hand; will ribbon out about one inch.	Leaves slight moisture on hand when squeezed; will ribbon out about two inches.	0.0
0.2					0.2
	Appears moist; makes a weak ball.	Makes a hard ball.	Forms a plastic ball;		
0.4			slicks when rubbed.	Will slick and ribbon easily.	0.4
	Appears slightly moist. Sticks together				
0.6	slightly. Very dry, loose; flows through fingers (wilting point).	Makes a good ball.	Forms a hard ball	Will make a thick ribbon; may slick when rubbed.	0.6
0.8		Makes a weak ball.			0.8
			Forms a good ball.	Makes a good ball.	
1.0		Will not ball.			1.0
1.2			Forms a weak ball.	Will ball small clods; will flatten out rather than crumble.	1.2
		Wilting point.			
1.4					1.4
			Small clods crumble fairly easily.	Clods crumble.	
1.6					1.6
1.8			Small clods are hard (wilting point).		1.8
2.0				Clods are hard cracked (wilting point).	2.0

Adapted from "Field Method of Approximating Soil Moisture for Irrigation by John L. Merriam, Transactions of the A. S. A. E., Vol. 3, No. 1, 1960.

sometimes ribbon out to almost two inches when squeezed between thumb and forefinger.

Once the basic textural group has been determined and proper column in table has been chosen the sample in the field moisture condition is examined. The procedure is to squeeze the sample into a ball (approximately 1 inch diameter) and to test this ball for strength. Its strength should be compared to the verbal descriptions in proper column of table to estimate the soil moisture deficiency in inches per foot of depth.

This chart assumes the average available soil moisture for the four textural classes as follows: coarse 0.7 inch/foot, light 1.3 inch/foot, medium 1.8 inch/foot, and fine 2.0 inch/foot. Division of each of these values by 12 and multiplication by 100 converts these values to percent available moisture on a volumetric basis. Division by the value for the dry bulk density of the soil converts to the available soil moisture range on a weight basis, the method most common for the gravimetric soil moisture determination procedure.

This method is only an estimation procedure for practical field use and should not replace precise measurements where these are needed. Each observer should calibrate his "touch and feel" as he learns the procedure and recalibrate his technique with the gravimetric technique from time to time.

Figure 1 is a sample calibration of the touch and feel method with the gravimetric soil moisture sampling technique. The irrigation evaluator must submit a similar graph of his touch and feel calibration on a weekly basis.

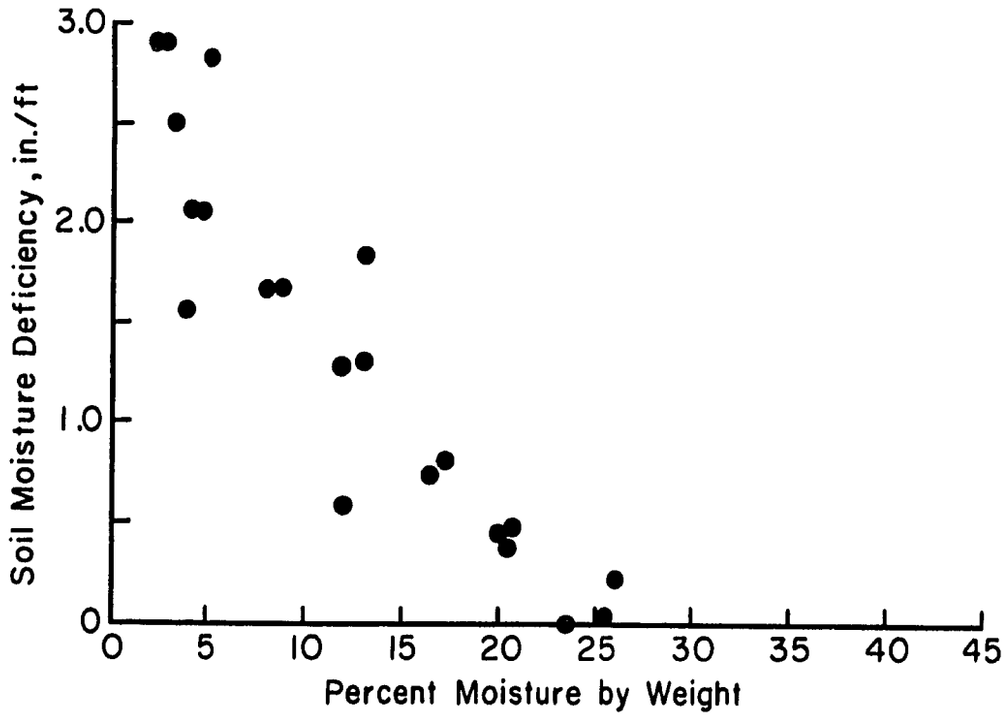

Figure 1. Sample Calibration of the Touch and Feel Method with the Gravimetric Soil Moisture Sampling Technique.

Appendix 4

GRAVIMETRIC SOIL MOISTURE DETERMINATIONS IN THE FIELD USING THE SUN DRYING METHOD[1]

Methodology Series Number Four

A. C. Early, W. D. Kemper, & Ch. Moh'd. Hayat Khan[2]

For the field worker, an electrical outlet and oven is not always available to dry a sample for the gravimetric method of soil moisture determination. An alternative procedure for drying the samples is to use the sun's energy, which is so abundantly available in Pakistan.

The procedure developed calls for the use of plastic sheets, or the same plastic bags in which the samples are stored, as the container to be exposed to the sun after the first weighing of the sample. The procedure of this step is to spread the sample out and break any clods present for maximum surface exposure to the sun and hence to minimize the required exposure time. The plastic sheets on which the sample of soil is also weighed should be 24 inch square 2 to 6 mil. polyethylene plastic. It is useful to weigh a hundred of these sheets before utilization to obtain the average weight of a sheet, as the sheet must be weighed with the sample in all subsequent steps. If a special weighing dish is used, the sheet need not be weighed. The alternative procedure, drying the sample in the same plastic bags in which the sample is stored after obtained in the field, requires the use of a larger plastic bag than is ordinarily used. The minimum size recommended is a 15" x 15" bag, so that the sides can be folded down to a two inch rim around the exposed sample. Since less surface exposure is obtained with the bag procedure than the sheet procedure, the bag procedure will require a longer exposure time for sun drying. The bag procedure has the advantages of requiring fewer containers in the field, where simplicity is a major consideration and of providing the sample from being lost to a sudden gust of wind or to accidental lifting of the plastic sheets. In selecting the type of plastic exposure container one must weigh the relative advantages and disadvantages of each technique. The average weight of the plastic bags is taken as with the plastic sheets.

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[1]Adapted to Pakistan conditions for Use in Field Irrigation Evaluations of Application Efficiency.

[2]Agricultural Engineer, Soil Physicist and Chief of Party, and Assistant Agricultural Engineer respectively, Colorado State University Water Management Research Project in Pakistan.

The following are the minimum exposure times required to bring the sample to within 1% of oven dry weight (after 24 hours at 105° Centigrade) before reweighing.

	Exposure Time	
Time of Year	Sheet Method	Bag Method
Hot Season	3 hours	5 hours
Cool Season	4 hours	7 hours

These tabulated times assume this number of hours of bright sunshine. On cloudy days or partially cloudy days, the drying cannot be conducted. On windy days the plastic sheet method should not be attempted and the bag method of exposure should only be used if the samples can be dried with confidence that no external soil or dust is being added to the sample. Overnight exposure of the sample should not be practiced, even in the hottest season, as this is the time of the year when dust storms are most frequent, and samples are readily lost if exposed at night.

The site at which the samples are exposed should be exposed on a roof or in a court yard, visible to the measurer and where minimal disturbance would occur due to the presence of dogs, birds, or children. Figures 1, 2, and 3 below provide the drying curves obtained from December (for cool season) and July (for hot season) calibration of the two methods for dry and wet sample (starting moisture content).

The bag method was not calibrated in the December, 1974, test. The suggested exposure time (seven hours) for bags in the cool season was estimated to provide a margin of safety for this technique.

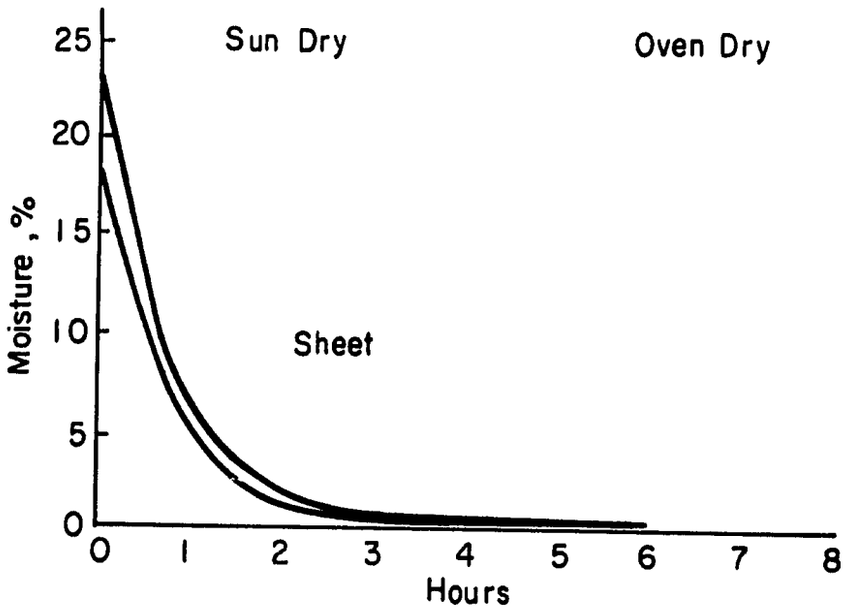

Figure 1. Wet Sample (December, 1974)

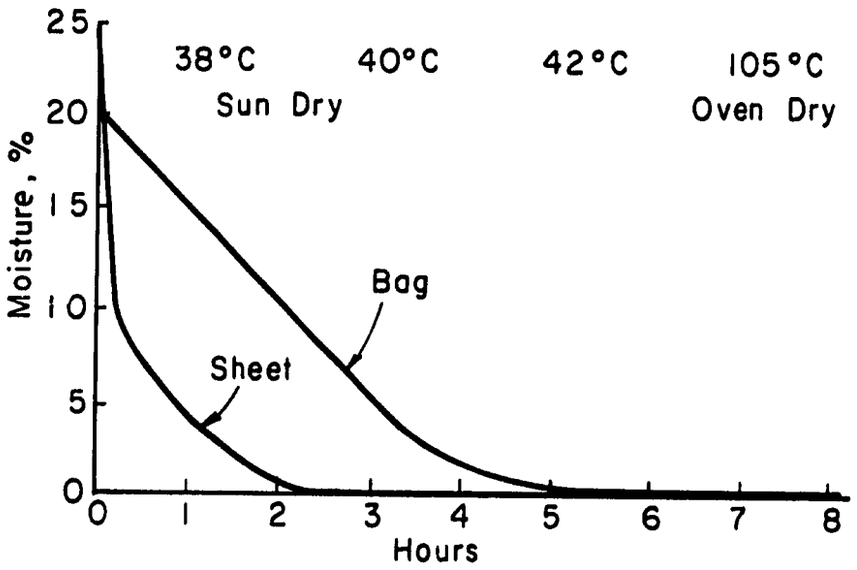

Figure 2. Wet Sample (July, 1975).

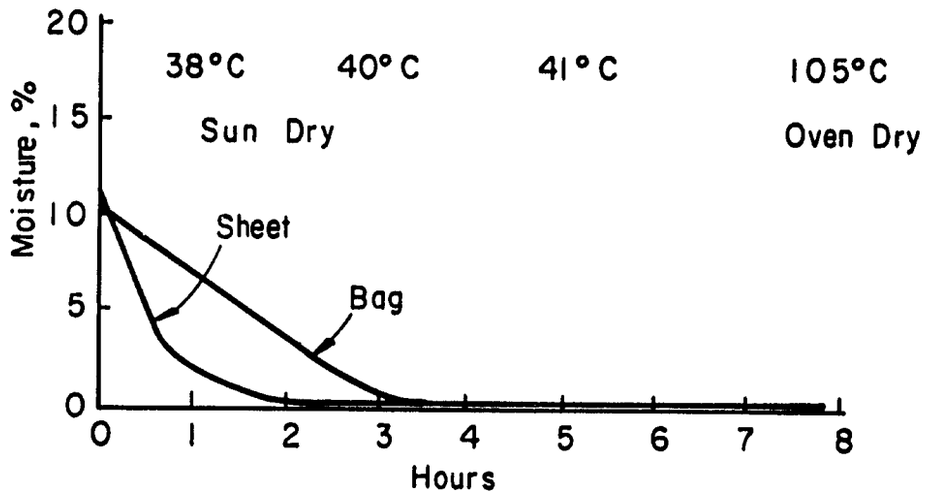

Figure 3. Dry Sample (July, 1975).

Appendix 5

SOIL MOISTURE SAMPLING AND CALCULATION USING A KING TUBE SAMPLER

Methodology Series Number Five

Alan C. Early[1]

The King Tube sampler can be a useful tool to the water management specialist in Pakistan. The tube if properly constructed and when correctly utilized can provide volumetric samples of soil to calculate dry bulk density as well as the soil moisture percentages. However, the extremes in soil moisture condition limit this procedure. In very dry soils, some of the sample is often left in the hole and the dry bulk density is biased too low. In very wet soil conditions some of the sample is often left inside the tube, also biasing the determination downward from the tru

The following are some precautions and instructions for taking soil samples and procedures for making the soil moisture calculations:

1. Inspect tube for interior rust. Clean and polish if necessary.

2. Measure inside diameter of cutting edge of tube and exterior depth calibrations from the cutting edge. Reject tube if linear measurements are off by .005 (.01 centimeter) or more.

3. Select representative site from field to be sampled.

4. Align tube vertically and strike the tube vertically into ground allowing pointed edge of hammer to move inside the tube in an up and down motion. Never swing the hammer as a driving device.

5. Place a straight edge on the ground next to the hole as a reference point to stop sample tube at the first foot graduation.

6. Remove the hammer from inside the tube and orient it horizontally (perpendicular to the tube) passing the hammer slot over the end of the tube. Rotate the hammer by 90° in a horizontal plane and lift the tube slowly, vertically from the ground.

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[1]Agricultural Engineer, Colorado State University Water Management Research Project, Pakistan.

7. Place your left index finger quickly over the cutting edge of the tube as soon as it is out of the ground to prevent soil sample spillage.

8. Invert the tube with top of tube over the container (moisture tin or plastic bag) which is to keep sample in proper moisture condition until weighing. Force the sample loose by pushing with left index finger. If tube is properly constructed, cleaned and polished periodically the sample should fall freely into container. Cover the container immediately to prevent moisture loss.

9. Repeat steps 4 through 8 for as many depth increments as are desired.

10. Repeat steps 3 through 9 for at least two replicates in other representative sites of the field under study.

11. Weigh the soil sample in the wet condition.

12. Dry the soil sample.

13. Reweigh the soil sample after sufficient exposure to drying (zero change in weight to further drying).

14. Make calculations as follows (and complete the attached data sheet):

a) Volume of Sample = $\pi(\frac{D}{2})^2$ H in cubic centimeters.
Where D is inside diameter at the cutting edge in centimeters.
H is depth increment of sample usually 6" or 12" (15.24 cm or 30.48 cm respectively)

b) Weight of Water in grams = (Wet weight of sample & Container grams) - (Dry weight of sample & Container grams)

c) Net dry weight of sample in grams = (dry weight grams) - (weight of sample container - grams)

d) Percent moisture by weight basis = $\left(\frac{\text{Weight of Water}}{\text{Net Dry Weight Soil}}\right) \times 100$

e) Field dry bulk density in grams/cubic centimeter = $\frac{\text{Net dry weight soil}}{\text{Volume Sample}}$

f) Percent Moisture by volume basis = (Field dry bulk density) x (Percent moisture by weight basis) = $\frac{(\text{Weight of Water})}{(\text{Volume of Sample})} \times 100$

SOIL MOISTURE SAMPLING REPORT

Observers_____ and_____ Weight of plastic bag_____ g
Date_____ Hours Drying Time_____
Date Last Irrigation_____ Diameter of king tube_____ cm
Date of next irrigation_____ Volume of sample 6" = ____ cc 12" = ____ cc

Rep	Trtmt	Depth	WetWt(g)	DryWt(g)	WtH_2O	NetDryWt	%MC-Wt	DBD	%MC-Vol	ASM(in/ft)
		1(0-6")								
		2(6-12")								
		3(12-24")								
		4(24-36")								
		5(36-48")								
		6(48-60")								
		7(60-72")								

Rep	Trtmt	Depth	WetWt(g)	DryWt(g)	WtH_2O	NetDryWt	%MC-Wt	DBD	%MC-Vol	ASM(in/ft)
		1(0-6")								
		2(6-12")								
		3(12-24")								
		4(24-36")								
		5(36-48")								
		6(48-60")								
		7(60-72")								

Rep	Trtmt	Depth	WetWt(g)	DryWt(g)	WtH_2O	NetDryWt	%MC-Wt	DBD	%MC-Vol	ASM(in/ft)
		1(0-6")								
		2(6-12")								
		3(12-24")								
		4(24-36")								
		5(36-48")								
		6(48-60")								
		7(60-72")								

Rep	Trtmt	Depth	WetWt(g)	DryWt(g)	WgH_2O	NetDryWt	%MC-Wt	DBD	%MC-Vol	ASM(in/ft)
		1(0-6")								
		2(6-12")								
		3(12-24")								
		4(24-36")								
		5(36-48")								
		6(48-60")								
		7(60-72")								

Rep	Trtmt	Depth	WetWg(g)	DryWt(g)	WgH_2O	NetDryWt	%MC-Wt	DBD	%MC-Vol	ASM(in/ft)
		1(0-6")								
		2(6-12")								
		3(12-24")								
		4(24-36")								
		5(36-48")								
		6(48-60")								
		7(60-72")								

APPENDIX 6

Influence of Initial Seed Moisture Content on Germination and Emergence of Maize

Larry Nelson and Willard Schmehl[1]

Stand establishment has been identified as a major problem in the production of maize and other kharif crops of the Punjab. High daily temperatures, low seedbed moisture and soil crusting are recognized as contributing factors to poor stands.

A series of laboratory studies were conducted at Colorado State University, Fort Collins, Colorado, to determine the effect of initial seed moisture on the germination of cotton, maize, and sorghum. During the summer, a series of greenhouse studies were undertaken to determine the influence of initial seed moisture content on the emergence of maize and sorghum when planted in soils of varying moisture content. This report will deal with germination and emergence studies conducted with maize.

METHODS AND MATERIALS

Four separate laboratory and greenhouse studies were conducted to determine the influence of initial seed moisture content on the germination and emergence of maize. Pioneer brand 3596, a single cross hybrid, was selected for its uniform germination. Germination of the hybrid was 95% or higher in tests using recommended germination procedures (1).

Initial seed moisture content in this report refers to the per cent water in the seed (fresh weight basis) at the time of planting. Initial seed moisture contents of 5, 12, and 17% equilibrium moisture were obtained by storing for one week at appropriate relative humidities. Saturated solutions of inorganic salts were placed in the bottom of laboratory dessicators to obtain desired humidities, by the method of Winston and Bates (3). The 22% moisture content was obtained by soaking maize seed in water for 2 hours prior to planting. Seed moisture contents were determined with a Delmhorst crop moisture detector and periodically checked by gravimetric moisture determinations.

Laboratory Studies

Germination studies were conducted on a two-way thermogradient plate (2). Within a predetermined range, this devise simultaneously provides all possible alternating and constant

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temperature conditions. The temperature gradient selected for the study ranged from 25 to 50°C (77 to 122°F). The first gradient, progressing from left to right on the thermogradient plate, was alternated every 12 hours with a second gradient progressing from front to back. Temperatures were monitored by a set of 20 thermocouples placed around the plate and in contact with the germination paper.

Four hundred seeds of one moisture content were placed, embryo side down, 2.5 cm. apart over the entire surface of the thermogradient plate. An equal number of seed at each of the remaining moisture contents were placed on the plate surface with the same spacing, but offset from the previously placed seed to avoid touching. A quick drying lacquer base spray paint was applied to each group of seed prior to planting for identification. Preliminary tests indicated lacquer base paint was not detrimental to germination.

The study was conducted over a 5 day period with 3 replications. Germination counts were made at 9 different time periods. Seedlings were removed when the radicles attained a length of 1 cm. The location and time of removal were recorded on 20 x 20 matrix data sheets with a decreasing scale, 9 to 0 representing each successive time period. A series of computer programs were used to average the replications, calculate a moving average of 9 adjacent points, and plot a graduated series of shaded concentric squares representing germination intensity patterns. The size of each square is directly proportional to the numerical value assigned for a germination period at a particular seed position.

Greenhouse Studies

Three greenhouse studies were conducted to determine the influence of initial seed moisture content, available soil moisture, and temperature on the emergence of maize. Table 1 lists the treatment variables for each study. Daily measurements of emergence, and soil and air temperatures were taken for each study.

Soils used in the studies were a San Luis loamy sand, a Nunn silty clay loam and an equal-volume mixture of the two soils, representing light, heavy, and medium textures, respectively. The soils were air-dried and screened to pass a 2-mm sieve. Field capacities were determined by saturating the upper portion of soil in 250-ml. tall-form beakers with 60 to 80 ml. of water, equilibrating the samples for 48 hours and then determining the soil moisture content of surface samples gravimetrically. Field capacity values were 10%, 13% and 20% for the light, medium, and heavy textured soils, respectively.

The first study was conducted at optimum temperatures and available soil moistures (Table 1). Ten seeds of each initial moisture content were placed, embryo side down, in 800-ml. beakers containing 850 grams of the sandy loam soil. An additional 327 gs of soil were added to cover the seed, giving a total soil volume of 750 cc and planting depth of 2.5 cm. Soils were brought to field capacity with the addition of 118 ml. of water. The beakers were covered with polyethylene bags and secured by rubber bands to reduce evaporation loss. The beakers were then set inside two quart paper containers and placed in a growth table under artificial light set at a 10-hour day length for a period of 7 days. At the end of the 3rd day, the polyethylene bags were removed and the soils were brought to field capacity on the 4th and 6th days.

The second study was conducted with the medium and heavy textured soils at optimum temperatures and low available soil moistures (Table 1). Available soil moisture at the time of planting was 25% for the top 20 cc of soil and 50% for the bottom cc. of soil. The soils were brought to their respective moisture contents by weight. Water was applied as a mist as the soil was mixed by hand. The soils were then placed in polyethylene bags, sealed and allowed to equilibrate for 24 hours. This method produced a uniformly moist soil with minimal clumping. For this study, the permanent wilting point was considered to be one-half the value of field capacity. Therefore, 25% available water for the medium and heavy textured soils was 8.1 and 12.5%, respectively, and 50% available water for the two soils was 9.8 and 15%, respectively. Planting procedures were the same as indicated previously, except fot the method of placing seeds in the soil. Seeds were embedded in the soil at 50% available water with the blunt end of a pencil, leaving the side antipodal to the embryo, exposed to the drier soil at 25% available water. The study covered a 14-day period. At the end of the 14th day, all ungerminated seeds were removed from the beakers and given a standard germination test.

The third study was conducted with the medium and heavy textured soils under conditions of high daily temperatures (25 - 45°) and low available soil moisture (Table 1). Planting procedures were identical to those of the second study. This study was conducted over a 15-day period. All soils were brought to 90% field capacity on the 9th and 12th day when over 50% of the soil had reached the permanent wilting point. To prevent soil crusting, a 50-ml hypodermic syringe was inserted 5 cm. into the soil, providing subsurface irrigation with minimal soil disturbance.

Table 1. Treatment variables employed in Greenhouse studies.

	Treatment	Soil texture	Soil Moisture Content	Daily Temperature Range	Initial Seed Moisture
Study I*					
	1	Loamy sand	Field capacity	20 - 30°C	5%
	2	Loamy sand	Field capacity	20 - 30°C	12%
	3	Loamy sand	Field capacity	20 - 30°C	17%
	4	Loamy sand	Field capacity	20 - 30°C	22%
Study II					
	1	Loam	25-50% available**	20 - 30°C	5%
	2	Loam	"	20 - 30°C	12%
	3	Loam	"	20 - 30°C	17%
	4	Loam	"	20 - 30°C	22%
	5	Silty clay loam	"	20 - 30°C	5%
	6	Silty clay loam	"	20 - 30°C	12%
	7	Silty clay loam	"	20 - 30°C	17%
	8	Silty clay loam	"	20 - 30°C	22%
Study III					
	1	Loam	"	25 - 45°C	5%
	2	Loam	"	25 - 45°C	12%
	3	Loam	"	25 - 45°C	17%
	4	Loam	"	25 - 45°C	22%
	5	Silty clay loam	"	25 - 45°C	5%
	6	Silty clay loam	"	25 - 45°C	12%
	7	Silty clay loam	"	25 - 45°C	17%
	8	Silty clay loam	"	25 - 45°C	22%

*Studies replicated three times

**The soil moisture content at the time of planting was adjusted to 25% of the available moisture content in the top 200 cc of soil and 50% in the bottom 750 cc of soil.

RESULTS AND DISCUSSION

Laboratory Studies

Germination was essentially complete by the 5th day. Seed which did not germinate, particularly those at the higher temperatures, were dead and had been attached by decaying organisms. Intensity patterns in Figure 1, show a decrease in the time required for germination as initial seed moistures increased. Maximum germination occurred between alternating and constant temperature zones of 25 to 40 C. Alternating temperatures increased the range of germination to 47 C, although the time required for germination increased at temperatures above 40 C.

Results show that the major effect of initial seed moisture content on germination occurred during the first 42 hours (Figure 2). Seed at 22% initial moisture content began to germinate during the first 24 hours and reached 50% germination by 42 hours. Germination of seed at 12 and 17% initial moisture content started at 36 hours. After 48 hours 50% of the seed had germinated. The rate of germination of seed at 22% initial seed moisture began to decline after 30 hours. Germination rates of seed at lower initial moisture contents (5, 12 and 17%) also declined after 30 hours, but the rate of decline was slower for the seed at the lower initial moisture contents. The difference in rates of germination allowed seed of lower initial moisture contents to reach the level of germination of the seed with higher initial seed moistures between 48 and 72 hours (Figure 2). After 60 to 72 hours, the seed moisture content had no effect on percentage germination. Total germination for seed at 5, 12, 17 and 22% initial moisture contents after 96 hours were 73, 73, 71 and 72% respectively (Figure 2).

Greenhouse studies

It was of interest to know, if the relationship of higher initial seed moisture contents and increased initial germination response would hold for emergence of maize seed planted under varying conditions of temperature and soil moisture. In the first study, the emergence of maize, at optimum temperatures and soil moistures, was essentially complete by the sixth day (Figure 3). The effect of increased initial seed moisture on emergence was apparent on the third day when the per cent emergence of seed at 22, 17, 12 and 5% were 80, 45, 47, and 26%, respectively. The initial lag in emergence for seed at lower initial moistures was made up within two days, with a final emergence of 90% or higher for all initial seed moistures.

The second study was conducted to determine whether the increased initial germination response of seeds with higher moisture contents could be found in situations where soil

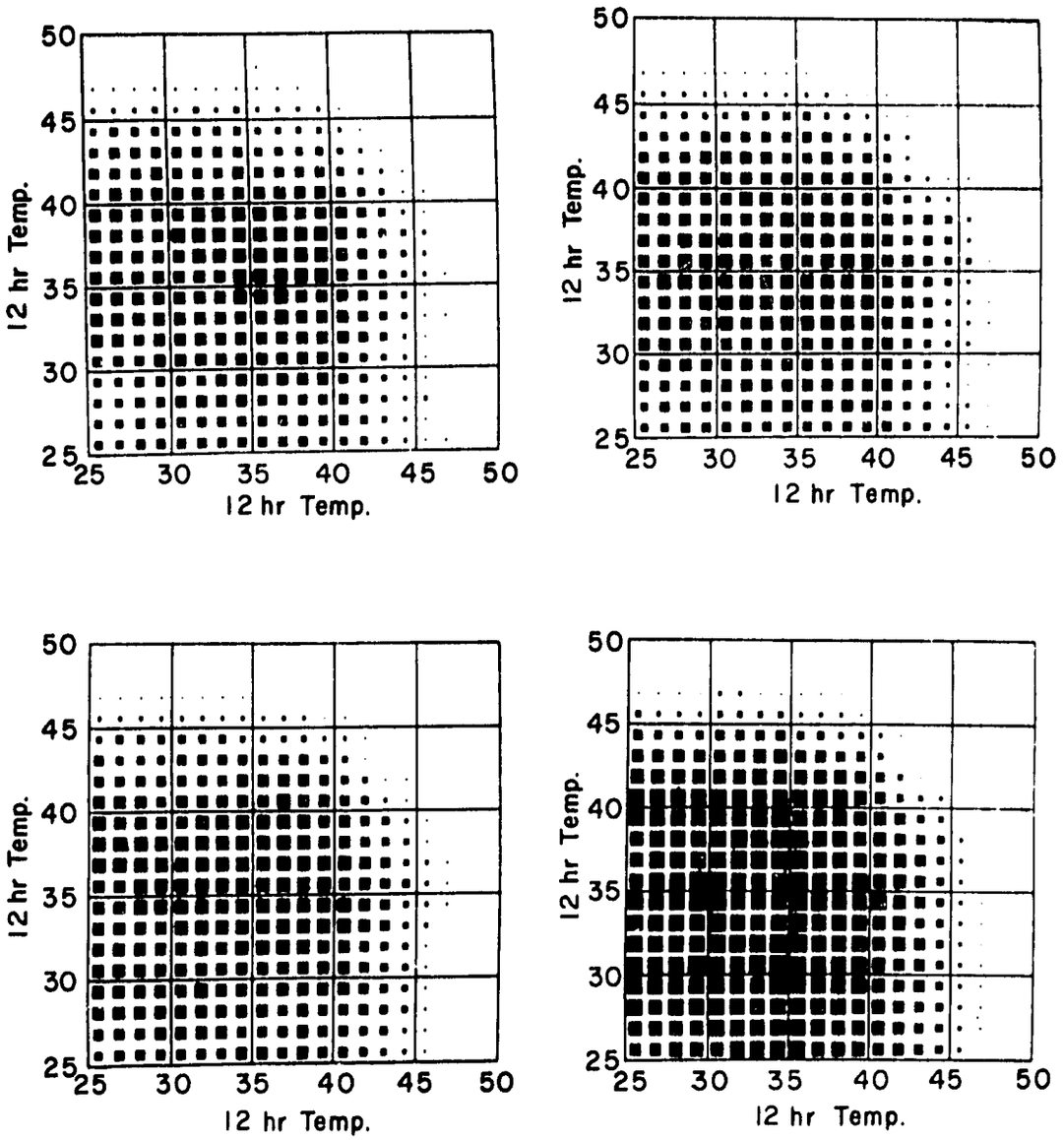

Figure 1. The effect of temperature in the germination of maize at four initial moisture contents (A)5%, (B) 12%, (C)17%, and (D)22%. The diagonal from lower left to upper right represents constant temperatures.

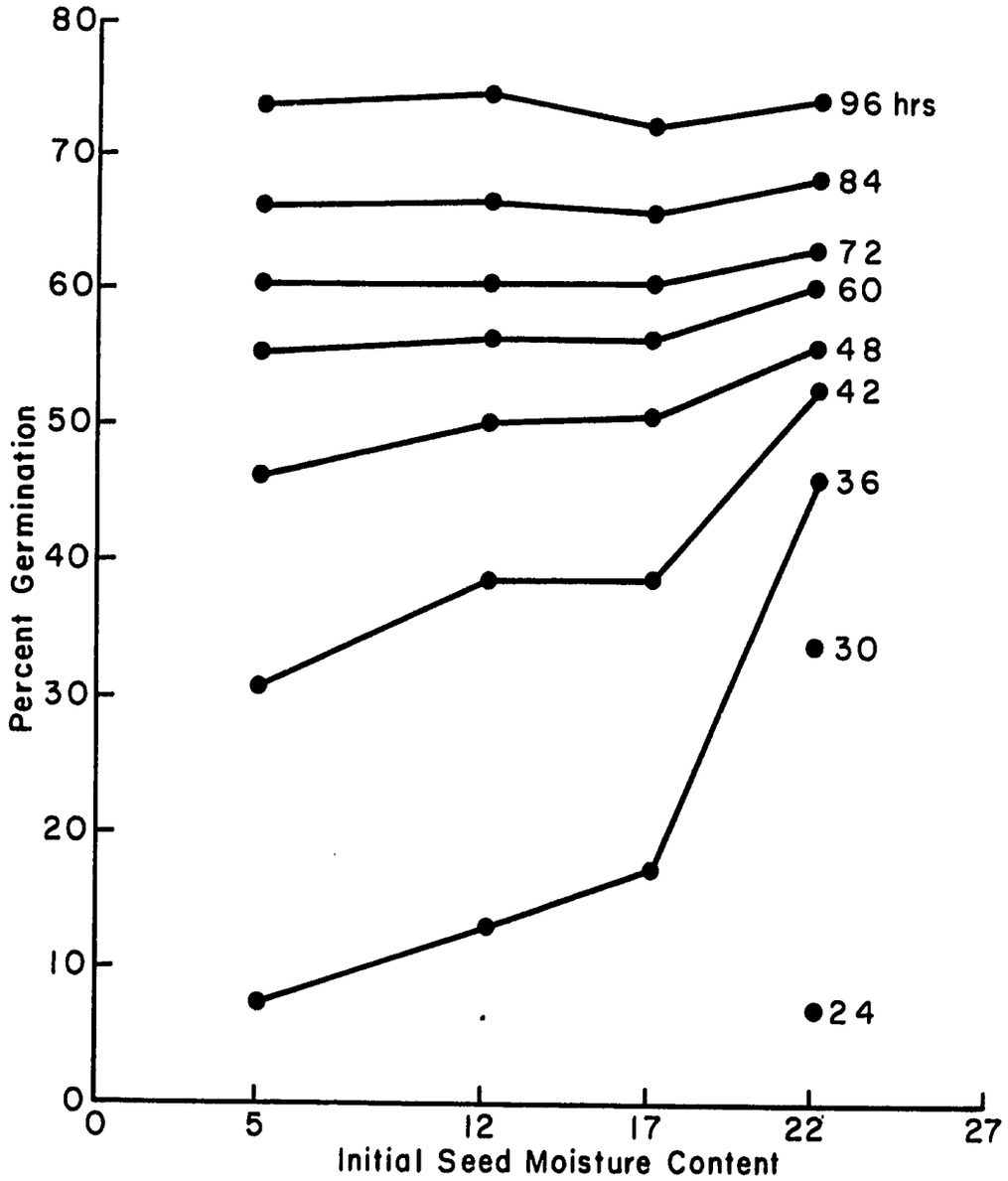

Figure 2. Effect of initial seed moisture content on the total germination of maize seed for various germination period.

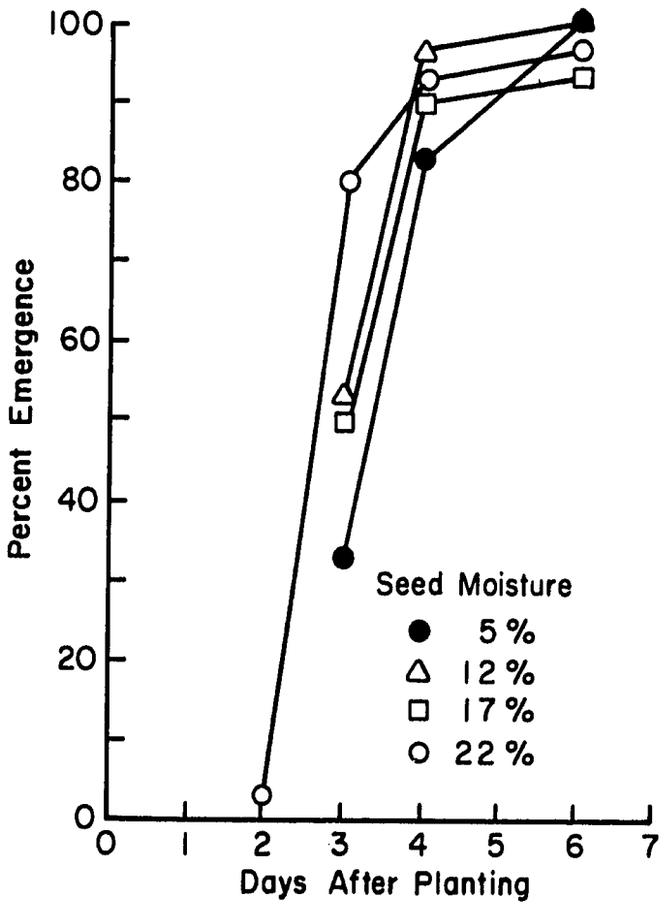

Figure 3. Effect of initial seed moisture content on the percent emergence of maize as a function of time after planting sandy loam at 20 - 30 degrees C and field capacity moisture.

moisture becomes a limiting factor. The emergence of maize, as shown in Figure 4, was severely affected by low soil moisture. Emergence was delayed by three days in the heavy textured soil (Figure 4). Total emergence of the seed with 5, 12, 17 and 22% initial moisture contents were 43, 66, 83, and 93% in the heavy textured soil and 0, 3, 10, and 58% in the medium textured soil, respectively. Upon termination of the fourteen day study, seed which had not emerged were removed and germinated using standard germination procedures. Germination was 60% or higher for seed of each initial moisture treatment, indicating that increased emergence would have occurred with a supplemental irrigation applied as late as fourteen days after planting.

In the third study, an attempt was made to simulate the temperature and soil moisture conditions with those of the Punjab during the kharif season. Daily maximum greenhouse temperatures ranged from 40 to 45 C and maximum soil temperatures at seed depth ranged from 38 to 43 C. The upper centimeter of soil reached a maximum temperature of 48 C. Daily exposure to maximum soil temperatures ranged from two to three hours. Evening low air temperatures ranged from 25 to 30 C.

There was no seedling emergence for the first nine days in the medium textured soil, while seed at 22% initial moisture content had only a 30% emergence in the heavy textured soil (Figure 5). After both soils were brought to 90% field capacity, by subsurface irrigation on the 9th and 12th day, total emergence of seed at all initial moisture contents were significantly increased (Figure 5).

CONCLUSIONS

The results of this study implicate increased initial seed moisture as a factor contributing to better emergence of maize. The practice of sowing maize seed with relatively high moisture contents could help growers to improve stand establishment, particularly where soil moisture may be a limiting factor. Where high daily temperatures are associated with low seedbed moisture, sowing seed with relatively high moisture contents will probably have to be augmented with extra irrigations.

REFERENCES

1. Association of Official Seed Analysts. 1970. Rules for testing seeds. Proc. Assoc. Off. Seed Anal. 60(2):36.

2. _____. 1971. The thermogradient plate for seed germination research: construction plans and procedures. U.S. Dep. Agr., ARS 51-41.

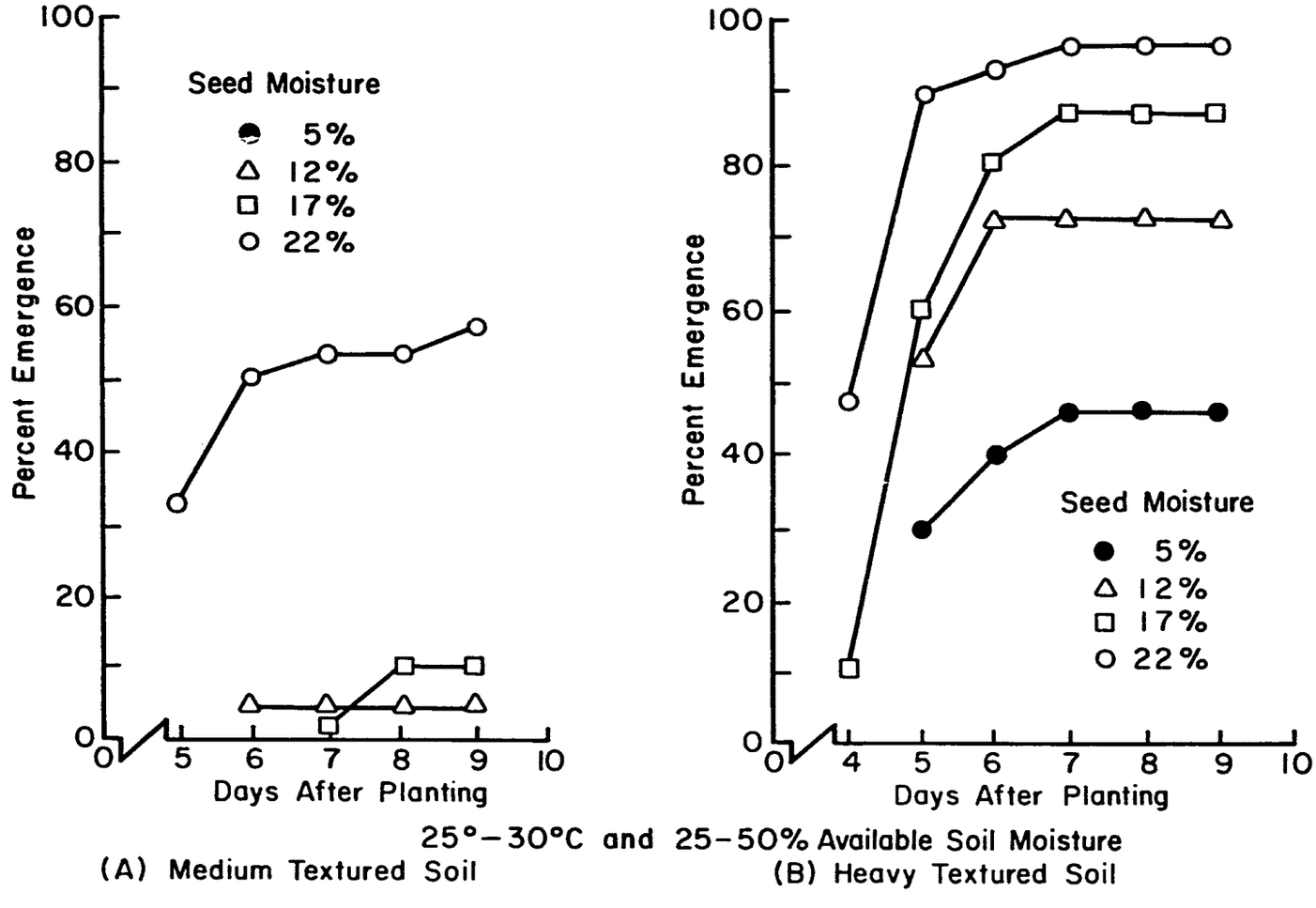

Figure 4. Effect of initial seed moisture content on the percent emergence of maize as a function of time after planting in 20 - 30 degrees C and 25 - 50 percent available soil mositure.

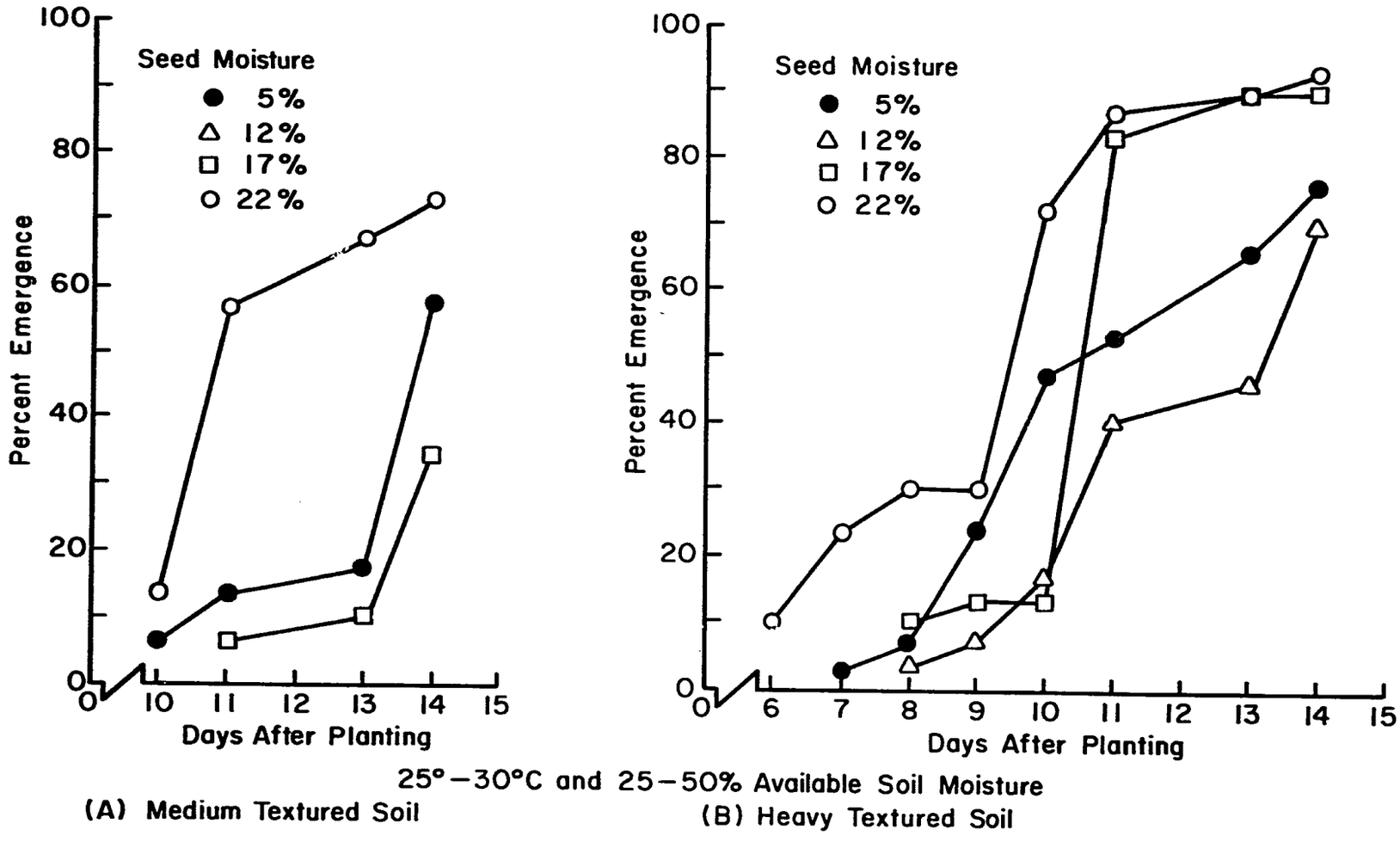

Figure 5. Effect of initial seed moisture content on the percent emergence of maize as a function of time after planting.

3. Winston, Paul H. and Donald H. Bates. 1960. Saturated solutions for the control of humidity in biological research. Ecology 41(1):232-237.

APPENDIX 7

EFFECT OF EXCESS MAGNESIUM ON CORN GROWTH

W.T. Franklin and J.S. Olsen[1]

INTRODUCTION

Excess magnesium (Mg) in solutions and soils has long been known to result in reduced plant growth. There have been two main explanations advanced to account for this reduced plant growth. The first theory is that Mg simply has a "toxic effect" (Gauch and Wadleigh, 1944). A toxic effect, as defined by Leon Bernstein (1964), results in specifically recognizable toxicity symptoms. Plant toxicity symptoms of Mg in plants have not been described in the literature. The second main theory of depression of growth by Mg is that a Ca-deficiency is induced by partial exclusion of calcium (Ca) from plants by Mg (Hayward and Wadleigh, 1949). Other explanations advanced to account for growth depression by Mg are a "general plant nutrient imbalance" brought about by excess Mg and, in part, a "high pH" effect.

Several reports in the literature indicate that whenever Mg exceeds Ca in nutrient and soil solutions, plant growth depression takes place ($Ca/Mg<1$). Magnesium exceeds Ca in more than half of about 1500 groundwaters analyzed by the Land Reclamation Directorate at Lahore. This poses a potentially serious problem in using these groundwaters for irrigation of crops, especially for high bicarbonate waters that precipitate Ca during concentration in the evapotranspiration process.

This report constitutes the results of a preliminary study to evaluate the effects of Mg on corn growth. Objectives of the study included comparing growth depressing effects of a neutral Mg-salt ($MgSO_4$) with a more alkaline $Mg(HCO_3)_2$ and with a low salt and high salt waters containing more Ca than Mg. Single Mg-salt solutions were used to determine whether or not recognizable Mg-toxicity symptoms could be detected.

MATERIALS AND PROCEDURES

The experiment was conducted in the greenhouse using 3.5 kg of a calcareous loam soil placed in 3.78 L (1 gal)

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[1]Associate Professor and Laboratory Assistant, Department of Agronomy, Colorado State University, Fort Collins, Colorado, respectively.

cans in which a copper tube was soldered into the bottom for drainage. The experiment was set up in a randomized block design replicated 4 times.

Water Compositions

Eight waters varying in ionic composition and concentration were used:

1. Tap water (check), $ECx10^6$ = 78mmho/cm; SAR=0.1

2.3. $Mg(HCO_3)_2$, $ECx10^3$ = 1.0 and 3.0 mmho/cm. The desired $MgCO_3$- deionized water suspensions. After the $MgCO_3$ was completely dissolved, air was bubbled through the solutions to equilibrate the solution with the CO_2 partial pressure of air.

4,5,6. $MgSO_4$, $ECx10^3$ = 1.0, 3.0 and 6.0 mmho/cm

7,8. Mixed Salt, $ECx10^3$ = 3.0 and 6.0 mmho/cm, SAR=5.0; Ca:mg proportion = 3:1; Cl:SO_4 proportion = 2:1. These treatments were included to differentiate "salinity effects" from "Mg-effects".

Ion and Salt Equilibration with Soil

Prior to the experiment the soil exchange complex was predominantly saturated with Ca. First, in the case of the single Mg-salt treatments, concentrated solutions of $MgSO_4$ containing about 1 1/2 times the calculated amount of Mg needed to replace exchangeable Ca were applied to the soil. Also, concentrated "mixed-salt" solutions were applied to bring the ion composition of the exchange complex into equilibrium with the ion composition of the water. The concentrated solutions were followed by exhaustive leaching with the different waters to reduce the salt composition of the effluent to the level of that in the water. All 8 waters dissolved soil lime. Thus, in the case of the single Mg-salt treatments complete cation saturation with Mg was not possible.

Planting, Fertilization and Irrigation

Six corn seeds were planted in each can and later thinned to 3 plants per can. On a soil weight basis, 10 ppm of $N(NH_4NO_3)$ were applied each irrigation. Single applications of 50 ppm P ($NH_4H_2PO_4$), 5 ppm Fe (Fe-EDDHA), and 3 ppm Zn (Zn-EDTA) were made.

The time of irrigation of all plots was based on the amount of moisture depletion by the "tap water" treatment. All treatments were irrigated upon or just before 75% moisture depletion of the tap water cans. Each can was weighed before irrigation and a 50% leaching fraction applied (excess irrigation equal to evapotranspiration). Suction was applied

at the drain tube to facilitate drainage. The effluent solution (drainage water) was saved for chemical analysis.

Harvesting and Chemical Analysis

The corn plants were harvested at initiation of tasseling. Leaves and stems were harvested and weighed separately. The leaves were ground after drying and subsamples from each can were digested in HNO_3-$HClO_4$ solution. The digested sample was analyzed for Ca and Mg by atomic absorption spectrophotometry. The corn roots in one replication of each treatment were separated from the soil by soaking and thoroughly washing with water. The roots were oven-dried and weighed.

The effluent solutions were analyzed for electrical conductivity pH, Ca, Mg, HCO_3 and partially for Na before planting and after each irrigation.

RESULTS AND DISCUSSION

Top and Root Growth

The yield results of corn top-growth and root-growth shown in Fig. 1 as "relative yields" using the tap water treatment as 100%. Relative yield is plotted versus average soil solution conductivity ($ECx10^3$) rather than water conductivity in order to more closely reflect the average of the root zone.

The average $ECx10^3$ of the soil solution was calculated as a simple average of conductivity of the effluent at the end of equilibration before planting and effluent after irrigation. According to salt balance theory, a 50% leaching percentage should double the concentration of the effluent. The effluent conductivity of the $MgSO_4$ and salt mix solutions very closely approximated this relationship. The $Mg(HCO_3)_2$ effluent composition changed little during the irrigation cycles, especially for the $Mg(HCO_3)_2$ applied at $ECx10^3 = 3.0$. This indicates that the effluent solution was saturated with respect to nesquehonite ($MgCO_3 \cdot 3H_2O$).

The $Mg(HCO_3)_2$ water depressed top growth (TDM of leaves and stems) to a much greater extent than either the $MgSO_4$ or salt mix solution. The data indicate that salinity effects are minor compared to other growth depressing effects because the conductivities of the $Mg(HCO_3)_2$ soil solutions were the lowest of the applied salt solutions. Depression of root growth was similar, but not entirely equal, to top growth reduction. The root growth indicated for the salt mix at EC = 3 is not believed to be typical of the other 3 replications.

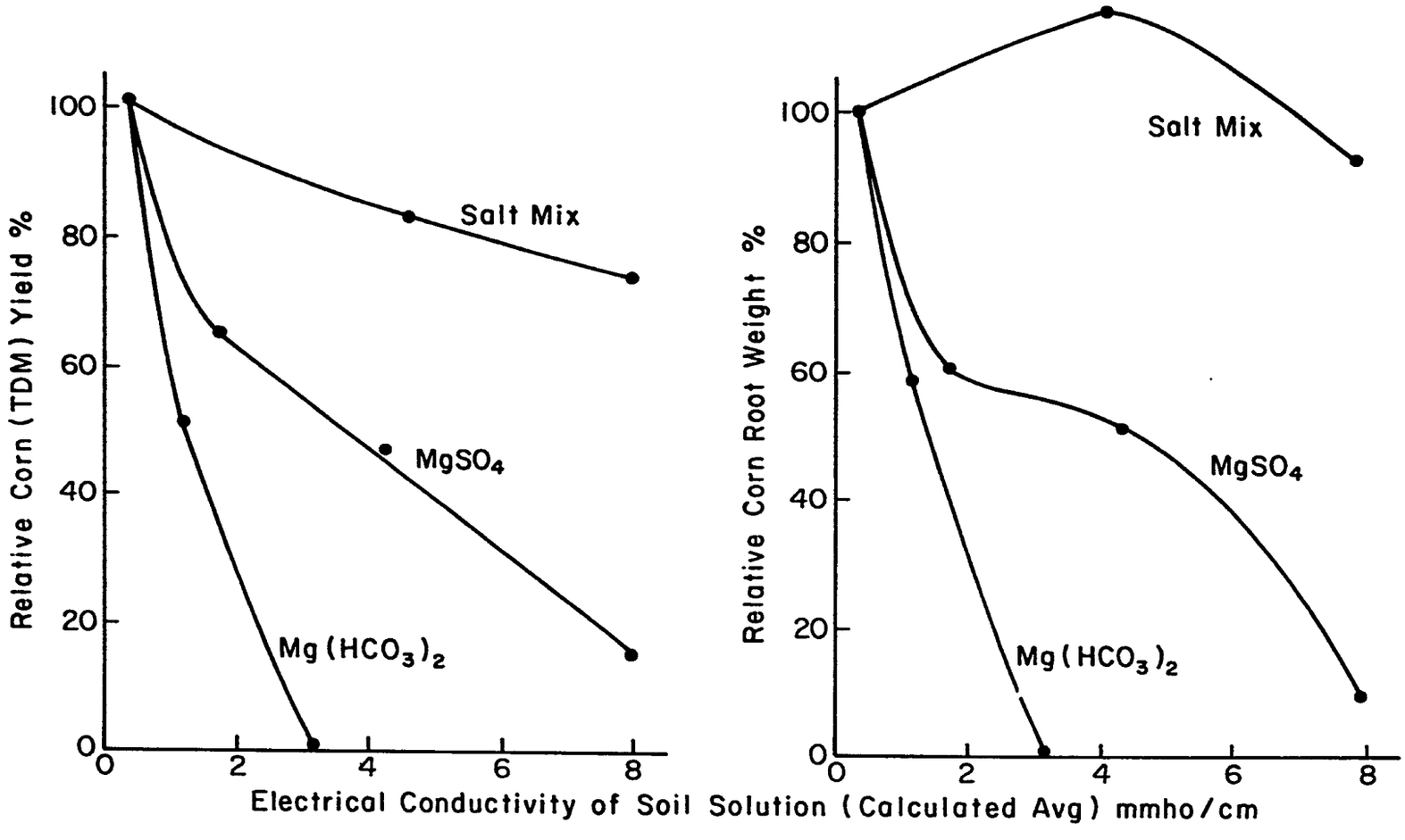


Figure 1. The effects of salt composition and soil solution conductivity on the relative growth of corn tops and roots.

Calcium and Magnesium Content of Leaves

The Ca and Mg content of leaves for the various treatments are summarized in Fig. 2. The single Mg-salt waters depressed the Ca content and increased the leaf Mg markedly. The ratios of Ca and Mg in the leaves were very closely related to the average Ca-Mg ratios in the soil solution (Fig. 3). Mild Ca-deficiency symptoms were observed to occur on plants watered with $Mg(HCO_3)_2$, $ECx10^3 = 1.0$ and with $MgSO_4$, $ECx10^3 = 1.0$ and 3.0. Very pronounced typical Ca- deficiency symptoms occurred on plants irrigated with $Mg(HCO_3)_2$, $ECx10^3 = 3.0$ and $MgSO_4$, $ECx10^3 = 6.0$, especially during the seedling stage. No plant symptoms that could be construed as "Mg-toxicity" symptoms were observed throughout the experiment.

The Ca and Mg content of the leaves of plants watered with both $Mg(HCO_3)_2$ and $MgSO_4$ at $ECx10^3 = 1.0$ were almost identical (Fig. 2). Yet, the yield of plants watered with $Mg(HCO_3)_2$ was 15% less than plants watered with $MgSO_4$. Thus, Ca-Mg uptake or salinity differences do not explain the difference in yields. Water pH or possibly other nutrient imbalances are involved. The pH of the $Mg(HCO_3)_2$ effluents were usually at least 1pH unit higher than equivalent $MgSO_4$ effluents.

Transpiration

Transpiration was calculated as the amount of water evapotranspired (determined by weighings) minus the amount of evaporation of water form soil in cans in which plants were not grown. The transpiration rate during the 5-day period prior to harvest is related to the average weight of wet leaves in Figure 4. Transpiration has most often been associated with salinity stress in many publications. These data show a much better relationship between total leaf weight and transpiration rate than to soil solution salinity, although the $MgSO_4$ waters show the expected trend.

LITERATURE CITED

Bernstein, Leon. 1964. Salt tolerance of plants. USDA Agr. Info. Bull. No. 283. 23p.

Gauch, H.G. and C.H. Wadleigh. 1944. Effects of high salt concentrations on growth of bean plants. Bot. Gaz. 105:379-387.

Hayward, H.E. and C.H. Wadleigh. 1949. Plant growth on saline and alkali soils. Advan. in Agron. 1:1-38.

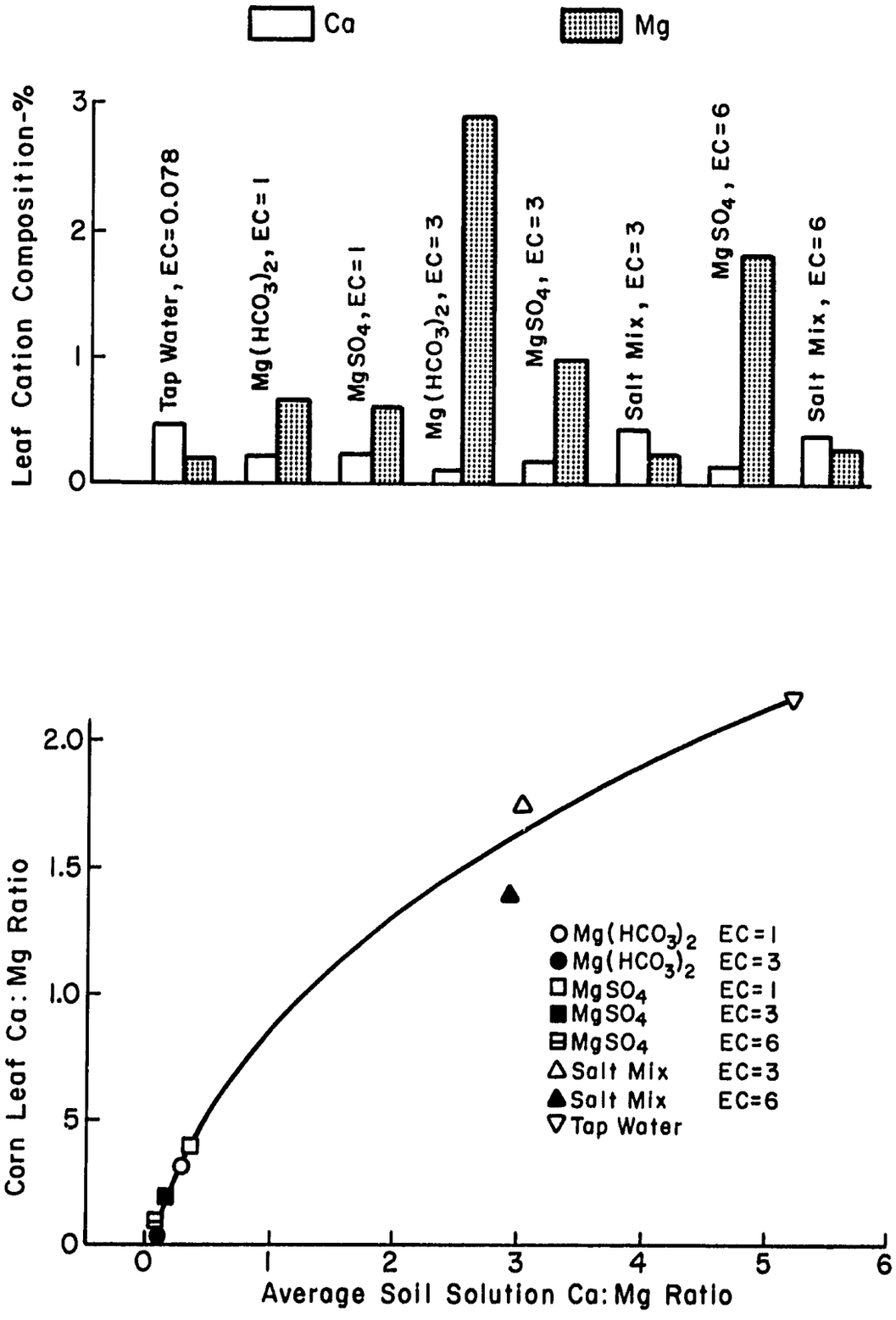


Figure 3. The relationship of Ca-Mg ratio in corn leaves with Ca-Mg ratio in the soil solution.

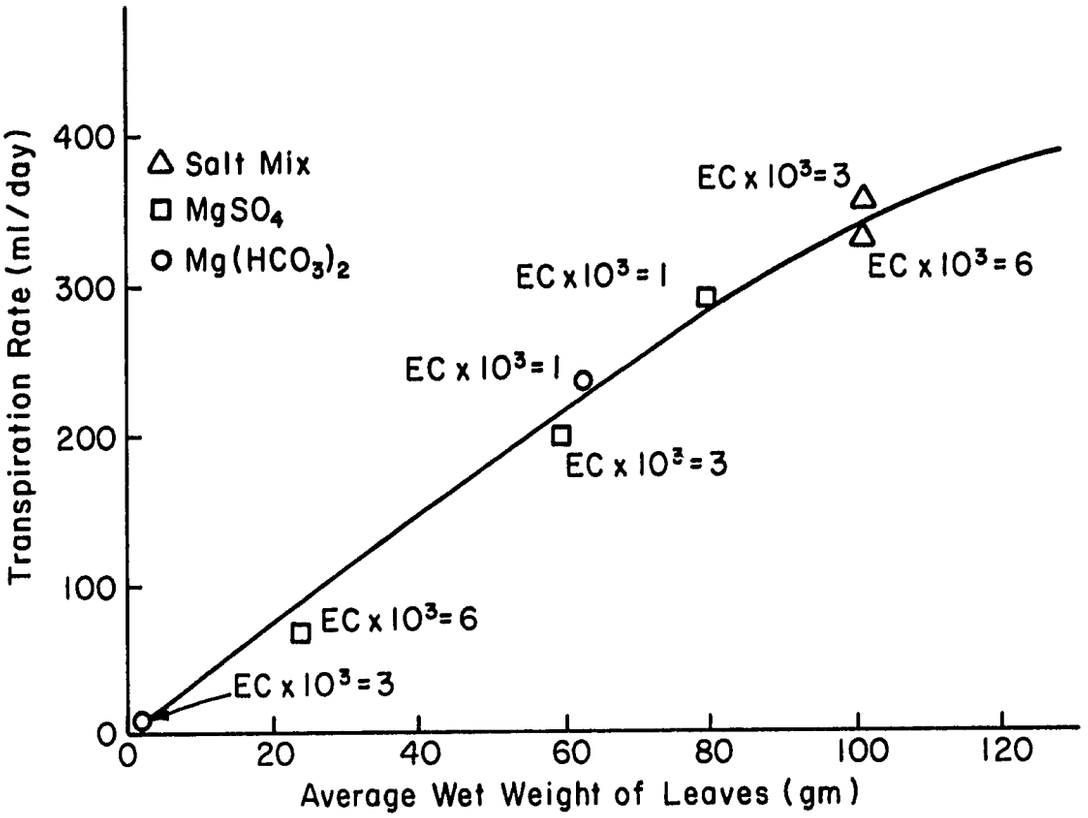


Figure 4. The relationship between leaf weight (leaf surface) and transpiration by corn plants during last 5 days prior to harvest.

Appendix 8

INSTRUCTIONS FOR METEOROLOGICAL OBSERVATIONS WATER MANAGEMENT RESEARCH A DEMONSTRATION GUIDELINE

Alan C. Early[1]

Introduction

A small meteorological station to make observations of rainfall and evaporation can be a useful tool for scheduling irrigation applications in conjunction with detailed crop and soil moisture observations. This installation is also useful to document climatological events in relation to crop growth stages. The purpose of this guideline is to provide detailed instructions for field workers to measure evaporation and rainfall daily.

Observations must be made daily at the same time so that the measurements reflect an exact 24-hour period. The preferable time for observation is 0800 hours to make our observations comparable to those made by other agencies taking readings at other locations.

Evaporation

The evaporation pan must be filled and maintained with clean pump water in the range of 1 to 3 inches below the rim. When the water level drops to 3 inches from top of rim due to evaporation, water should be added to raise the level to 2 inches from the top of rim. When water rises to within 1 inch of the top due to rainfall accumulation, water should be removed to lower the water level to 2 inches from the top of rim. Anytime water is added or removed, two hook gauge readings must be taken, one before adding or removing the water and the other after the change of water level. These before and after measurements are needed to determine the exact amount of water added or removed and to provide a new reference point for the following day's reading.

The evaporation pan is equipped with a stilling well for placement of a hook gauge used to provide a precise measurement of water surface elevation. Two such measurements 24 hours apart then provide a measurement to open surface evaporation, provided rainfall did not occur. If rainfall occurs during the 24 hour period, the rain gauge reading must be taken into account when calculating the evaporation.

[1]Agricultural Engineer, Colorado State University Water Management

Maintenance of the evaporation pan is important to its continued utilization. Debris from windstorms must be removed and periodic maintenance is required to remove algae deposits. Security of the evaporation pan is important. A small barrier of thorned branches is necessary to discourage dogs and other animals from drinking from the pan and to keep children from swimming therein. If stones or clods of earth are found in the pan, a note must be made in remark column of data sheet; a reading of water surface elevation with hook gauge before; and a second reading of hook gauge after removal of the objects is required for correction of readings.

The remarks column of the data sheet is just as important as the data taken. A record of extraordinary events can offer a valuable part of the data and explain anomalous readings. Extraordinary events would include dust storms, heavy rainstorms, frost, heavy ground fog, etc. Remarks should also include effects of the interference of humans, animals and birds on the water level in the pan.

Rainfall

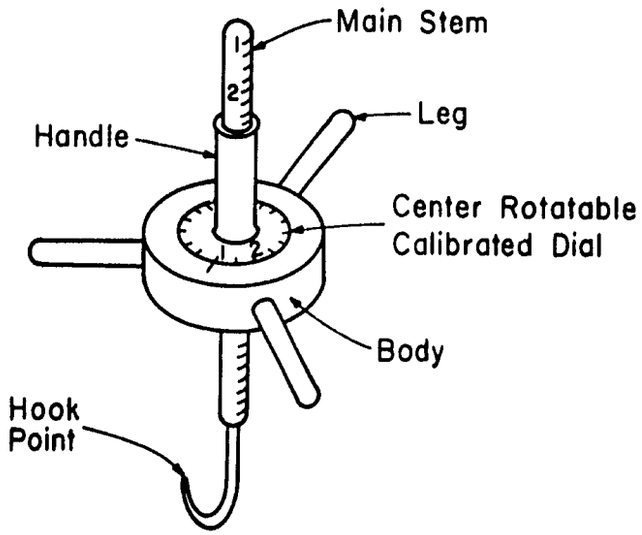
Rainfall measurements are especially important to water management research activities because rainfall is an additional water input to the soil to support plant growth. Rainfall measurements are needed to make precise determinations of evaporation. Maintenance and security of the rain gauge must be observed and if necessary a lock and chain to hold the receiving funnel/top on the rain gauge must be provided.

The rain gauge should be checked daily as rainfall during the observer's absence would be important to note. When the observer is present, a general indication of the duration of the rainfall event(s) during the 24 hours is important. Whether a shower, heavy rain, or all day drizzle are the important characteristics to note.

Evaporation Measurements

The diagram on the following page provides an introduction to the parts and calibrations of a hook gauge.

The construction of the hook gauge is based on a calibrated main stem that has exactly 20 threads per inch (or 2 threads = 2 revolutions per 1/10 of an inch) and a center rotatable calibrated dial that has 50 radial calibration points. The main stem is calibrated in inches and tenths of inches and is read at the top of the handle of the center rotatable calibrated dial. The center rotatable calibrated dial reads from .001 to .050 or .051 to .100 depending upon whether the dial is in the first or second revolution for that tenth of an inch. This is determined by the position of main stem calibrations.



Procedure

1. Place hook gauge on stilling well in prepared grooves always aligning it in exactly same direction.

2. Rotate the center dial lowering hook into the water until point of hook is beneath the water surface.

3. Reverse rotation of center dial raising the point of hook slowly until it just breaks through the water surface.

4. Read main stem and center dial calibrations to nearest 1/1000 of an inch.

5. Repeat steps 2 to 4 until three successive measurements give the same readings.

6. Record value of water surface elevation.

7. Remove hook gauge and store in safe, secure place until next day being careful not to damage or bend the hook.

Rainfall Measurements

The rainfall measurements are made from a narrow tube that is used to provide a magnification of actual measurement for added precision. Measurements are made simply by recording the volume of water in a graduated cylinder beneath the

collecting funnel/top of rain gauge. Measurements are then converted to inches of depth from an appropriate conversion table.

Daily Procedure

1. At arrival on the site - note any disturbances and record.

2. Open rain gauge and record volume of water collected - empty cylinder after recording.

3. Place hook gauge on stilling well and record water surface elevation.

4. If water is lower than three inches from top of rim - add water and re-read water surface elevation and record. If water is higher than 1 inch from top of rim, remove water and re-read water surface elevation and record. If foreign objects are found in evaporation pan - remove them and re-read water surface elevation and record.

5. Remove hook gauge to secure place.

DATA SHEET METEOROLOGICAL OBSERVATIONS
IRDP WATER MANAGEMENT DEMONSTRATION PROGRAM - LAR & SHADAB

Location_____ Month_____ Time_____

Date	Hook Gauge REading Before	After	Evaporation	H_2O Cylinder Reading Volume (ml)	Rainfall	Remarks
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						
31						
TOTAL						

Conversion Chart for Rainfall
(milliliters collected to inches depth equivalent)

ml	in depth	ml	in depth	ml	in depth	ml	in depth	ml	in depth
1/2	.0016	10 1/2	.0326	20 1/2	.0637	30 1/2	.0948	40 1/2	.1259
1	.0031	11	.0342	21	.0653	31	.0963	41	.1274
1 1/2	.0047	11 1/2	.0357	21 1/2	.0668	31 1/2	.0979	41 1/2	.1290
2	.0062	12	.0373	22	.0684	32	.0995	42	.1305
2 1/2	.0078	12 1/2	.0388	22 1/2	.0699	32 1/2	.1010	42 1/2	.1321
3	.0093	13	.0404	23	.0715	33	.1026	43	.1336
3 1/2	.0109	13 1/2	.0420	23 1/2	.0730	33 1/2	.1041	43 1/2	.1352
4	.0124	14	.0435	24	.0746	34	.1057	44	.1367
4 1/2	.0140	14 1/2	.0451	24 1/2	.0761	34 1/2	.1072	44 1/2	.1383
5	.0155	15	.0466	25	.0777	35	.1088	45	.1399
5 1/2	.0171	15 1/2	.0482	25 1/2	.0793	35 1/2	.1103	45 1/2	.1414
6	.0186	16	.0497	26	.0808	36	.1119	46	.1430
6 1/2	.0202	16 1/2	.0513	26 1/2	.0824	36 1/2	.1134	46 1/2	.1445
7	.0218	17	.0528	27	.0839	37	.1150	47	.1461
7 1/2	.0233	17 1/2	.0544	27 1/2	.0855	37 1/2	.1165	47 1/2	.1476
8	.0249	18	.0559	28	.0870	38	.1181	48	.1492
8 1/2	.0264	18 1/2	.0575	28 1/2	.0886	38 1/2	.1197	48 1/2	.1507
9	.0280	19	.0591	29	.0901	39	.1212	49	.1523
9 1/2	.0295	19 1/2	.0606	29 1/2	.0917	39 1/2	.1228	49 1/2	.1538
10	.0311	20	.0622	30	.0932	40	.1243	50	.1554

ACE:nhd

Appendix 9

AUTOMATIC RABI DRILL CALIBRATION PROCEDURES
-An Extension Guideline-

A. C. Early

Discussion

Prior to seeding experimental and demonstration plots the automatic rabi drill (ARD) requires calibration. This is due to the difference in texture and granular structure of the various fertilizers available and due to the fact that this is not a precision planter precalibrated at the factory. For these reasons, the following procedures require three replications to draw conclusions for rate per acre from a given dial setting. Also the trial and error procedure of successive approximations is made to attain the desired settings for experimental purposes.

The procedure includes first making some basic measurements of the ARD and calculating the number of revolutions necessary to cover an equivalent area of land.

Then a set of prescribed steps is provided for making the calibration. Finally a data sheet is provided for summarizing the measurements calculating the rates and guiding the observer to reach the desired dial settings for field sowing.

Once the calibration is completed it is recommended that all seed and fertilizer be removed and replaced in the original container. The bullocks that are to be used for seeding the field should be hooked to the drill and allowed to make at least half a dozen rounds on the field. This is for both the operator and the bullocks to become accustomed to the ARD, and may prevent loss of seed and fertilizer and save some embarrassment with a run-away team and ARD.

A final statement must be made about utilization and maintenance of the ARD. Continued use of the ARD requires that this machine be maintained and lubricated periodically.

When seeding, the operator should frequently check for seed and fertilizer passage through the transparent plastic connector tubes. Frequent observation of seed box and fertilizer box will indicate when additional supplies are needed or when bulking of contents can prevent free flow of the materials. When seeding in the field the operator would do well to carry pliers, as the drive mechanism with local drive chain often needs adjustment. It is better to have the

tools to make a few adjustments while the seeding takes place than to have a break-down jeopardize finishing the seeding on a given day.

Measurements

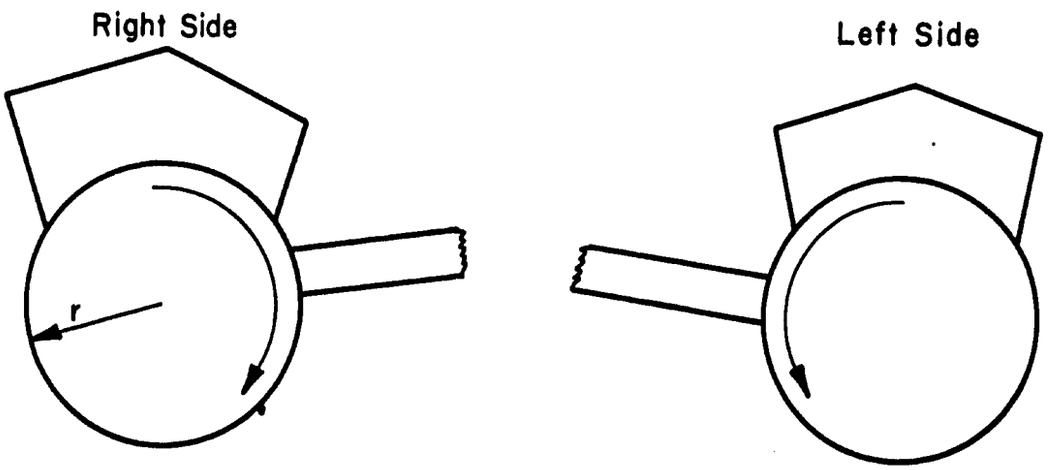
1/10 acre application

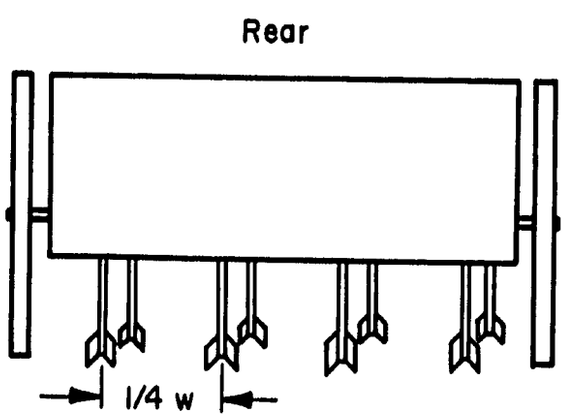
$$2\pi rwx = 43,56.0$$

$$x = \frac{693.2789}{rw}$$

where

π = 3.14159
4 = radius of drive wheel in feet
w = width of rabi drill coverage in feet
x = number of complete revolutions of wheel to give 1/10 acre application





Steps

1. Clean seed box and fertilizer box free of dirt

2. Block drill firmly up off the ground on bricks with operating attitude of seed and fertilizer boxes maintained

3. Tie string around drive wheel at one location so counting of revolution will remain clear

4. Fill seed box with the seed to be used and fertilizer box with fertilizer

5. Select setting on seed rate dial and on fertilizer rate dial in the middle of range available and mark location with pencil

6. Place small cans or boxes under each of the 4 seed spouts and 4 fertilizer spouts

7. Rotate drive wheel predetermined number of rotations (right wheel clockwise or left wheel counter clockwise) to give 1/10 acre application

8. Weigh total seed and total fertilizer applied for 1/10 acre record on summary sheet

9. Replace weighed seed and fertilizer in drill boxes and repeat steps 6-8 above twice or until good agreement is obtained for three consecutive trials

10. Calculate the mean of the three trials and the rate of application per acre

11. If the respective seed/fertilizer application rate is less than the application rate desired for the field experimental dosage increase the rate dial setting by 1/10 of the maximum range and repeat steps 6-9 above recording and calculating as before. If the application rate is greater than the desired rate reduce the dial setting and repeat steps 6-9.

12. Continue the procedure of adjustments by smaller increments in succession until the desired application rates are obtained in three successive trials

Summary Sheet

Setting_____ Seed dial_____Fertilizer dial

Trial	1	2	3	Mean	Rate/acre (10 times mean rate)
Sr of seed	____	____	____	____	_____
Sr of fert.	____	____	____	____	_____

Setting_____ Seed dial_____Fertilizer dial

Trial	1	2	3	Mean	Rate/acre (10 times mean rate)
Sr of seed	____	____	____	____	_____
Sr of fert.	____	____	____	____	_____

Setting_____ Seed dial_____Fertilizer dial

Trial	1	2	3	Mean	Rate/acre (10 times mean rate)
Sr of seed	____	____	____	____	_____
Sr of fert.	____	____	____	____	_____

Setting_____ Seed dial_____Fertilizer dial

Trial	1	2	3	Mean	Rate/acre (10 times mean rate)
Sr of seed	____	____	____	____	_____
Sr of fert.	____	____	____	____	_____

Setting_____ Seed dial_____Fertilizer dial

Trial	1	2	3	Mean	Rate/acre (10 times mean rate)
Sr of seed	____	____	____	____	_____
Sr of fert.	____	____	____	____	_____

Setting_____ Seed dial_____Fertilizer dial

Trial	1	2	3	Mean	Rate/acre (10 times mean rate)
Sr of seed	____	____	____	____	_____
Sr of fert.	____	____	____	____	_____

Setting_____ Seed dial_____Fertilizer dial

Trial	1	2	3	Mean	Rate/acre (10 times mean rate)
Sr of seed	____	____	____	____	_____
Sr of fert.	____	____	____	____	_____

Setting_____ Seed dial_____Fertilizer dial

Trial	1	2	3	Mean	Rate/acre (10 times mean rate)
Sr of seed	____	____	____	____	_____
Sr of fert.	____	____	____	____	_____

Setting_____ Seed dial_____Fertilizer dial

Trial	1	2	3	Mean	Rate/acre (10 times mean rate)
Sr of seed	____	____	____	____	_____
Sr of fert.	____	____	____	____	_____

APPENDIX 10

WATERCOURSE LOSSES AS RELATED TO COMPOSITION AND CONDITION OF BANKS[1]

W.D. Kemper[2], Wayne Clyma[2], Moh'd Akram[3], Moh'd Hanif[3], Iqbal Parvez[3]

INTRODUCTION

Spillage plays a major role in water losses when watercourses are at full capacity or overloaded. However, even when obvious spillage is not taking place, most of the watercourses measured to date lose from 5 to 20% of their water per thousand feet of watercourse. Such losses require seepage rates through the wetted perimeter of the watercourse of from one to four inches per hour which are generally far greater than the infiltration rates of soils in the same areas.

Close inspection of the banks of sections with high losses and measurements of loss using the ponding method indicate that most of the loss occurs through small holes or highly permeable soils in the upper, steeper portions of the watercourse banks. Holes in the lower portions of the banks and the bed tend to fill up with sediment and lose less water. The high permeability of these watercourse banks stems from the ideal conditions for plant growth thereon. The plants are not generally harvested and their seeds, stems and roots furnish a rich supply of food for a teaming population of ants, beetles, worms and other insects and grubs which honeycomb the banks as they harvest their food and build their homes and nesting places. Rodents which live on these insects and their larvae are attracted to their prey and further riddle the banks in their search for food. In many areas the banks of these ditches are the only land high enough to escape complete inundation. These facts combine to make watercourse banks the most densely populated and most permeable soils in Pakistan. This high permeability also deprives many Pakistani farmers of 20 to 40% or more of their precious water each year.

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[1]The studies reported herein were conducted by the Colorado State University field party and the Water Management Research groups of the Mona Reclamation Experimental Project of WAPDA and the Integrated Rural Development Program. Portions of this work were supported by USAID contracts AID/ta-c-1100 and project agreements 73-4 and 73-5.

[2]C.S.U. Party Chief, C.S.U. Agricultural Engineer, respectively.

[3]Mona Reclamation Experimental Project Assistant Agricultural Engineers.

The possibility of providing farmers with 20 to 60% more water at their fields has led to the initiation of a major study at the Mona Reclamation Experimental Project to evaluate lining materials which can reduce watercourse losses. These materials and designs cover a range from 13 inch thick, vertical, masonry walls built on a masonry base, through trapezoidal shaped sections of thin concrete, brick or soil cement brick, to packed earth sections. This report outlines observations in the latter category at the Mona Project and at the Shadab area (near Lahore) by members of the Mona and IRDP staffs.

Methods

Most of our previous observations on rates of water losses in watercourses have utilized flumes to measure water losses under normal flow conditions. However, losses large enough for flumes to measure accurately usually require a thousand feet or more of watercourse length. Consequently, the ponding method was used in this study where we desired to identify areas on watercourses with high or low losses as determined by the conditions of the banks or the methods used in their construction.

The ponding method consists of filling the watercourse with water (to at least the normal flow depth) and then measuring the rate at which the water level recedes. Knowing the area (width and length) of the watercourse surface allows calculation of the rate of loss.

As an example, a 305 foot long branch watercourse had been used by a farmer for two hours to irrigate his fields. The watercourse flow rate was estimated at 3.0 cusecs. When the farmer had finished irrigating his field, the outlets from the watercourse to the field were closed and the inlet from the main watercourse into this branch was closed a few minutes later when the water level in the branch was 0.03 feet above the level noted during irrigation. The rate of fall of the water surface is plotted in Figure 1. Through this range of fall, the average width of the watercourse did not change by more than 10% from the measured five feet, and consequently the rate of loss in cusecs per 1000 feet of watercourse length is approximately 5 x 1000 x feet of fall/second. The fall rate was about 0.23×10^{-3} feet/second when the water level reached the "operational" level and had decreased to 0.067×10^{-3} when the water level had fallen 0.26 feet below the operational level.

These rates of fall correspond to water losses of 1.0 cusecs/1000 feet and 0.34 cusecs/1000 feet respectively. The decline in rate of loss with decreasing head is more rapid than the change in head would predict if the permeability of the wetted periphery were uniform, indicating that

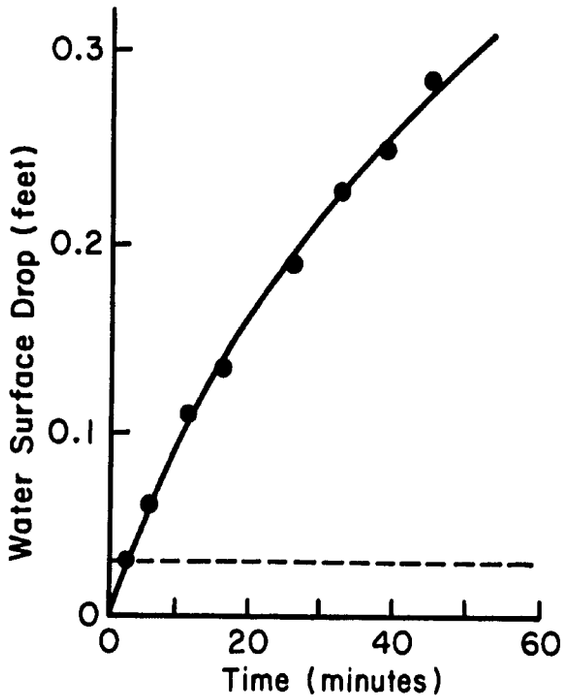


Figure 1. Water loss from branch watercourse with sod banks in sandy loam.

permeability of the upper zones of the bank (0 to 0.27 feet below the normal operating water surface) are much more permeable than the rest of the perimeter. The average infiltration rate into the wetted perimeter was 0.15 x 10^{-3} feet per second 96.5 inches/hour) when the water was at normal operating level and 0.04 x 10^{-3} feet per second (1.7 inches/hour) when the water table had fallen one quarter of a foot below that level. Rates of infiltration in adjacent irrigated fields are less than 0.5 inches/hour after they have been wet for over two hours. The soil texture along this watercourse section is a sandy loam.

Another watercourse section 200 feet away had recently been constructed by the farmers on a soil that is similar and slightly sandier. Two hundred and ten feet of this watercourse was divided into seven watercourse sections labeled A to G, which were treated as follows:

A. Banks removed and sandy subsoil, free of large roots was used to build the banks, which were stepped on to make them reasonably solid as they were built.

B. Left with loose banks full of old sugarcane roots and crowns, grass sod and other organic matter.

C. Identical to A.

D. Identical to B except a few of what appeared to be rodent holes were noted in the bottom of this section.

E. Compacted by stamping on the top and inside of the bank, leaving the organic materials put there by the farmer.

F. Identical to D.

G. Same as E.

Results in Sandy Soil

The rates of water surface fall in section A - D are plotted in Figs. 2 and 3. Section D lost water most rapidly. There were two holes in the bottom of this section into which water ran rapidly, which accounted for the difference in loss rate between this section and sections B and F. These holes were about 2" in diameter and looked like rodent holes. However, water continued to run into them at a rapid rate as long as water was in the watercourse. This indicates that these holes connect to an extensive network of tunnels below the earth surface into which the water can run and through whose walls permeability is sufficiently rapid to maintain a flow rate down the hole of over 0.02 cusec. The flow rate into these holes was essentially

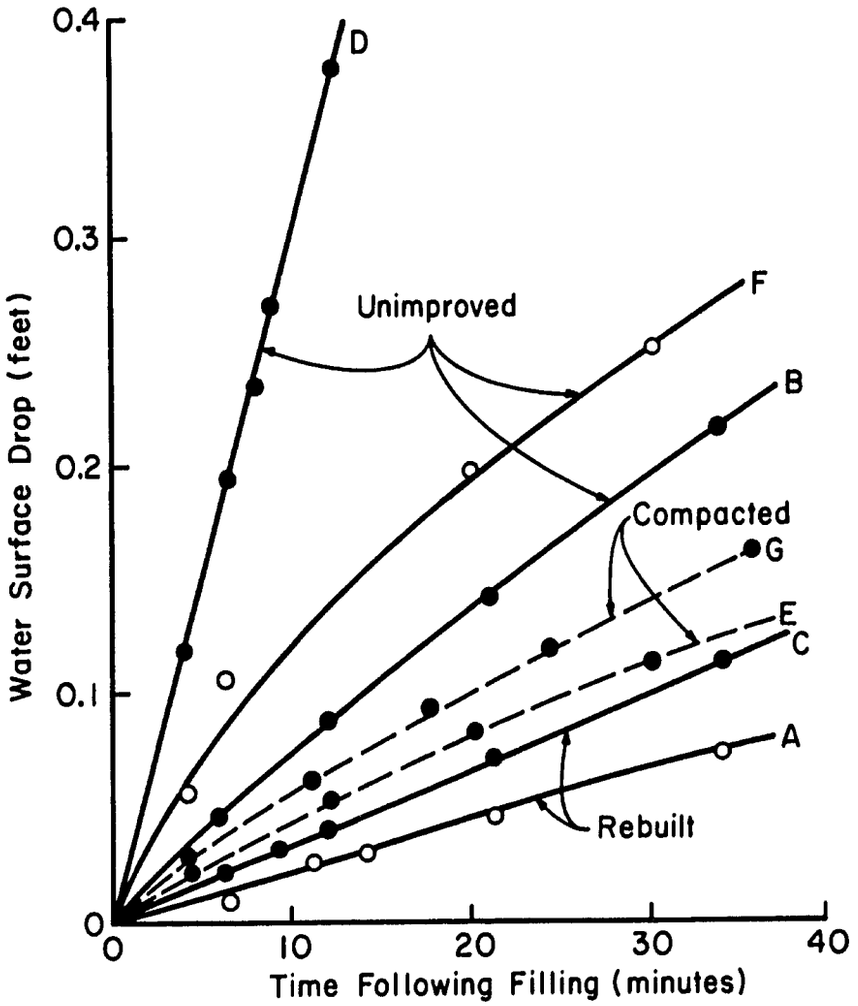


Figure 2. Water loss from newly constructed sections of a watercourse in loamy sand soil.

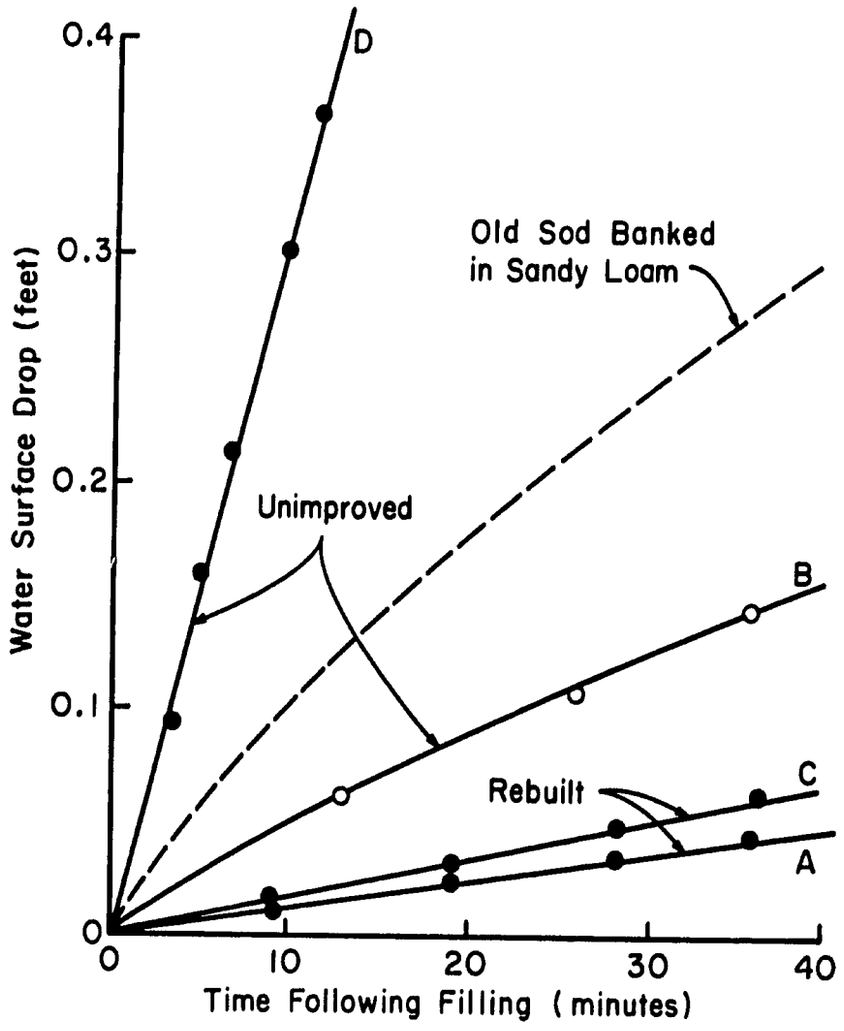


Figure 3. Water loss from newly constructed watercourse sections in loamy sand following second filling.

unchanged during the second filling. These holes are easy to plug once they are located. The loss rate (see Table 1) out of the unimproved sections, B, D and F following the first filling were 0.38, 1.54 and 0.44 cusecs per 1000 feet respectively, for an average of 0.79 cusecs/1000 feet. Sections E and G in which the banks had been simply compacted had loss rates of 0.14 and 0.16 cusecs/1000 feet for an average of 0.15 cusecs/1000 feet following the first filling. In Sections A and C the banks had been removed and rebuilt with soil free of sugarcane stumps and other large organic materials. Loss rates in these sections were 0.10 and 0.16 cusecs/1000 feet for an average rate of 0.13 cusecs/1000 feet following this first filling. Following the second filling the average rates of loss in the unimproved and rebuilt section were 0.83 and 0.04 cusecs/1000 feet respectively. If section D is removed from consideration on account of the large holes, the average rates of loss in the unimproved section is 0.13 as compared to 0.04 cusec/1000 feet in the rebuilt section.

For comparison, loss rates from the old sod bank sections are shown in Figure 2 and in Table 1. After being wet for over two hours, the loss rate from this watercourse was still about 0.75 cusecs/1000 feet. Since the soil of the rebuilt section is even sandier than at the old sod bank section, it appears that in these sandy soils, loss rates can be reduced (at least temporarily) from around 0.75 to less than 0.10 cusecs per 1000 feet by removing the porous organic matter filled banks and rebuilding them with relatively "clean" loamy sand soil.

Results in Loam Soil

At the Mohlenwal Kurd Watercourse, near Lahore, there is a watercourse leg which runs through old sod bank sections to the edge of a four acre piece of recently leveled land. About four months prior to this study, a new ditch 440 feet long was constructed through this land. Some weeds and grass have begun to grow on the banks of this new watercourse section, but it is still essentially free of the mass of roots, old sod, etc., that characterize the sections above and below this field. It was observed that while soil for several feet on each side of the old sod sections was wet from seepage following an irrigation turn, there was little evidence of seepage outside the banks of this new watercourse. Since the soil texture is a fairly uniform loam in this area the seepage differences appear to be associated with the presence or absence of organic matter, insect and rodent burrows, etc., in the banks. To quantify differences in loss rates from these watercourse sections, the following sections were filled and bunded.

Table 1. Characteristics of Watercourse Sections.

	Water Surface Fall Rate At Operating Level (Ft/sec)	Operating Characteristics Width Feet	Depth Feet	Cusecs Loss per 1000 ft. Watercourse	Operating Flow Rate Cusecs	% of Flow Lost per 1000 ft.
Sections of the Watercourse serving T.W. 78 at Mona						
Sod banks in sandy loam	0.15×10^{-3}	5.0	1.3	0.75	3.0	25
Rebuilt Section A in Loamy sand	0.03 "	3.3	1.1	0.10	2 Est.	5
Unimproved Sect. B in Loamy Sand	0.15 "	2.5	1.1	0.38	2 Est.	19
Rebuilt Section C in Loamy Sand	0.05 "	3.2	1.1	0.16	2 "	8
Unimproved (holes) D in Loamy Sand	0.55 "	2.8	1.1	1.54	2 "	77
Packed Section E in Loamy Sand	0.05 "	2.7	1.1	0.14	2 "	7
Unimproved Section F in Loamy Sand	0.19 "	2.3	1.1	0.44	2 "	22
Packed Section G in Loamy Sand	0.06 "	2.6	1.1	0.16	2 "	8
Second Filling Section A	0.010 "	3.3	1.1	0.03	2	2
Second Filling Section B	0.053 "	2.5	1.1	0.13	2	7
Second Filling Section C	0.015 "	3.2	1.1	0.05	2	3
Second Filling Section D	0.55 "	2.8	1.1	1.54	2	77
Sections of the Watercourse at Mohlenwal Kurd (Shadab)						
Old Sod Banks above Rauf Field (a)	0.021×10^{-3}	2.7	0.9	.057	0.48	12
Middle Section in Rauf Field (c)	0.011 "	2.5	0.8	.027	0.48	6
Compacted Section in Rauf field (b)	0.003 "	2.7	0.7	.008	0.48	2
Sod Section below Rauf Field (e)	0.20 "	2.7	0.7	.54	0.48	112
Second Sod Section below Rauf Field (f)	0.063 "	1.7	0.7	.11	0.48	23
Section in lower end Rauf field (d)	0.008 "	2.7	0.7	.022	0.48	5

a. The 200 ft. long old sod bank section immediately above leveled field. This section had thicker and higher than average banks than is normal for the overall watercourse.

b. The first 140 foot section in the Rauf field which was built four months prior to these measurements, on which an extra one or two inches in height had been added to the banks about eight days prior to these measurements. The added soil had been compacted by walking on it.

c. The middle 200 foot section of the watercourse through the Rauf plots was constructed as per farmer practice - had practically no freeboard when irrigation water was flowing, and had a few small leaks at old nakkas, but was essentially free of old organic matter in the banks.

d. The bottom 100 feet of the watercourse in the Rauf plots which had an inch or two of freeboard, banks which were generally at least a foot thick, and had no obvious leaks at previous nakkas.

e. The 200 foot section immediately below the Rauf field which had sod banks and two large holes in the bottom.

f. The second 200 foot section below the Rauf field which had old sod banks, but reasonably good freeboard.

The water surface drop as a function of time is shown for these sections in Figures (4) and (5) and rates of loss computed for when water height in the sections was at the operating level (water level observed while adjacent fields were being irrigated) are given in Table 1.

The continuing high rate of loss in section (e) caused us to believe that the holes in the bottom of this ditch were "piping holes" connected to the river channel which is only about 800 yards away. However, similar holes and rates of losses at Mona T.W. 78 watercourse, where there is no nearby river channel, indicate that these holes may simply be connected to a network of rodent holes which can draw water at a rapid rate for a long period of time. Leaving this high loss, hole affected watercourse out of the considerations, average loss rate for the sod bank sections was 0.087 and for the new sections was 0.016 cusecs per 100 feet. Adding to the banks and compacting them resulted in a loss rate of 0.008 cusecs per 1000 feet as compared to 0.025 cusecs per thousand feet in the uncompacted "farmer built sections".

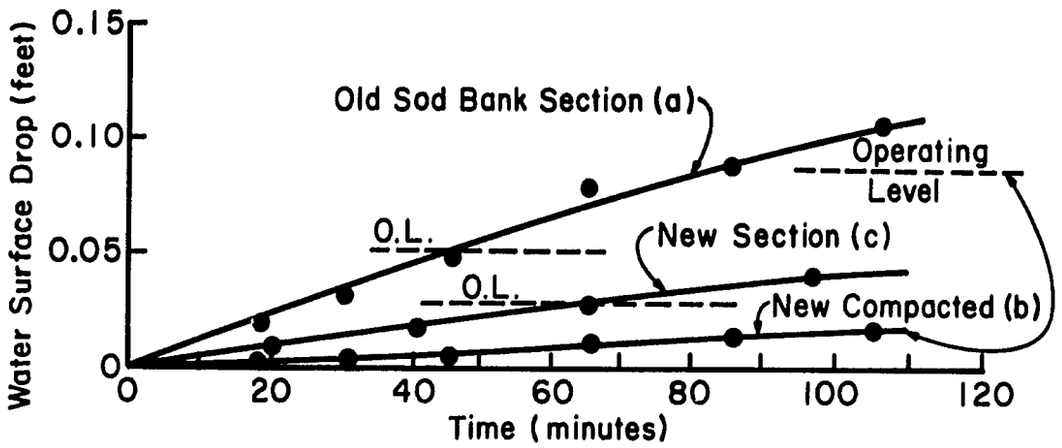


Figure 4. Water loss from sections of Mohlenwal Khurd watercourse in loam soil.

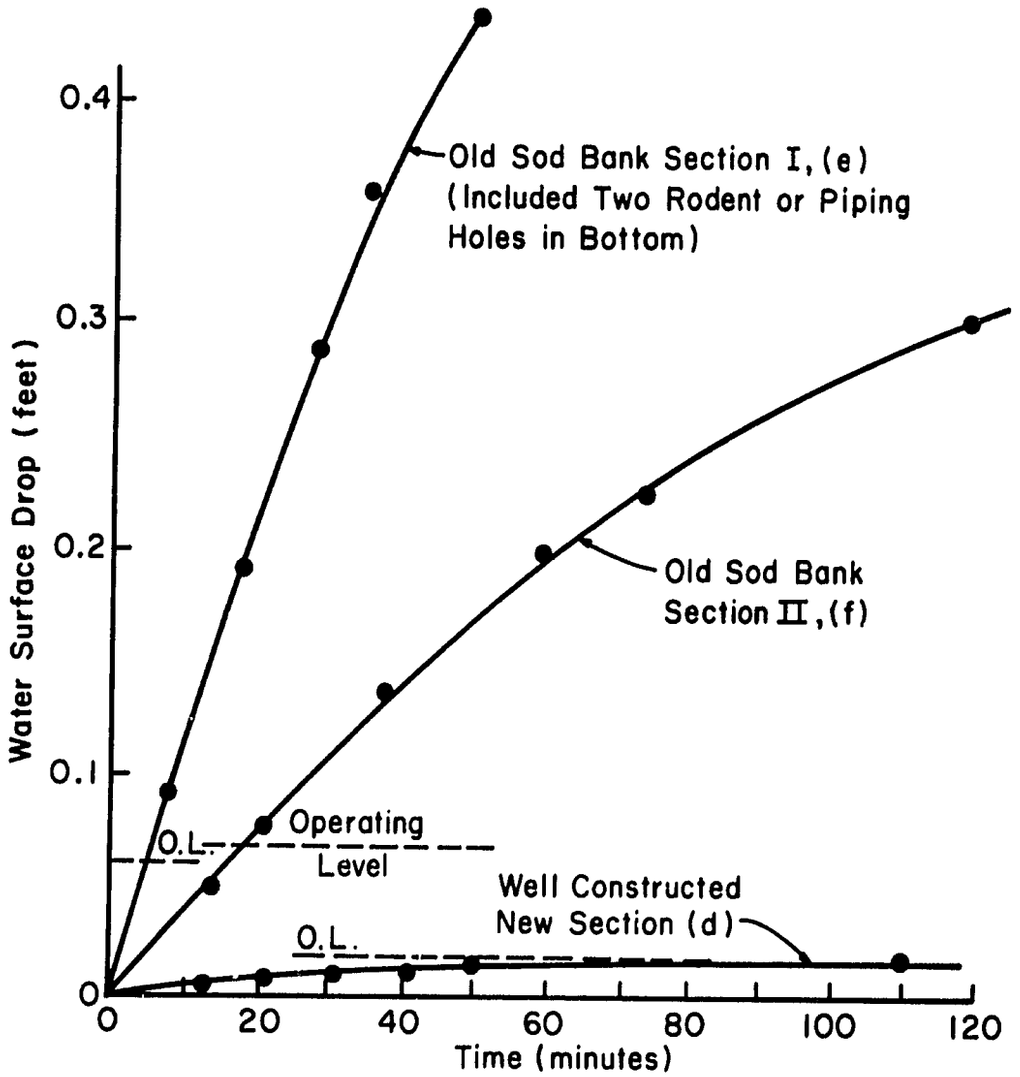


Figure 5. Water loss from sections on and below the Rauf plots of the Mohlenwal Khurd watercourse (loam soil).

While these rates of loss per unit length of watercourse in the loam soil are considerably less than those in the sandy soil, the normal flow in the watercourse in the sandy soil was about four times as great, so the relative losses were somewhat comparable.

In general these data show that rates of loss, while influenced by soil texture, are even more strongly influenced by the presence of rodent holes, and leaky sod banks. These holes can be plugged and the sod banks can be replaced with earth. Decreases of at least 75% in losses was achievable in these sections. How frequently and what type of maintenance and renovation is needed to maintain these low loss rates needs to be determined.

Pucca lining has benefits in addition to temporary decrease in seepage loss, and may still be needed - particularly if farmers will not maintain kacha sections. However, it is clear that new well compacted earth banks can dramatically reduce seepage losses from watercourses to levels which are almost practically negligible in soils ranging from loams to loamy sands.

This limited sample also indicates that holes connecting the watercourse to underground maze of rodent channels may cause a major portion of watercourse seepage losses. Since such holes are easily detected, their closure should be considered as one of the first steps in reducing watercourse losses.

Loss Rates from a Newly Constructed, Poorly Compacted Watercourse

Branch D (4000 feet) of the watercourse serving T.W. 78 at the Mona Reclamation area is a compacted earth, trapezoidal test section designed to carry five cusecs. However, most portions of this branch were compacted only on the surface, after all the fill soil (3 to 4 feet high in some places) had been placed in the banks. There was concern that these uncompacted banks, despite their being 30" high, 18" wide at the top, with a 1:1 slope, would give way when the channel was filled with water. The branch was divided into seven sections between the six drop structures on this watercourse. Each section was filled with water to about four inches higher than the design operating level. Nine sizeable leaks through the bank in the total length of the watercourse began as the sections were filled. Seven of these were stopped by trampling the banks above the leaks in time to prevent major damage although banks subsided from 2 to 8" in the process. Two of the leaks developed into major washouts before they were detected. These washouts were quickly repaired and measurements of the rate of fall of the water surface began within an hour of the time

that the sections were filled. Despite the poorly compacted condition of the banks the loss rates in the six sections measured were fairly low as indicated in Table 2 except for the subsection between drop structures 5 and 6. In this section compaction was particularly poor and several seeps along its sides were apparent. In the rest of the sections the loss rate averaged about 0.07 cusecs per thousand feet. The average loss along the total 4000 foot length of this channel was about 0.10 cusecs per 1000 feet. When this branch watercourse is carrying 4.6 cusecs at the top end, for which it was designed, the total loss in 4000 feet would be about 0.4 cusecs or 9%. This is considerably lower than the average losses measured in the large earthen watercourse in this area, despite the fact that this newly constructed watercourse was poorly compacted.

Potential for Water Savings Through Changing the Composition and Condition of the Watercourse Banks

From these data (Table 2) and previous findings it is apparent that newly constructed watercourses that are reasonably well compacted can have losses which are less than 2 or 3% of the flowing water per thousand feet. These low losses on newly constructed courses compared to high losses on old watercourses are explainable in terms of the observable leaks and observable holes in the upper portions of old sod banks on watercourses. Observations on the banks of the watercourse at tubewell 91 (Mona) indicate that 80% of the leaks were within the three inches of the full flow (canal and tubewell) operating level.

These facts raise the following subsidiary questions in terms of cost of water than can be saved by "renewing" watercourses.

1. How much will it cost to make new banks of a watercourse?

2. How long will it take for natural processes to make the new banks leaky again?

3. Can moderate maintenance (such as weeding the ditch banks) delay the processes which increase the permeability of the banks?

Regarding the first question, rates of construction using the operations indicated in Figure 6 indicate that one beldar can construct from 50 to 100 feet of watercourse per day depending on the size of the watercourse. Assuming a 1 cusec watercourse, 1000 feet long, a beldar should be able to remove the old banks to soil surface level and replace these with good compacted earth at a rate of one hundred feet per day. He should therefore complete the 1000 ft. section in 10 days. If he is paid Rs. 8/day, reconstruction of this 1000 ft. will cost Rs. 80. Assuming that this renovation drops the loss

Table 2. Characteristics of 6 sections of Branch D of the watercourse serving T.W. 78 at Mona.*

Sections between drops#	Water Surface Fall Rate (Ft/sec) At Operating Level**	Cusecs Loss per 1000 feet	Designed Flow Rate Cusecs	% of Flow Lost per 1000 feet
Start - 1	$.014 \times 10^{-3}$	0.08	4.6	1.7
1-2***	.012 "	0.07	4.6	1.5
3-4	.015 "	0.08	4.6	1.8
4-5	.011 "	0.06	4.6	1.3
5-6	.041 "	0.23	4.6	5.0
6-end	.017 "	0.09	4.6	2.0

*Texture of the soils ranges from loam to sandy loam

**This was an average depth of about 1.9 ft. In these basins, formed between the drop structures, water was 3 to 6" deeper at the top than at the bottom ends. At this average depth the width of the water surface averaged about 5.6'

***Section between drop structures 2 and 3 is very short and was not measured.

from .14 cusecs to .04 cusecs/1000 feet, the amount of water saved in 24 hours will be 0.10 x 24 - 2.4 cusec hours which is also 2.4 acre inches or 0.2 acre feet. If that watercourse branch carries flow for 50 days/year and the renovation lasts for one year, the farmer will receive about 10 acre feet of water for an investment of Rs. 80 or about Rs. 8/acre/foot. This compares favorably with private tubewell water, which costs between Rs. 100 and 200 per acre foot (based on charges of from Rs. 4 to Rs. 8/hour for supply from private tubewell delivering 0.5 cusecs to the field).

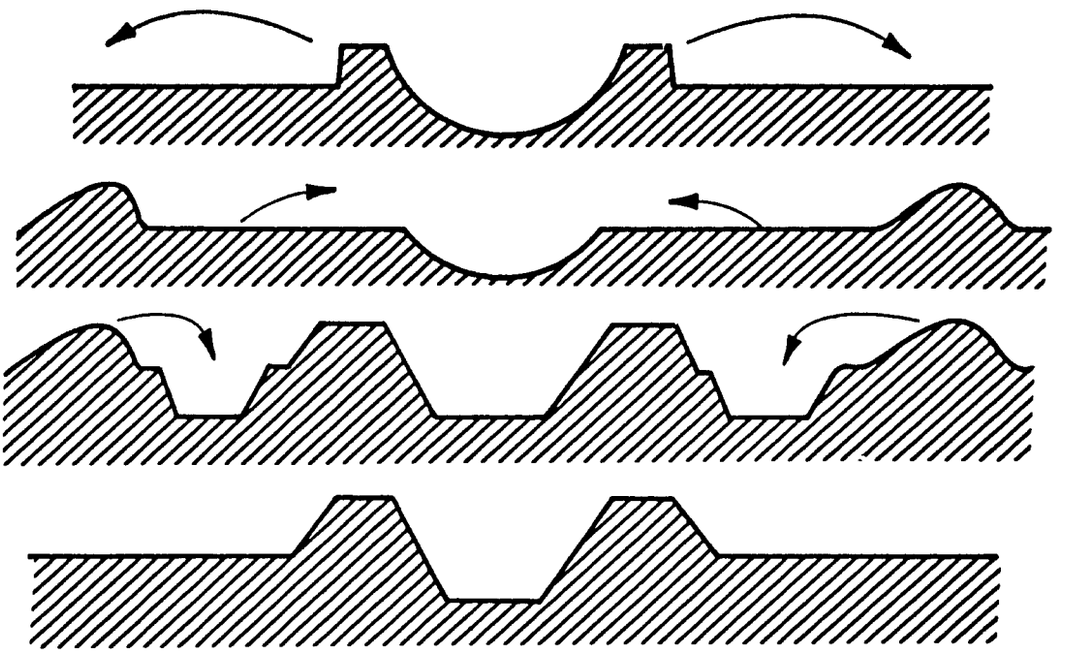
If the watercourse was to carry 4 cusecs, for 50 days/year, the beldar could remake the sides on about 50 feet per day and the savings were about 5% per thousand feet. The cost of the saved water to the farmer would again be Rs. 160 for 20 acre feet, or Rs. 8/acre-foot. Even if the beldars are not well nourished and can do only 25 feet/day, the cost of the saved water would be only Rs. 16/day.

If land adjacent to the watercourse is fallow, the reconstruction process indicated in Figure 6 may be mechanized. Tractor or bullock powered scrapers or karahs may be used to cut away the old porous sod filled banks and carry them into the field. On the return trip, "clean soil" (minimum plant residues) may be brought back and deposited in a 3 or 4 inch layer on the banks and in the watercourse. The soil on the banks may be then compacted with tampers, by foot, or using a small sheeps foot roller (such as the bullock drawn roller) constructed for Mona. The loose soil in the watercourse may then be moved onto the banks with kasis or using a V ditcher. In either case, final shaping and compaction to ensure proper cross section and low permeability is essential. Tractor drawn scrapers to remove the banks and bring clean soil to the pads and tractor drawn ditchers to make the new watercourses should be able to reconstruct as much as 1000 feet of watercourse per hour if operated properly by an experienced driver. Figuring rental on the tractor and the scraper and the ditcher and wages for the operator at Rs. 50 per hour, the cost of reviewing those watercourses could be only 50/1000 feet, which would be cheaper than laborers with kasis. Costs of tractor powered reconstruction will be determined and compared with kasis reconstruction methods.

Bullock powered scrapers and possibly ditchers may also have potential to help farmers improve their watercourses. These have been constructed and will be evaluated for this purpose.

How long a watercourse will stay renewed will depend on:

1. How well the farmers are organized to maintain the improved watercourse,



Steps Using Kassees:

1. Cut Off Banks and Move Away from Watercourse.
2. Borrow Soil from bear Watercourse and Compact in Layers about 3" Thick to Form New Banks.
3. Pull Soil from Old Banks into the Borrow Pit.

Figure 6. Labor intensive reconstruction of a watercourse.

2. whether there are pucca, or kacha nakkas, and

3. what maintenance procedures can be developed.

Resume of Findings to Date

1. Measured losses from watercourses using inflow-outflow measurements with flumes are of the same magnitude as when using the ponding method.

2. From 70 to 80% of the losses in watercourses, on the three soils (loam to loamy sand) studied and using the ponding method, occurred in the porous upper portions of the banks. Most of this loss can be stopped by reconstructing these banks with "clean" compacted soil.

3. Water saved in this manner is much less expensive than water from private tubewells.

ACKNOWLEGEMENTS

The authors express their appreciation to Mr. M. Iqbal and Mr. M. A. Cheema of the Mona Reclamation Experimental Project Staff and to Mr. Shaukat Ghauri of the IRDP Water Management staff who assisted in this study.

Appendix 11

COMPARISON OF WATERCOURSE LOSSES MEASURED BY FLUME AND PONDING METHODS[1]

Field Day Report

W.D. Kemper[2], M. Akram[3], M. Afzal[3], Pervez Iqbal[3] and Wayne Clyma[4]

INTRODUCTION

Reports from the Mona Reclamation Experimental Project and C.S.U. Water Mangement team on Water Losses in watercourses have indicated losses much greater than those previously assumed in planning SCARP development programs in the Indus Basin Irrigation System. The large differences have caused many individuals to raise the following questions:

1. Are the measured losses representative of other areas in the Indus Basin?

2. Are the methods used for measuring the losses adequately precise or biased in any manner?

3. If these new measurements are accurate, what is the reason for such losses?

To help answer these questions, Mr. Mohiuddin Khan and Mr. M. Badruddin, Chief Engineers in WAPDA, organized a meeting of personnel from WAPDA, Harza Engineering and Colorado State University and invited personnel from the Irrigation Department and Integrated Rural Development Program, at which water losses could be discussed in detail.

WAPDA HOUSE SESSION

This meeting consisted of a three hour session on July 24, 1975 at which Director Ashraf of the Mona Experimental Research Project and Drs. Clyma and Kemper of C.S.U. described the losses which have been measured, the methods used for measurement, and their limitations. Personnel from the other

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[1]Based on data collected by WAPDA, Irrigation Research Institute, Harza Engineering, Integrated Rural Development Program and Colorado State University personnel.

[2]C.S.U. Water Management Research Party Chief, Pakistan.

[3]Assistant Agricultural Engineers, Mona Reclamation Experiment Project, WAPDA, Pakistan.

[4]Agricultural Engineer, C.S.U. Water Management Research Project, Pakistan.

agencies asked questions and described their own experiences with measuring watercourse losses. In summary the following water transmission efficiencies and irrigation application efficiencies have been measured over the last three years by MREP, IRDP and CSU personnel on over 30 watercourses in the Lahore, Mona, Mian Channu, Lyallpur and Multan areas.

Water transmission efficiencies are expressed as the amount of water flowing through the nuccas into the field divided by the amount of water flowing through the mogha and are usually multiplied by one hundred so they can be expressed as a percentage. Measured transmission efficiencies have ranged from 15 to 95% with the average about 60%. The losses are due primarily to leakage through the banks resulting from rodent holes, insect holes, old root holes, inadequate filling of old nuccas, erosion and borrowing of soil at junctions which leads to narrow leaky banks and to water used in wetting and filling the watercourse. The biological activity is concentrated in the upper portion of the banks and measurements have shown that these upper positions have much higher permeability. Factors such as silting or growth of vegetation in the channel, which force the operating level of water in the watercourse up to these porous sections of the banks cause large increases in water loss.

Irrigation application efficiencies are defined as the amount of water which the soil can hold in the plant root zone divided by the amount delivered through the nucca to the field. When the amount delivered to the field is less than what could be held by the soil the application efficiency is considered 100%. Measured application efficiencies have ranged from 0 to 100% with an average between 30 and 40%. During December 15 through February 15, average evapotranspiration periods (e.g. March 15 - April 15 and September 15 - October 15) soil holding capacity often exceeds the amount of water applied. However, even during these months over irrigation occurs on some fields. Further details of these measurements may be obtained by writing to C.S.U., P.O. Box 1028, Islamabad.

FIELD SESSION

The next session of this meeting was convened on the Mohlenwal Khurd watercourse in the Shadab area near Lahore on July 25, 1975. There was no water in the canals near Lahore so Mr. Moh'd Hussain who owns an electric powered tubewell and land in that area was asked for permission to make measurements on his watercourse.

I. OBJECTIVES OF THE STUDY

Basically the objectives were to demonstrate and compare methods for measuring watercourse losses and to observe watercourse losses and determine their cause.

II. METHODS USED

A. The Flume Method

1. General Procedure

The most common procedure has been to install flumes at two points on a watercourse and subtract the flow that takes place through the second flume from flow taking place through the first flume to obtain a measure of the loss from the watercourse between the two flumes.

2. Site Selection

A site must be selected in which the head loss caused by the flume will not cause the water to overtop the watercourse. Building up the banks in the section above the first flume to prevent overtopping is allowable. Overtopping between the two flumes as a result of raising the water level at the second flume would cause an over estimate of the normal watercourse losses and must be avoided. In watercourses such as the one selected for measurement in this study, where the water level approaches the top of the banks, it is essential to minimize the head loss at flumes and often necessary to operate these flumes in a submerged condition where the head loss can range from 0.04 and 0.10 of a foot. In this range the precision of the measurements is about plus or minus 5% of the flow rate measured. Consequently, fairly long stretches of watercourse must be involved between the flumes so the losses will be sufficiently larger than the experimental variation.

3. Equipment

Cutthroat flumes developed by Prof. Skogerboe at C.S.U. were used. These flumes are available in the whole range of sizes and are manufactured in Pakistan. The head loss at these flumes is approximately inversely proportional to the width of their throats, and the accuracy of the measurement generally improves as the headloss increases. If there is sufficient slope on a watercourse that a few tenths of a foot of head loss does not cause appreciable backing up of the water and moving water into more permeable sections of the bank, a narrow flume should be used. For instance, when flows are less than one cusec, a flume with a 4" wide throat could be used. However, the watercourse measured in this study had little freeboard so the flumes with throats 8" wide were used in order to minimize the rise of water in the watercourse. The flume was also placed in a section of the watercourse where a small increase in head would not appreciably affect the over loss from the watercourse.

Studying calibration tables for these flumes shows that there is a transition zone, as one goes from free flow to submerged flow, in which additional variation may occur. Generally, it is best to avoid these variations by raising or lowering the flume at the time of installation so that the flow is either definitely in the free flow or definitely in the submerged flow range.

These flumes have been calibrated with the base in the horizontal position and with the water flowing directly to the flume. Consequently, they must be installed with the flume floor completely horizontal in both the direction of flow and at right angles to the flow. A small spirit level is generally used to assure that these conditions are met.

4. Head Changes, Watercourse Storage and Slope

If the difference in flow between the first and second flumes is to be taken as a measure of the amount of loss from the watercourse, the amount of water in that watercourse must not be changing appreciably at the time that these measurements are taken. In other words, the water level in the watercourse should be constant and should not be either rising or receding. If the rate of flow coming into the watercourse is relatively constant this steady condition is generally met after a reasonable period of time. The length of this time is dependent on the length of the watercourse section, the average width of the watercourse section, the rate of flow and the slope of the watercourse. Generally, a volume of water equal to about twice the volume of the watercourse section to operational level must be passed through the first flume before the steady condition at the lower flume is attained. In some cases, where the infiltration into the banks of the watercourse is relatively rapid, an even longer period of time must be allowed before representative loss measurements can be obtained.

5. Conditions Under Which Flume Measurements of Losses are Recommended.

If measurements are desired during the time when the farmer is actually using the water, flow measurement using flumes is the recommended procedure for loss measurement. The allowable headloss in this flow measurement must be as great or greater than 0.04 of a foot for reasonably accurate flume measurements. Measurements of flow accurate to within plus or minus 4% can be obtained if the allowable head loss is as great as 0.20 of a foot. In general, the accuracy with which the measurement can be taken and the rate at which water is leaking out of the watercourse per unit length of watercourse determine the distance over which measurement losses can be taken. For instance, if a watercourse is losing 20% of its water per thousand feet at least a thousand feet

of watercourse length must be included between the flumes if the loss measurement is to be accurate within ± 10 percent of its absolute value (i.e., ±2R of the total flow rate). If the flume is being used under submerged conditions, two thousand feet of watercourse will be necessary to achieve the same degree of accuracy.

Total watercourse transmission efficiencies can be measured in watercourses by measuring all the water that comes out of a watercourse through nuccas to the fields and dividing this by the total amount of water that comes into the watercourse through the mogha. In cases where monitoring of practically all the nuccas has been possible through an extended period of time (e.g., "Where Water Goes In A Watercourse", C.S.U.-Mona Report) "operational" losses, such as filling watercourses, broken bunds, etc., cause total transmission efficiencies to be considerably lower than the steady state values commonly used to estimate transmission efficiencies.

B. Ponding Method

1. General Method

Water is introduced into a section of the watercourse which is then closed at both ends and the rate at which the water level recedes is measured. The volume of water leakage out of the watercourse is calculated from the rate at which the surface recedes and measures of the width and length of the section. This method cannot be used while water is being delivered to the farmer's field and the seepage out of the watercourse during the time of measurement is a loss of water to the farmer.

2. Equipment

A measuring tape or yardstick is needed to measure the width of the watercourse and a one foot rule, marked off in hundredths of a foot or in tenths of an inch to measure the height of water in the watercourse. A watch with which to measure the elapsed time and a shovel or kusie to build the dams at the ends of the sections are the basic equipment needed for this measurement.

3. Length of Section versus Slope

This method is not well adapted to use on long undivided sections, particularly when the watercourse has considerable slope through such sections. Immediately after the two ends of a section are closed, the water level is considerably higher in the upstream end. This water continues to flow downstream, raising the elevation at the lower end and decreasing the elevation at the upper end until the surface is level. If the section is several hundred feet long, these adjustments will continue for several minutes after the ends

are closed. If the cross section is large and if the channel is free of weeds and grass, oscillation of the surface may actually occur back and forth in this channel for 20 or more minutes after the ends are closed. Under all conditions it appears that these readjustments of the water surface will have the least effect on a measurement of rate of water recession in the watercourse if the measurement is taken at a point which is equally distant from the two ends of the section. It is generally best to place the measuring rule in the water anchoring it firmly in the soil at the bottom of the watercourse with a selected point on the rule even with the level of the water in the watercourse. It should be done, if possible, while the water is flowing to the farmer's field under natural conditions. The watercourse should then be filled to a level slightly in excess of this normal operating level and rate of fall of the water surface should be determined by measuring the height of water at frequent intervals. The slope of the height of water level versus time curve is the rate of fall. As this line crosses the normal operating level, the rate of fall can be used with the surface area of the water in the section to estimate the rate of loss in that section under the operating condition.

4. When to Repair Banks and Bunds

When a watercourse is filled to a level above the normal operating level some banks may be overtopped. If no erosion is taking place and the water is not doing damage to adjacent lands or crops, it is best to allow this overflow to continue since it is a phenomena which will occur if the water in the watercourse is raised to that level. On the other hand, if the over flow is washing away soil rapidly so the bank or bund is changing shape and the leakage channel is becoming larger then the leak should be stopped.

5. Conditions Under Which the Ponding Method is Recommended

When detailed information concerning the losses of water along several short sections of the watercourse is needed, the ponding method is well adapted to obtaining those measurements. The ponding method is also useable when two or more treatments are to be compared along a watercourse because short sections of even 20 or 30 feet in length are adequate to make a test using this method. In general, water losses determined by the ponding method are about as accurate as the measurement of the surface area of the water in the watercourse.

III. LOSSES MEASURED

A. With Flumes

The general layout of the watercourse is shown in Figure 1. The water originates from the tubewell shown in the bottom left corner. It was turned into the test section[1] through flume #2 at 0845 hours. This test section carried water to the sorghum field indicated in the upper right on Figure 1. The first water reached this sorghum field at approximately 0912 hours. Flume #3 was installed in the watercourse about 15 feet in front of this nucca. The flows measured through flumes #1, #2, and #3 are shown in Figure 2. When the steady state had been achieved flow through flume #2 was 0.36 cusecs, the flow through flume #3 was 0.125 cusecs.

B. Using the Ponding Method

At 1100 hours one member of the group went up the watercourse setting measurement rules in the watercourse with the zero mark on the one foot rules one inch above the operating level and the one inch mark was therefore level with the surface of the water. These were placed at the midpoints at each of the four sections indicated in Figure 1. The nakka leading into the sorghum field was then closed and the level of water in the fourth section was raised until it was almost one inch above the operating level. Then a dam was thrown across the upper end of the section and readings of elevation of water were taken as a function of time as indicated in Figure 3. Each section was successively filled and the recession rates were measured as indicated in the data points of Figure 3. During the same period of time, two men proceded up the watercourse measuring the width of the water surface and the depth of water in the channel above every 50 feet along the watercourse. The averages of these measurements are shown in Table 1.

At about 1140 hours a break occurred in the bund which had been used to close the nakka into the sorghum field and water flowed out of section 4 rather rapidly until the break was closed about five minutes later. This break accounts for the inflection seen in the curve of section 4 shown in Figure 3. A few other small breaks occurred in bunds which had been constructed to retain the water in the sections, during the time that they were being filled to levels higher than the operating level. These were closed quickly and made no noticeable impression on the curves representing the other three sections.

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[1]This test section was 1245 feet long and contained a few inches of water through much of its length as a result of leakage into the section from adjacent irrigated fields and of recent rains.

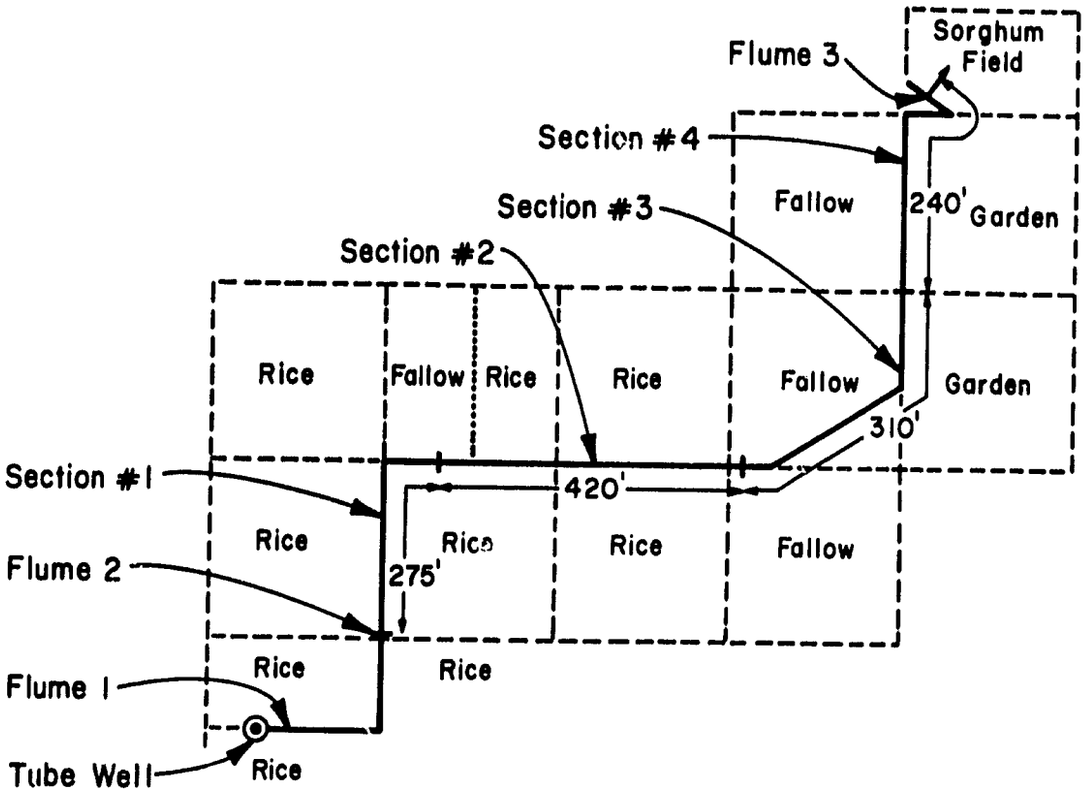

Figure 1. Traditional watercourse, Village Mohlanwal-Khurd, Lahore.

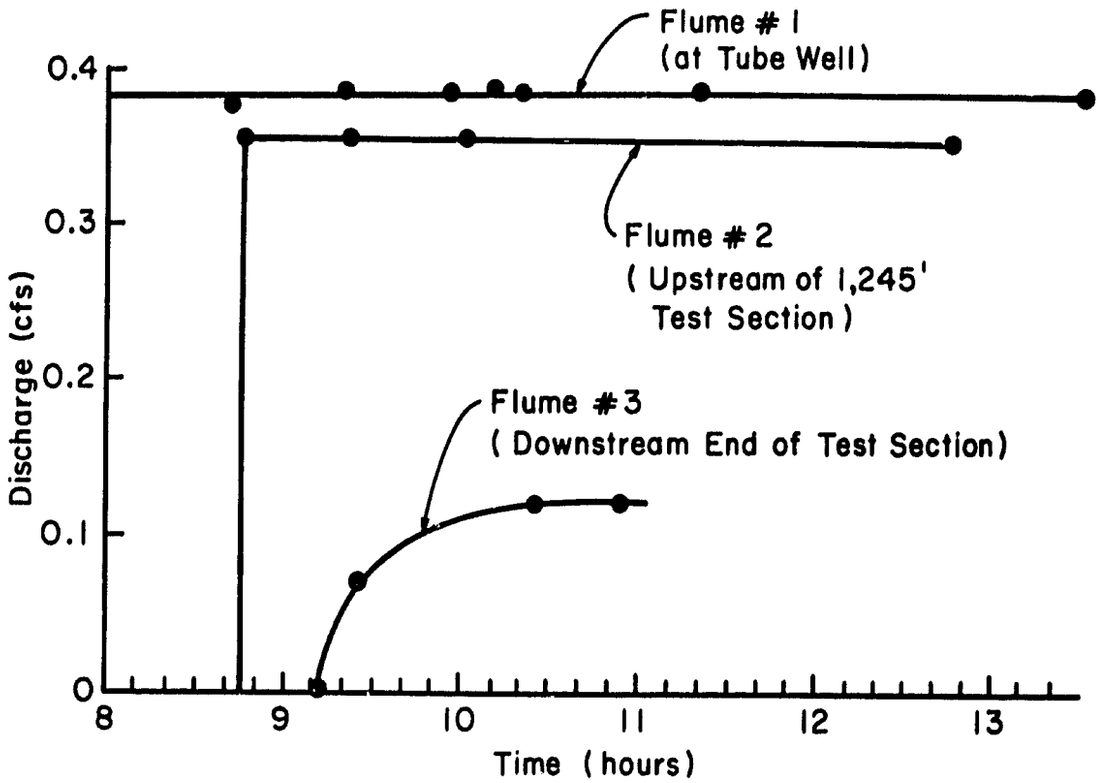

Figure 2. Flow measured at flumes indicated in Figure 1.

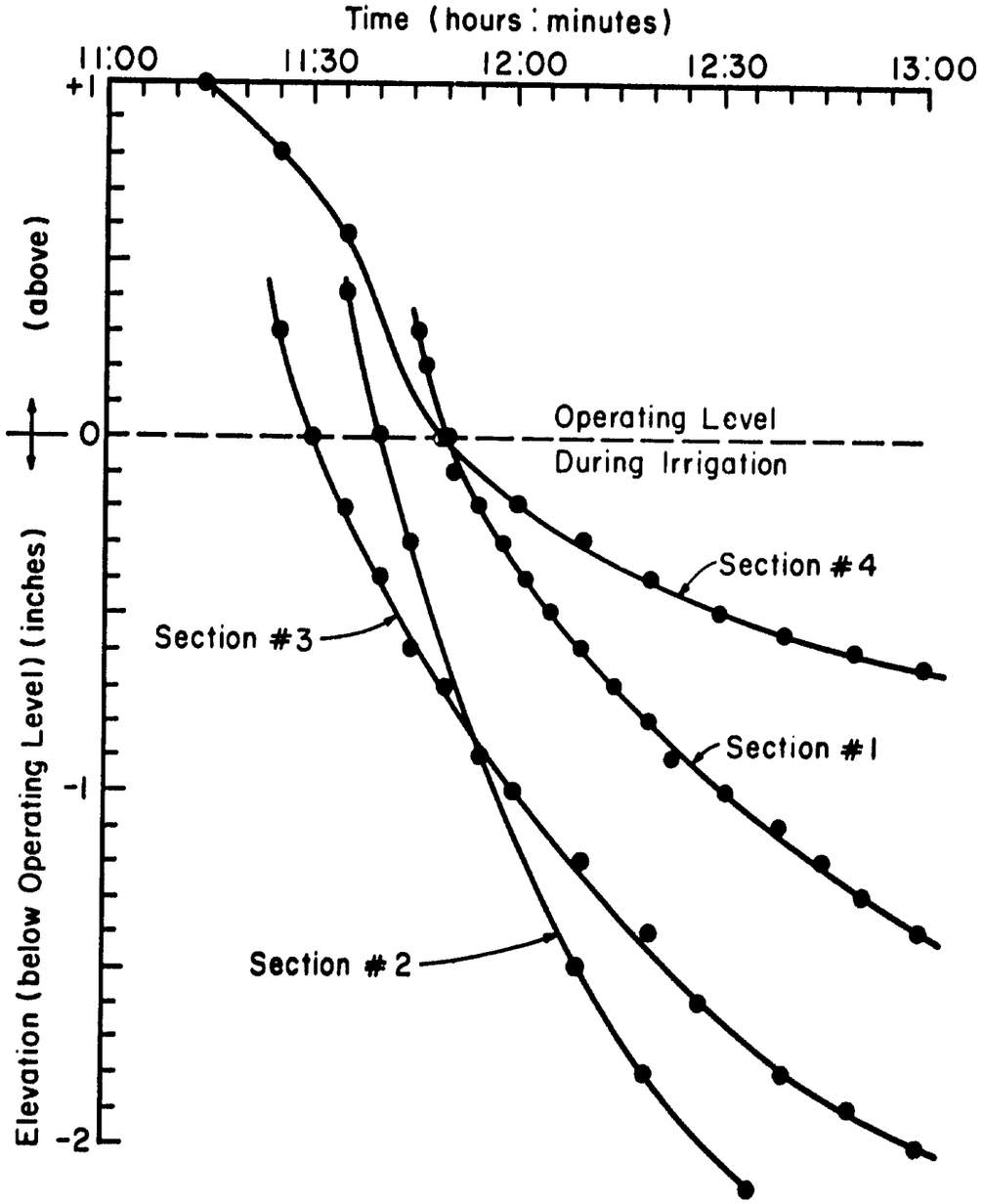

Figure 3. Recession rate of water surface in the four test sections indicated in Figure 1.

Table 1. Measured and Calculated Data on Watercourse Sections

Section Number	1	2	3	4
Length (ft.)	275	420	310	240
Width (ft.)	3.5	3.8	3.9	2.4
Surface area ($ft.^2$)	962	1596	1209	1056
Rate of Fall (ft/sec)*	.000070	.000093	.000068	.000029
Loss Cusecs	.067	.148	.082	.030
Water Depth (ft.)**	.80	.93	.85	.66
Wetter Perimeter (ft.)	5.1	5.7	5.6	5.7
Total Wet Surface ($ft.^2$)	1402	2394	1736	1368
Loss Rate (Cusecs/$10^6 ft.^2$)	47	62	48	22

*This rate of fall of the water surface is calculated when the surface was at the operational level.

**Measured in the watercourse.

COMPARISON OF LOSS RATES USING FLUME AND PONDING METHODS

Loss measured by flume = 0.360 -0.125 = 0.235 cusecs

Loss estimated by ponding method

Section	Loss (cusecs)
1	.065
2	.148
3	.084
4	.030
TOTAL	.327 cusecs

An estimate of the rate of water loss from this watercourse during its use for water transmission can be obtained from these ponding measurements. By taking the slope of the lines from Figure 3 as these pass through the operating level, the rates of recession of water surfaces may be calculated in feet/second. These rates of recession may be multiplied by the water surface area (square feet) of their respective sections to yield the rates of loss (cusecs) from the respective sections. These slopes and flow rates were calculated from Figure 3 and are expressed in Table 1 along with the related data necessary to make the calculations of loss rates from each section. Since the loss rates in the four sections showed significant differences, a description of these sections is given below.

Section #1 was between rice fields with an operating water level about four inches above the level of water in adjacent flooded rice fields.

Section #2 was between flooded rice fields with a sod filled trimmed narrow banks (on the left hand side facing downstream) and an operational level about six inches above the water in the rice field on the left.

Section #3 was primarily between fallow fields with operational level about four inches above the adjacent fields.

Section #4 was through an outdoor kitchen and garden area where heavy human and animal traffic have compacted about half of the banks.

Comparison in Figure 4 shows that section 2 with the trimmed sod filled banks had the highest rate of leakage and section 4 where a large part of the banks were compacted by traffic had the lowest rate of loss. Lowering the water surface in any of these sections to two inches below the operational level reduced the rate of loss to one-third or less of losses at the operational level. Adding the losses from the four sections as estimated by the ponding method (as shown in Table 1) yields a rate of loss about 1.4 times as large as that measured for the total watercourse section using the flumes. The greater loss measured with the ponding method was probably due to a phenomena noted by several participants in these measurements. After the dams had been formed at the two ends of a given section of the watercourse, the head continued to rise at the lower end of that section and to recede at the upper end of that section for several minutes. During this time, some overtopping occurred in the lower ends of these sections and the loss rate due to overtopping was undoubtedly greater than the concurrent reduction in loss caused by a lowering of the water level at the upper end of these test sections. This phenomena

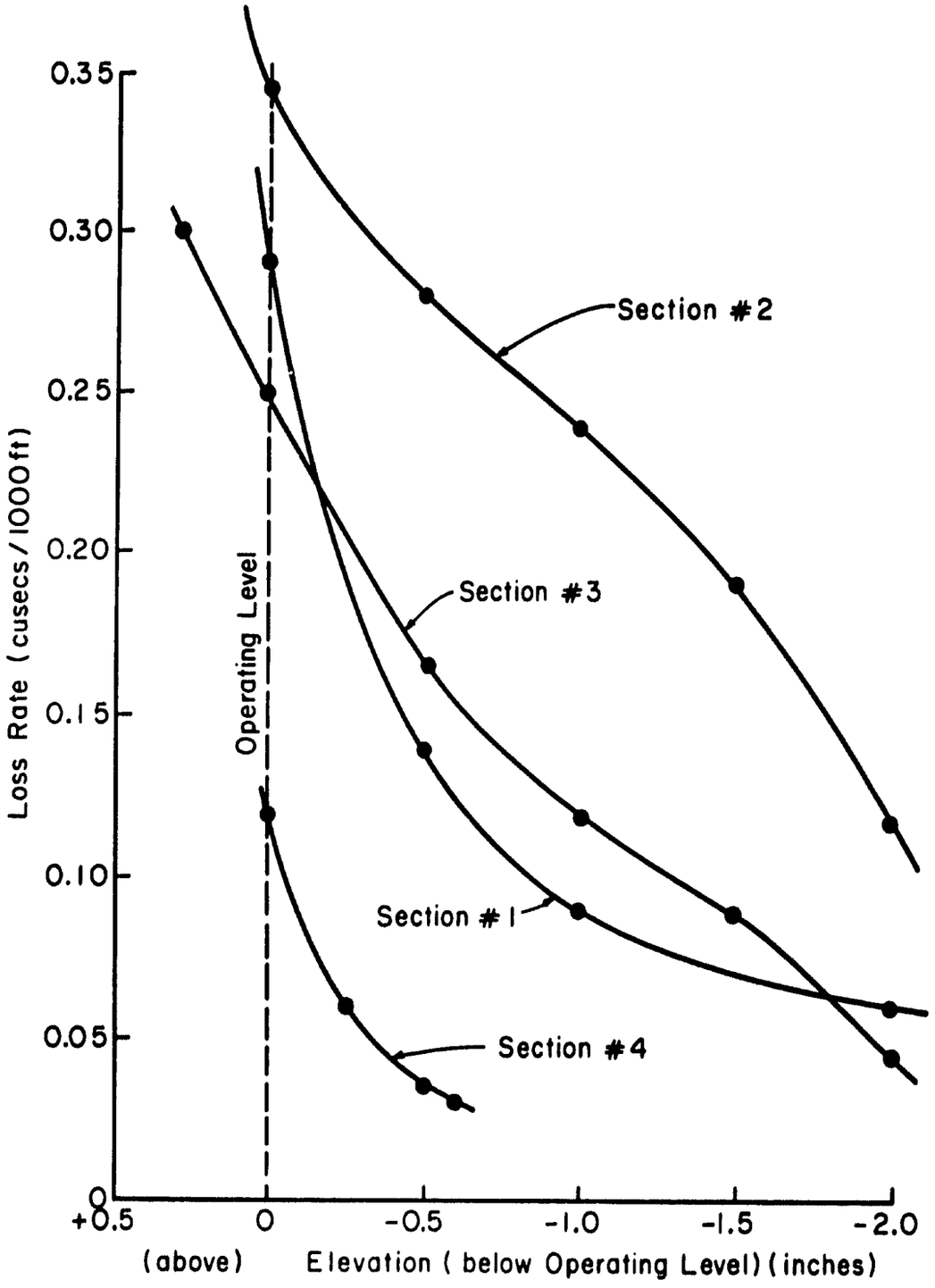

Figure 4. Effect of water surface height in watercourse on rate of water loss in sections shown in Figure 1.

could have been reduced to a small fraction of what occurred in this study if the sections had been reduced in length to about one hundred feet.

Most of the channel was overgrown with grass. This grass reduces the velocity of water and causes a given flow of water to occupy a larger cross section (higher level) of the watercourse. After the water had leveled in each section, differences in levels between sections could be measured across the dams in the watercourse. It was apparent that there was a total fall of about a foot on this 1,245 feet long watercourse. Depths of water during operation in this watercourse were about 0.8, 0.9, 0.9, and 0.7 in the sections 1 to 4 respectively. The use of Mannings equation indicates that watercourses of these sizes and slopes will carry over 0.7 cusecs of water at an operational depth of 0.5 feet when they are reasonably free of grass.

Consequently, it appears that Mr. Hussain can lower the operational level in his watercourse by more than two inches by removing the grass. He should reduce his losses to about 0.08 cusecs in this test section and should increase delivery to his sorghum field from the present 0.13 cusecs to about 0.28 cusecs with the supply of water from this well.

Assuming that a beldar can clean 40 feet of this watercourse per hour it will cost Rs. 31.00 to clean this 1,245 feet watercourse. Assuming that this cleaning will allow the delivery to be 0.3 cusecs instead of 0.13 cusecs, for five irrigation turns of 24 hours each, about 20 acre/inches, or 1.7 acre feet of water would be saved. The cost of this extra water delivered to the field would be 21/1.7 = Rs. 20.00/acre foot.

When Mr. Hussain sells water to other farmers he charges Rs. 4.00 per hour. Since the flow at the well is about 0.4 cusecs, the buyer of the water is paying approximately Rs.10.00 per cusec hour which is equal to Rs.120.00/acre foot at the well. Moreover, if the recipient has the same rate of loss as occurred in this study (64% loss during steady state, but probably 75% loss if water required to fill the watercourse is considered) the cost of water reaching the field will be Rs.360.00 to 480.00 per acre foot of water.

Accepting these assumptions, measurements and calculations, it is apparent that farmers in this area with tall grass in their watercourse can increase their water supply in the field at low cost by cleaning and maintaining the watercourses. Investment in tubewell water is comparatively a much more expensive source of water for the farmer.

IV. CONCLUSIONS REGARDING THE WATERCOURSE LOSS MEASUREMENTS

Losses measured on the 1,245 feet watercourse using flumes were 0.24 cusecs. Losses measured on the 4 sections of this watercourse using the ponding method (and evaluating recession rate at water levels which on the average were equal to the operational level) totalled .33 cusecs. Greater loss using the ponding method was due, at least in part, to levels of water in the lower ends of the sections exceeding the operational levels, and the high rates of loss that occurred as water levels increased. The greater losses resulting from this unequal level of water in these ponding sections would have been reduced to a practically negligible level if the sections had been reduced to 50 or even 100 feet in length.

Both methods, when used carefully, provide good estimates of watercourse loss. However, it is apparent from Figure 4 that the loss rate is highly dependent on the level of water in the watercourse. When the water level dropped an inch below the current operational level, losses could be reduced to half their current values. These results emphasize the potential of frequent cleaning of watercourses to reduce water losses.

These loss rates are percentagewise, higher than the average measured by the Mona, IRDP and CSU water management teams. The greater loss was probably due in part to more than the average amount of tall grass in this watercourse.

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Appendix 12

WATERCOURSE LOSSES[1]

Wayne Clyma, Arshad Ali and Mohammad Ashraf[2]

Watercourses in Pakistan are the important link that carries water from the mogha to the farmer's field. Pakistan has a truly modern irrigation system from the barrage to the mogha. However, a review of almost any watercourse in Pakistan results in the conclusion that the watercourse is improperly designed, improperly operated and poorly maintained with the result that a considerable amount of the already inadequate water supply never reaches the farmer's field. This paper will review briefly the functions of a watercourse, discuss the causes for losses, present the results from measurements of losses and propose a program of watercourse improvement.

FUNCTIONS OF A WATERCOURSE

A properly designed watercourse should carry the design flow with a freeboard of at least six inches and not result in excessive deposition or erosion of sediment within the watercourse. The water should be delivered at the field with sufficient head to adequately irrigate the field, usually a minimum of six inches to one foot.

The operation of a watercourse should allow delivery of the water without excessive loss, whether at the head or the tail. Dependability of delivery is also essential during operation as a widely fluctuating flow makes impossible the application of a given amount of water on a field. Proper operation of a watercourse requires provisions for either stopping the flow at the mogha, diverting un-needed water into a drainage system or storing the water on the watercourse. During certain periods of time excess water will result and disposal of this water must not be on the farmer's field.

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[1]Paper prepared for presentation of the CENTO Panel Meeting on the Optimum Use of Water in Agriculture, March 3-5, 1975. This research was supported in part by USAID Contract AID/ta-c-1100 Water Management Research in Arid and Sub-Humid Lands of the Less Developed Countries.

[2]Agricultural Engineer, Colorado State University, Water Management Research Contract, Islamabad; Assistant Professor and Chairman, Department of Irrigation and Drainage, Faculty of Agricultural Engineering, Agricultural University, Lyallpur; and Project Director, Mona Reclamation Experimental Project, Water and Power Development Authority, Bhalwal, respectively.

Watercourse maintenance is necessary for proper system operation. Farmers must reach an agreement on the operation of the system and an agreement is also necessary for proper maintenance of the watercourse. Regular maintenance is required in order to retain the proper cross section and grade and in order to prevent excessive growth of grass, weeds, trees and other obstructions as well as to prevent the deterioration of diversions, nakkas, and sides of the watercourses over time. Without maintenance, a properly designed and constructed watercourse can rapidly deteriorate into an ineffective delivery system.

Because of essentially no engineering design, rigid operational criteria, inadequate maintenance and a sustained neglect in providing farmers with any assistance, an ineffective watercourse distribution system has resulted. The only conclusion possible, after observing farmers on a number of watercourses, is that lack of knowledge and a complexity of social and institutional constraints have resulted in sustained, ineffective operation of water delivery systems from the mogha to the farmer's field. A number of factors have been identified which result in ineffective watercourse operation.

CAUSES OF POOR WATERCOURSE OPERATION

Watercourse losses consist of seepage and spills. Seepage is water that is lost by flowing through the soil in the sides and bottom of the watercourse. Seepage losses are not lost from the water system of Pakistan as the water usually enters the ground water and is available for pumping. When an inadequate supply of water is available, seepage losses are direct losses to the farmer on that watercourse because of reduced crop yields.

Spills involve the loss of water from the watercourse to the ground surface either by overtopping, breakage of the bund and direct flow, and leakage through improperly closed and/or maintained nakkas. Water lost by spillage then either evaporates, is transpired or goes to the ground water from the soil surface outside the watercourse. Spills also reduce crop yields on both sides adjacent to the watercourse by over-irrigation. Seepage has been recognized as a source of loss for water in Pakistan but spills are frequently ignored. In these studies, spills usually equal and frequently exceed the losses due to seepage. Factors which have been identified as contributing to significant watercourse loss are: seepage; inadequate capacity; improper cross section; improper alignment; clogging of the watercourse with trees, grass, weeds and sediment; leaky nakkas; and in-channel storage below the ground surface.

Seepage

Soil type, vegetation within the watercourse, root and rodent holes and excessively wide cross sections due to improper maintenance all increase seepage. Seepage losses on most watercourses are measured in feet per day while infiltration rates of fields are only a few inches per day.

Inadequate Capacity

Many watercourses have been observed with freeboards of 0.01 to 0.1 in. of freeboard. Others had overtopped and the spillage had spread from 50 to 100 feet into adjacent fields. Because watercourses are frequently below ground, the farmer must increase the level in the watercourse to irrigate the adjacent field. This frequently results in additional overtopping.

Improper Cross Section

Bifurcations, buffalo wallows, excessive sediment accumulations requiring frequent cleaning result in increased seepage and spills on many watercourses. Farmers also reduce the thickness of the sides of the watercourse increasing the seepage and resulting in overirrigation of the fields adjacent to the watercourse. To extend a field a few feet, a farmer may damage his crops for 50 feet.

Clogging of the Watercourse

Trees, grass and weeds within the watercourse increase seepage and use water by evapotranspiration. Sediment alters the channel cross section and may submerge the mogha reducing the water supply to the entire watercourse.

Leaky Nakkas

Soil used to maintain the bund cause low areas around many nakkas and leakage causes almost continuous inundation while water flows past the nakka. Improperly closed nakkas develop leaks or completely wash out causing substantial loss of water. In a 500 acre watercourse there are as many as 2,500 potential leaks.

Channel Storage

Many sections of a watercourse are below ground. Corey and Clyma (1973) have suggested that several million acre feet can be lost because farmers are unable to use the water on their fields.

All of the above factors combine to cause excessive seepage and spillage on most watercourses in Pakistan. The

loss is also a function of a number of other factors which have not been carefully studied. These include the effects of flow rate, watercourse length, soil type, frequency of maintenance, and probably other factors. While desirable to quantify all factors, the most significant point is to observe the magnitude of the total loss. By eliminating these obviously significant losses, improvement in delivery efficiencies can be obtained. Data have been collected on watercourse losses in Pakistan, for approximately two years. An evaluation of these losses is presented below.

EVALUATION OF LOSSES

Seepage and spillage does not occur at a constant rate over time and space. Some spillage, such as from leaky nakkas, probably increase significantly at night because it is difficult to see and close small leaks in nakkas during the night time. When SCARP tubewells or private tubewells add water to the canal water already in the watercourse, during the time the added water is present seepage and spills will increase.

Just after farmers have performed their regular maintenance, losses will be less. During some periods of the year the water level in the distributary is above full supply level and the flow and losses in the watercourse will increase. During some periods of the year water is surplus resulting in less maintenance by the farmers and in additional spillage.

Units for Losses

Losses discussed are the average for both seepage and spills. The time period number of locations for which data have been collected provide a preliminary basis for quantifying watercourse losses in Pakistan.

Losses in this paper are defined primarily in terms of delivery efficiency and loss rate in cusecs per thousand feet. Delivery efficiency, E_d is defined as:

$$E_d = \frac{\text{(Flow of water at the mogha)}}{\text{(Flow of water at the field)}} 100$$

Delivery efficiency is a measure of the performance of the watercourse and when combined with application efficiency is a measure of the effectiveness of water use. Loss rate is defined as:

$$\text{Loss Rate} = \frac{\text{Initial flow - Final flow}}{\text{Distance between points in feet}}$$

The units usually used are cusecs per thousand feet. Using a loss rate per unit length permits comparison of different lengths of channels and different flow rates.

Probably the most correct method for reporting loss rate is in terms of a seepage rate. The loss between two locations on the watercourse is measured. The length of the section and the wetted perimeter at several locations in the watercourse is measured. The average wetted perimeter is calculated and the loss rate may be reported as:

$$\text{Loss rate} = \frac{(\text{Initial flow} - \text{Final flow})}{(\text{length})\ (\text{wetted perimeter})}$$

This loss measurement may be reported as a seepage rate. Inches per hour, feet per day, cusecs per million sq. ft. are some of the common units of measurement.

Methods of Measurement

Three procedures have commonly been used to measure watercourse losses. They are:

1. inflow-outflow measurements,
2. ponding measurements,
3. seepage meters.

Inflow and outflow measurements - Measurements of loss by location of appropriate measuring devices at two different locations on the watercourse offer several advantages. Continuous measurements are easy to obtain as measurements do not interfere with regular operation of the watercourse. Loss under dynamic operating conditions are measured and because of this circumstance are frequently more realistic than other procedures. When loss rates are small then errors in the measurement of an inflow and outflow may become a significant part of the loss measured.

Ponding measurements - This procedure involves building a bund at two different locations in a section of the watercourse and measuring the rate at which the water surface recedes with time. The loss measurements can be measured very accurately with a simple staff gauge or rule. Under some circumstances, however, increased deposition of sediment during the ponding measurements may decrease the loss rate. Ponding measurements do not allow the measurement of water losses during operation of the watercourse. Spillage is particularly difficult to evaluate from ponding studies.

Seepage meters - Seepage meters involve apparatus that can be installed within the sides or bottom of a watercourse and the rate of loss through the side of the watercourse measured by volumetrically determining the water loss from the apparatus. Differential seepage losses through the bottom or sides of the watercourse can be obtained at various locations.

Procedure

The data reported in this study were collected using inflow-outflow measurements on a number of different watercourses located in different areas of Pakistan. Rather intensive measurements have been made on two watercourses in the Mona Reclamation Experimental Project in conjunction with a farm water management study. Much of the data were collected in conjunction with an evaluation of the amounts of water applied to a field during irrigation of particular field by the farmer.

On most watercourses in Pakistan because of the flat gradient and the limited capacity, installation of a flume may affect both the seepage and spills that occur on the watercourse. This occurs because the installation of the flume raises the water level in the watercourse. In some areas this resulted in excessive spillage and the flume was removed and no measurements made. Bunds were increased to eliminate losses caused by installation of the flume in other instances. Inflow-outflow measurements were made using the cutthroat flume (Skogerboe, 1972)[1] which has been specifically designed for low gradient irrigation channels for flow measurement with a minimum head loss.

RESULTS

Watercourse losses have been measured at several different locations in Pakistan. Measurements have been made for various intervals of time from two weeks to two years. All data unless otherwise noted represent approximate steady-flow conditions. A brief discussion of the circumstances under which the data were collected is presented for each location.

Mian Channu

In an evaluation of the effects of precision land leveling on farmer practices near Mian Channu, delivery efficiencies were measured for six farms. Measurements were conducted throughout the season for Rabi 73-74. The results are presented in Table 1. Several private tubewells are located on the watercourse and data were collected during periods when both tubewell water and canal water were transported in the watercourse. During the latter part of the season canal flows were increased and the mogha discharge also increased.

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[1] Skogerboe, G.V., Bennet, R.S. and Walker, W.R. 1973. Selection and Installation of Cutthroat Flumes for Measuring Irrigation and Drainage Water, Colorado State University Experiment Station, Fort Collins, Technical Bulletin 120.

Table 1. Delivery efficiencies and average loss rates for unsupplemented and private tubewell watercourses near Mian Channu[1]

Farm No.	Initial Flow Mogha (cusecs)	Initial Flow TW (cusecs)	Initial Flow Total (cusecs)	Final Flow (cusecs)	Delivery Efficiency (Percent)	Distance (ft.)	Losses (cusecs/1000 ft.)
1	1.0	-	1.0	0.80	80	10,800	0.019
2	1.0	-	1.0	0.45	45	8,400	0.065
3	1.0	1.75	2.75	2.00	75	5,000	0.150
4	-	1.50	1.50	1.30	85	1,600	0.125
5	1.05*	1.70	2.75	2.60	95	4,300	0.035
6	1.45*	-	1.45	1.30	90	8,100	0.019

*One week after canal cleaning

[1]Results from "Effects of Precision Land Leveling on Farm Management and Irrigation Practices in Pakistan" by P.G.M. van der Boom and T.L.M.H. Gerards. Unpublished report of Agricultural University of Wageningen, the Netherlands. Agricultural Extension and Farmers Training Center, and Colorado State University.

Multan District

A watercourse improvement program was initiated in 1973 in cooperation with the Integrated Rural Development Program (IRDP) with model watercourses located at the Multan District and at Shadab near Lahore. The results of these measurements are presented in Table 2. The watercourse for Multan involved canal water only with an official flow of 1.9 cusecs.

Flow measurements were made during a two week period in June during the time of rauni irrigations for cotton. Private tubewells are located on the watercourse but they are not normally used in conjunction with canal water. Water was in demand during this period and spillage did not appear to be significant during the time of the measurements.

Shadab

The watercourse usually is supplied by operation of a system of Jalars but gravity flow can be used to irrigate some of the area. Water losses for a section of the watercourse used for a private tubewell were also obtained. Table 3 presents the results. The flow rates from all sources were low but the loss rates were unusually high.

Farmers had extended their fields by cutting into the sides of the watercourse resulting in high seepage rates through the sides. While water flowed through such sections of the watercourse, water would be ponded on the soil surface for 25 or more feet on both sides of the watercourse.

Lyallpur District

Table 4 presents the results of measurements of watercourse losses for a number of non-SCARP watercourses in Lyallpur District. These data were collected over a period of approximately six months to determine delivery efficiencies, irrigation practices and application efficiencies for non-SCARP areas. Data for a wide range of flows at the mogha were collected including some data for watercourses which were supplemented by private tubewells.

As a part of a larger water management study at the Mona Reclamation Experimental Project of SCARP II, three watercourses have been selected for detailed study before, during and after improvements on the watercourse have been made. The results of these measurements are presented in Table 5. The three watercourses are: Tubewell (TW) 78, a perennial watercourse; TW 122, a non perennial watercourse; and TW 137, an uncommanded area.

The seepage measurements at Tubewell 78 represent three different circumstances and these circumstances explain the

Table 2. Delivery efficiencies and average loss rates for canal water only on a watercourse in Multan District.

Initial Flow (cusecs)	Final Flow (cusecs)	Delivery Efficiency (Percent)	Distance (ft.)	Losses (cusecs/1000 ft.)
1.95	1.54	80	3550	0.115
1.95	1.65	85	4460	0.067
1.85	1.05	55	4210	0.190
1.50	1.20	80	5130	0.055
1.10	0.65	60	5920	0.074
0.90	0.70	80	5540	0.036
1.80	1.40	80	6130	0.065
1.90	1.40	75	7090	0.073
1.90	1.70	90	4460	0.045
1.90	1.70	90	5800	0.034
1.65	1.30	80	4550	0.079
1.70	1.65	95	1840	0.027
1.80	1.30	70	5130	0.097
1.90	1.75	90	1750	0.086
1.90	1.40	75	3000	0.167
1.90	1.80	95	500	0.053
1.80	1.35	75	6550	0.072
2.10	1.30	60	9170	0.087

Table 3. Delivery efficiencies and average loss rates for canal water or tubewell water at Shadab.

Date	No.	Initial Flow (cusecs)	Final Flow (cusecs)	Delivery Efficiency (Percent)	Distance (ft.)	Losses (cusecs 1000 ft.)
4/11/74	3	0.75	0.42	55	3680	.090
5/11/74	4	1.0	0.6	60	2000	0.200
6/11/74	2	0.6	0.3	50	2500	0.120
7/11/74	4	0.77	0.4	50	2000	0.185
8/11/74	Gravity	0.70	0.7	100	900	0
9/11/74	1	0.70	0.35	50	1000	0.318
12/11/74	4	0.90	0.4	45	3600	0.139
15/11/74	Gravity	2.2	2.0	90	1500	0.133
19/11/74	Electric TW	0.4	0.3	75	500	0.200
24/11/74	Electric TW	0.33	0.3	90	400	0.075

Table 4. Delivery efficiencies and average loss rates for canal water and private tubewell water on watercourses in the Lyallpur District.

Initial Flow (cusecs)	Final Flow (cusecs)	Delivery Efficiency (Percent)	Distance (ft.)	Losses (cusecs/1000 ft.)
0.85	0.70	80	4140	0.036
0.85	0.30	35	5640	0.098
0.85	0.80	95	2810	0.018
0.85	0.80	95	3680	0.014
1.74	1.16	65	8250	0.070
1.74	1.47	85	5150	0.052
1.47	1.1	75	1220	0.303
1.47	1.2	80	1010	0.267
1.47	1.3	90	800	0.212
2.0	1.0	50	7200	0.139
1.5	0.7	45	4400	0.182
1.5	0.5	35	5200	0.192
3.0	1.9	65	4200	0.262
2.2	1.6	75	6000	0.100
2.2	2.0	90	3150	0.063
1.2	1.1	90	1400	0.071
1.2	0.9	75	2000	0.150
0.8	0.7	85	1550	0.064
0.8	0.6	75	4200	0.048
0.6	0.5	85	3500	0.029
0.63	0.5	80	4650	0.029
0.8	0.5	60	5800	0.052
0.8	0.7	90	2000	0.050
0.8	0.72	90	600	0.133
0.8	0.64	80	1400	0.114
0.8	0.6	75	2000	0.100
0.8	0.7	90	2140	0.047
0.8	0.7	85	3850	0.026
0.7	0.63	90	4230	0.017
0.8	0.7	90	1900	0.053
2.4*	1.1	45	2750	0.473
1.2	0.9	77	1980	0.152
2.4	1.1	45	1320	0.985
1.15	0.8	70	2310	0.152
1.15	0.8	70	2860	0.122
2.36*	1.0	43	2860	0.476
2.4*	1.65	70	2310	0.325
2.4	1.7	70	2860	0.245
2.4	1.75	75	2830	0.230
2.0	1.3	65	3300	0.212
1.15	1.1	95	3520	0.014
1.4	1.4	100	880	0.000
1.4	1.3	90	1100	0.091
1.4	1.03	75	6000	0.062

*Measurement for private tubewell plus canal water.

Table 5. Delivery Efficiencies and Average Loss Rates for Watercourses at the Mona Reclamation Experimental Project

Date	Initial Flow (cusecs)	Final Flow (cusecs)	Delivery Efficiency (Percent)	Distance (ft.)	Losses (cusecs/1000 ft.)
			Tubewell 78		
19 June 73	4.9	4.1	85	2610	0.31
30 June 73	1.8	1.7	95	4680	0.02
7 July 73	1.8	1.1	60	8800	0.09
15 Nov. 73	1.8	1.0	55	5850	0.14
29 Nov. 73	1.8	1.0	55	4950	0.17
29 Nov. 73	1.8			6980	
29 Nov. 73	1.8	1.0	55	5450	0.14
6 Dec. 73	1.2	0.7	60	6240	0.11
19 June 74	2.25	1.8	80	2200	0.22
19 June 74	2.25	1.8	80	2000	0.24
19 June 74	2.25	1.5	65	2200	0.35
19 June 74	2.25	1.8	80	2200	0.22
21 Nov. 74	1.9	0.98	50	2400	0.38
21 Nov. 74	1.8	0.94	50	2600	0.33
21 Nov. 74	1.8	1.1	60	2525	0.27
22 Nov. 74	2.8	2.2	75	3300	0.18
22 Nov. 74	2.8	2.2	75	3300	0.19
22 Nov. 74	2.0	1.2	60	2700	0.27
22 Nov. 74	2.1	1.3	65	2800	0.27
29 Nov. 74	3.5	2.5	70	2200	0.44
			Tubewell 122		
9 May 73a	3.9	3.1	80	1350	0.6
9 May 73b	4.9	3.5	70	1350	1.0
15 July 73	3.2	2.2	70	4920	0.2
22 July 73	3.2	2.2	70	4920	0.2
7 Mar. 73	3.3	2.8	85	1400	0.36
12 Feb. 74	1.9	0.4	20	3250	0.47
			Tubewell 137		
10 Jan. 73	2.5	2.0	80	3880	0.13
11 Jan. 73	2.5	2.25	90	1300	0.20
13 June 73	2.3	1.3	66	2000	0.5*

* May be high because fully steady flow not established.

wide variation in seepage (Table 5). The measurement on June 30, 1973 was for the portion of the watercourse with a heavy soil (clay) and with only canal water flowing. The measurement on July 7, 1973 was on the lower end of the watercourse where the soil is sandy. The increased seepage on July 7 is caused by a sandy textured soil for the lower section of the watercourse.

The measurement on June 19 represents seepage for the heavy soil for flow conditions of tubewell plus canal water. When the flow in the watercourse is a maximum, seepage and spillage will be a maximum. Note that the length of watercoarse for the measurement on June 19 is almost one-half the length of the watercourse for the June 30 measurement. The losses in cusecs per 1,000 ft. is, however, fifteen times more for the high flow condition than for the low flow condition.

The losses at TW 122 have been measured on two different branches of the watercourse. The measurements in July are for the branch of the watercourse to be rehabilitated. The measurements for May and November are for a watercourse that parallels a road and seepage appears to be consistently higher for this branch of the watercourse. This is perhaps caused by an elevated position with respect to the road and poor maintenance along the road where the water losses do not damage any farmer's fields. The measurements in May and November were made at a greater discharge and this would also partially explain the greater loss. The seepage under the reduced flow conditions in July represent a significant loss. In the total length of nearly 10,000 ft. for that branch of the watercourse and with the flow at less than full capacity, the losses would probably exceed 50 percent of the initial flow. At maximum flow conditions, the seepage losses and spills would be even greater. The "b" measurement on May 9 was measured on the same section as May 9a. It illustrates what happens as the flow in a watercourse increases and the maximum capacity of the watercourse is approached. While the discharge at flume #1 increased 1.0 cusec the discharge at flume #2 increased only 0.4 cusecs. That is 60 percent of the increase was lost.

The measurements on tubewell 137 in Table 1 represent different conditions. The measurement on January 10 is for a relatively long section of the watercourse with a stable cross section and a relatively steep grade. The seepage rate is lowest for this section of the watercourse as would be expected. The second measurement on January 11 is for a wide flat bottomed portion of the channel on another branch immediately adjacent to the tubewell. This section would be expected to have the greatest seepage of any of the sections of the watercourse. In most of this section the bottom of the channel is over 10 feet wide and the soil is very sandy. Measurements were also obtained on June 13 and

14 for a lower portion of the watercourse - a section that is a continuation of the portion measured on January 11. The seepage for these measurements were considerably larger than expected because repeated power failures at the tubewell prevented steady-flow conditions from developing.

A comparison of the losses at tubewell 137 with the losses at tubewell 122 suggest that the losses at tubewell 137 do not substantially exceed the losses at tubewell 122. The soil at tubewell 137 is known to be very sandy. The textural classification of the watercourse at tubewell 122 is also toward a sandy loam rather than a silt loam. Thus, the losses would be expected to be similar. The biggest factor affecting losses at tubewell 122 is the relatively poor maintenance of the section of watercourse on which the high flow measurements were made and the greater discharge that must be conveyed through that section of the channel. Channels in sandy soils are usually flat bottomed and wide, and as a result, have a high seepage loss.

Sargodha District

Watercourse losses were measured for several watercourses in Sargodha District in connection with a request for assistance in evaluating the need for improved farm water management (Table 6). While the water supply at the mogha is relatively low, the losses are quite high. Visual inspection of the watercourses suggest that the factors causing the higher losses are vegetation and trees in the watercourse and a lighter textured soil which allows excessive seepage. Spillage did not appear to be a significant factor.

Seepage Rate

Seepage from a watercourse is a function of a number of factors including the rate of flow and the wetted perimeter. The most comparable method of representing seepage losses is to divide the cusecs per thousand feet of watercourse by the average wetted perimeter to obtain a seepage rate in cusecs per thousand square feet. Adequate measurements of watercourse cross sections for the various discharges, watercourses and particular lengths have not been made. Below is an estimate of seepage rate for the three Mona watercourses based on one or two measurements of wetted perimeter for the section of flow.

Table 6. Delivery efficiencies and average loss rate for watercourse in a SCARP area of Sargodha District.

Water-course	Initial Flow (cusecs)	Final Flow (cusecs)	Delivery Efficiency (Percent)	Distance (ft.)	Losses (cusecs/1000 ft.)
A	2.11	1.13	55	1320	0.742
B	0.24	0.13	55	660	0.167
C	1.40	0.99	71	880	0.466
D	1.07	0.61	55	1980	0.232
E	0.56	0.30	55	880	0.295
F	2.37	1.65	70	1100	0.654

Date	Initial Flow (cusecs)	Final Flow (cusecs)	Distance (ft.)	Channel Wetted Perimeter (ft.)	Seepage Rates (cusecs/ft.^{2} x 10^3
TW 78					
30 June 73	1.8	1.7	4,680	4.3	0.005
TW 122					
9 May 73	3.90	3.10	1,350	7	0.08
TW 137					
10 Jan. 73	2.5	2.0	3,880	4.9	0.03

These data are to be considered as preliminary estimates only since additional data are still required.

Average Loss

The results from measurements of watercourse losses at six different locations in Pakistan are presented in Figure 1. The results are presented as losses in cusecs/1000 ft. versus watercourse discharge. The loss is an average rate applicable for tubewell supplemented, canal water only and for a well maintained watercourse. The curves represent the average loss rate as determined from the arithmetic average of the loss rates in the interval around 1.0, 2.0, 3.0, 4.0 and 5.0 cusecs for canal water only and for supplemented watercourses. The data suggest that many watercourses are considerably above the average in actual loss rate.

The results in Figure 1 may be used to derive an average loss for a watercourse. The basic assumption required is the average distance travelled from the mogha to a field. Assuming a watercourse geometry for a particular size of watercourse, the average distance travelled weighed by time and distance, in irrigating all the fields on a watercourse would be:

Watercourse Area (acres)	Average Distance (ft.)
350	4,000
700	6,000

Table 7 presents the average loss rate for different discharges at the mogha and for different watercourse circumstances such as canal water or a well maintained watercourse. Using the average loss rate and average travel distance for a given watercourse area, the average delivery efficiency can be computed. The results are given below for canal water only, canal plus tubewell and a well maintained watercourse.

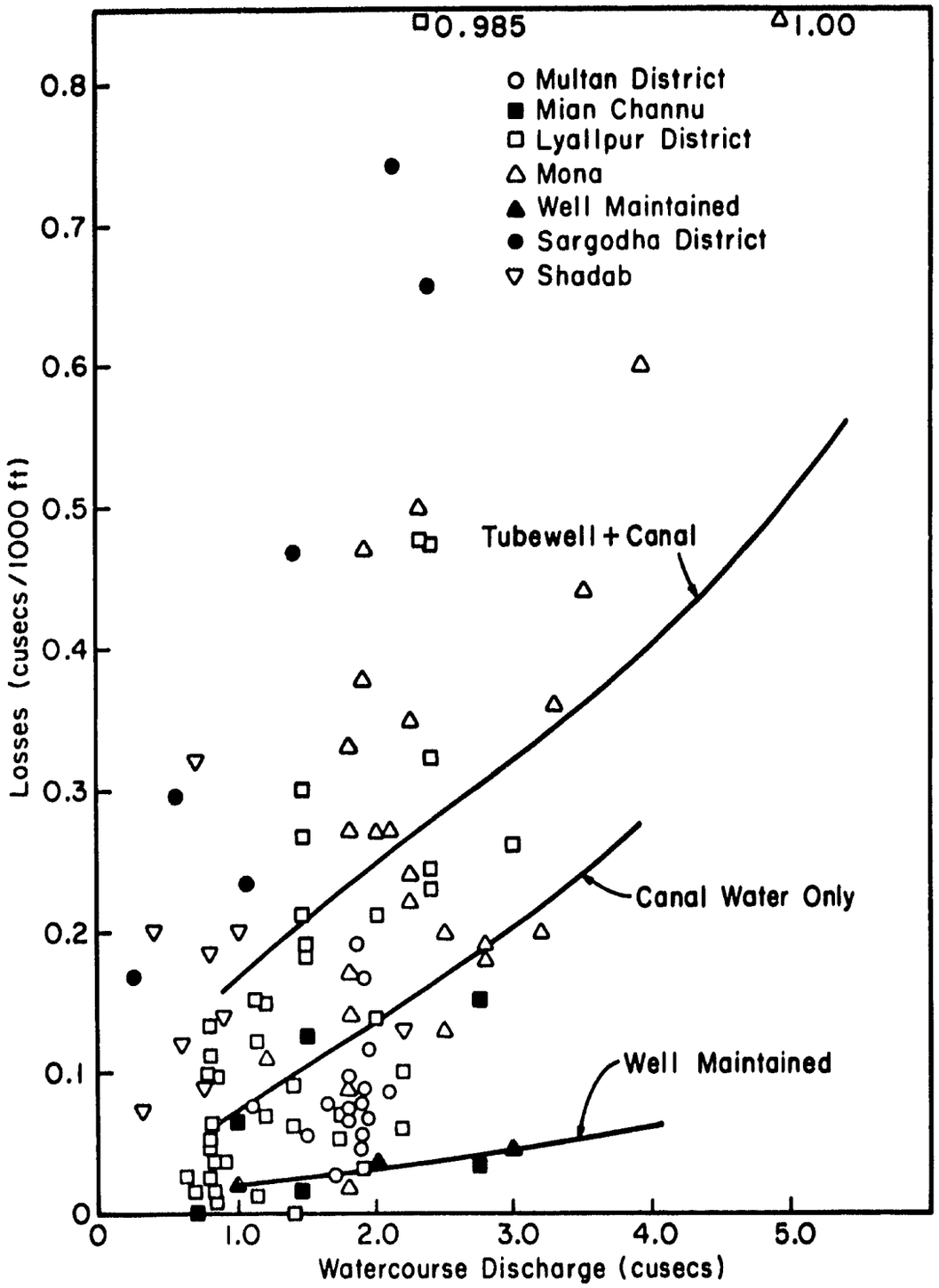

Figure 1. Average watercourse losses for well maintained canal water only and tubewell plus canal water for various locations in Pakistan.

Table 7. Average loss rates as a function of watercourse discharge and with tubewell supply

Discharge (cusecs)	Losses (cusecs/1000 ft.)
Canal Water Only	
1.0	0.075
2.0	0.13
3.0	0.20
Tubewell plus Canal Water	
1.0	0.16
2.0	0.25
3.0	0.32
4.0	0.40
5.0	0.51
Well maintained - canal and/or Tubewell	
1.0	0.020
2.0	0.035
3.0	0.045

Water Supply Rate (cusecs	350 Acres Well Maintained	350 Acres Canal Only	350 Acres Canal Plus Tubewell	750 Acres Well Maintained	750 Acres Canal Only	750 Acres Canal Plus Tubewell
	(Percent)					
1.0	92	70	36	-	-	-
1.3	92	71	-	-	-	-
2.0	93	74	50	89	61	
3.0	-	-	57	91	-	36
4.0	-	-	60	-	-	40
5.0	-	-	59	-	-	39

The results above and in Figure 1 suggest several points. Canal water only watercourses have a higher delivery efficiency than supplemented watercourses. This seems reasonable as the flow in such a watercourse would be more nearly constant and the capacity should be more nearly adequate. The canal plus tubewell watercourse have a higher average loss and major component of this increase is assumed to be spillage. When the size of the watercourse area is increased, the increase in flow and increase in travel distance result in increased losses. When tubewell water is added to these watercourses, a greater loss in water results.

A comparison of the loss rate for a well maintained watercourse as compared to the normal watercourses suggests the great value of proper maintenance. The two data points for a well maintained watercourse were obtained from Mian Channu by making loss measurements just after a major program of maintenance by the farmers on that watercourse. The results may not be considered an average for Pakistan, but are included to emphasize the importance of proper maintenance to reducing watercourse losses in Pakistan.[1]

The results above for average delivery efficiencies are limited in application because of the assumption concerning loss rate and average distance travelled. The relationships as sketched in Figure 1 accidentally result in a constant percentage loss as the flow rate increases. When the flow rate in a given watercourse increases, losses are more than proportionately increased. The lines sketched in Figure 1 are assumed to give the average loss. On many watercourses the actual loss exceeded the average by several magnitudes.

[1]Measurements of losses on improved sections of watercourses at Shadab and Mona have resulted in approximately the same loss rate. Unpublished data from Dr. W.D. Kemper.

Thus, on these watercourses the average delivery efficiency is much lower. For example, the data in Figure 1 for Shadab, Sargodha District and Lyallpur District have many or all of the points plotting much above the average loss rates lines.

The data collected to date on watercourses supplemented by public tubewells or private tubewells suggest that differences in losses are related to the differences in flow and not to the ownership of the tubewell. Private tubewells may have an over-all smaller average loss because much of the water is pumped and used without being added to the canal water, so the loss rate would be less because of the reduced discharge.

A PROGRAM FOR WATERCOURSE MANAGEMENT

These results demonstrate the excessive losses that occur on SCARP and non-SCARP watercourses in Pakistan. These losses are significantly greater than previously assumed and excessive compared to well maintained watercourses. With the shortage of water in non-SCARP areas and a deficient supply because of wastage in SCARP areas, it is imperative that Pakistan develop and implement a program of watercourse rehabilitation in order to reduce these losses.

In unsupplemented watercourses, water is sufficiently short by any criteria that the first priority must be additional supplemental water, whether this water is provided by a public tubewell program, a private tubewell program or an increase in canal capacity to enhance the existing canal water supplies. Programs to accomplish these objectives be of first priority. However, concurrently, as resources and personnel can be made available, a program of watercourse rehabilitation to reduce the excessive losses in watercourses in Pakistan must also be planned and implemented. There are more than a million miles of watercourses in Pakistan, and consequently, programs must be planned and implemented starting as soon as possible.

Based on the results of the above data, first priority in rehabilitation must be given to reducing losses in high water table areas especially where the area is underlain by saline and unusable ground water. In these areas construction of pucca watercourses to largely eliminate seepage must be implemented. This is because these losses further aggravate the waterlogging and salinity problems and without a reduction in these losses, the cost of reducing waterlogging and salinity will be excessive.

The next priority program must be a program of watercourse improvement for tubewell supplemented areas. As new SCARP projects are implemented, in order to receive maximum benefits and to ensure an economically beneficial project, a program of watercourse rehabilitation with appropriate,

economically feasible, watercourse improvement procedures must be implemented in order to provide the benefits of the increased water supply to every farmer on the watercourse. Data collected to date suggests that unless watercourse improvement is provided at the time of the implementation of a SCARP program, much of the benefits of the increased water supply will be wasted with concurrent cost increase and benefit decrease because of the ineffective use of the water supply.

As research results and field experience with specific types of materials are available, a program of watercourse improvement must be applied to SCARP areas that have already been implemented. Present losses on SCARP watercourses substantially reduce the water supply and waste needed electricity for pumping.

At present insufficient data are available to suggest a program for implementation of watercourse improvements in private tubewell areas. Apparently in some areas, private tubewell water is frequently added to the canal water supply and transported in the same watercourse. Under these circumstances the above data suggest that these watercourses should receive high priority for improvement. In other areas use of private tubewell water tends to be restricted to the area immediately around the tubewell and very little of the water is transported with the canal water in the same watercourse. Several alternative approaches to reducing losses in these circumstances could be suggested but insufficient data are available at the present time to quantify the benefits and costs of such programs.

In unsupplemented watercourses it seems that the first priority should be to provide additional water supplies where possible. An extended time frame will be required, however, in order to accomplish the provision of increased water supplies. Thus, depending upon the cusecs available in the watercourse and the level of maintenance of the watercourse provided by the farmers, a program of selected watercourse improvements should be provided. First priority, on these watercourses and on any watercourses where resources are not available to implement a formal watercourse improvement program, should be to educate the farmer on the losses incurred from poor operation and maintenance of his watercourse and instruct the farmer in methods and procedures to maintain and properly operate his watercourse so that substantial reduction in watercourse losses can be achieved.

Regular, routine, daily maintenance where frequent inspections are made from the point of use at the farmer's fields to the mogha and leaks are eliminated on a regular basis would be a substantially beneficial program. Thorough cleaning and reinforcement of the sides of the watercourse on a weekly or a monthly basis should receive the next priority. Information concerning the proper cross sections, grade and

alignment for watercourses of a particular capacity should also be widely distributed in Pakistan. Extension and irrigation people need to be instructed how to provide advice to the farmer. Particular specifications for each watercourse need to be provided depending upon the flow rates and in terms of the cross section, freeboard, slope, elevation and operational requirements needed to function effectively.

Under this suggested program, substantial increases in the delivery of water to the farmer's field can be achieved until a more formal and thorough program of watercourse improvement can be implemented on all watercourses in Pakistan. This program, if successful, would also enhance the various alternatives for watercourse improvement. If farmers demonstrate that given knowledge and understanding of the losses that occur on his watercourse, that he will consistently maintain and operate his watercourse to reduce these losses, alternative methods of watercourse improvement can be considered. Such a program of simple, proper watercourse maintenance can provide more water to the farmer under present conditions in Pakistan than several Tarbella Dams.

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A number of individuals have assisted materially in the collection and tabulation of these data. Mr. Waryam Ali Mohsin, Agricultural Engineer, CSU and Mr. Mohammad Afzal presently assistant Agricultural Engineer at Mona helped collect much of the early data at Mona. Mr. Waryam collected the data for Lyallpur District, Multan District and Shadab. Mr. Mohammad Akram, assistant Agricultural Engineer at Mona has collected most of the recent data at Mona and the additional data for Sargodha District. Various individuals at the Agricultural University, Lyallpur assisted in the collection of the Lyallpur District data largely as part of the NDVP. The assistance supplied by the Agricultural Engineering students at Agricultural University, Messrs. Zahid, Arshad and Amir in collecting some of the data is greatly acknowledged. Mr. Shafiq Sidiq, Mr. Raza Hussain, and Mr. Parvez, Agricultural Engineers with the Integrated Rural Development Program assisted in collecting the data at Shadab and Multan District. The authors also acknowledge the suggestion of Dr. Jerry B. Eckert, CSU for suggesting how to relate loss rate to discharge. The authors also acknowledge the helpful comments of the CSU field party.

Appendix 13

WHERE WATER GOES IN A WATERCOURSE[1]

W.D. Kemper[2], Moh'd Akram[3], M. Afzal[3], M. Iqbal[3]
and M.A. Cheema[4]

Most of the water loss studies to date have been conducted under conditions where steady state flow of water could be approximated. Such measurements under estimate the percentage of water lost in a watercourse because they do not account for the losses involved in filling the dead storage of the watercourse and they generally avoid those early periods of flow in a watercourse when the rate of infiltration into the banks is at its highest. Consequently, the following study was conducted during a 15 hour period when most of the turn on the watercourse branch indicated in Figure 1 occurred. All the water entering and leaving the branch of the watercourse was measured. The water was shifted from one to another of the sub branches two or three times giving ample opportunity to observe how much water was used to fill these watercourses and how much water drained out of these watercourses after the water had been cut off at the inlet.

The original warabundi schedule indicated that water was to be let into this watercourse at 0600 on Thursdays; however, on arrival at this watercourse at 0530 we found that water had already been turned into the watercourse and that the schedule had been changed so that water had been flowing into the first 1100 feet of the watercourse for at least three hours. Two fields had already been irrigated and two fields were in the process of being irrigated at 0600.

A. General Procedure

The main watercourse from the mogha and the tubewell down to this village branch of the watercourse has been lined with a brick lining which, when all the nuccas are properly closed, allows a delivery of about 90 percent of the water from the canal and the tubewell to the head of the village branch. The water entering this village branch was measured with a cutthroat flume 3 feet long, with a throat which is 8

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[1]Joint contribution from the Mona Reclamation Experimental Project and CSU. This work was supported by the U.S. Agency for International Development through contract No. AID/ta-c-1100 and Grant No. 204-75-3.

[2]Colorado State University Water Management Adviser.

[3]Mona Reclamation Experimental Project Assistant Agricultural Engineers

[4]Mona Reclamation Experimental Project Senior Hydrologist.

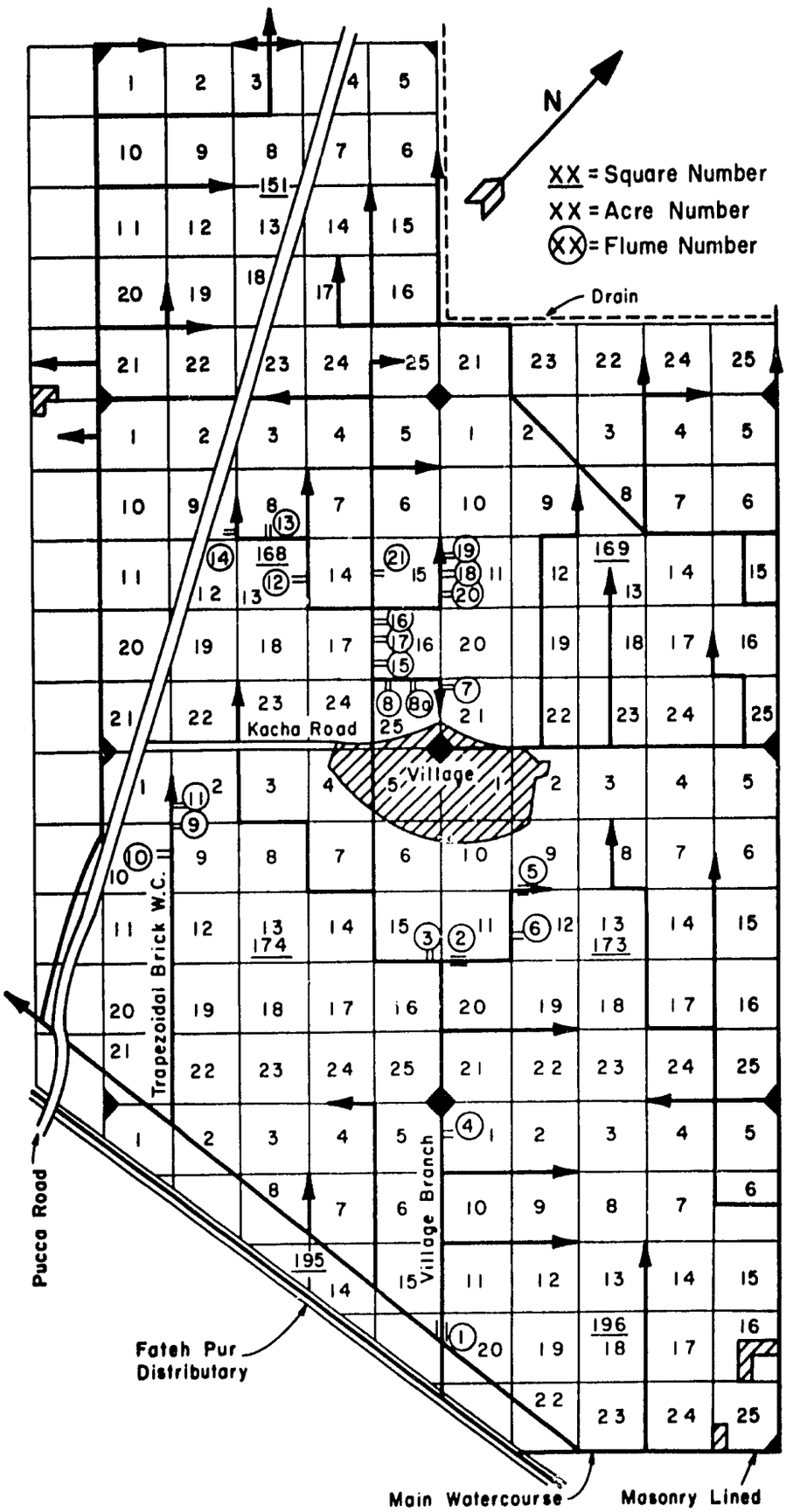

Figure 1. Section of the watercourse serving tubewell 78 in the Mona Project Area.

inches wide. The flow throughout the day was monitored with this flume and was fairly constant at about 4.7 cusecs (as shown in Figure 2) except for a period during which the tubewell was turned off in the early part of the evening. A main portion of the team then followed the water down to the points at which farmers were letting this water into their fields through nuccas or openings cut in the bank. In each of these nuccas a flume with length of 18 inches and a throat of 8 inches was installed. In cases where the flume was raising the water level appreciably above level at which it would normally flow into the ditch, we encouraged the farmer to cut another nucca from the watercourse into the field in which we installed a second flume. Generally, this maintained the water level in the watercourse near the normal operational level. In a few cases where installation of the flumes raised the water level above operational levels, banks were actually built up slightly to prevent measurement induced overtopping losses. The flumes were installed on the watercourse at the locations by the numbers in the circles in Figure 1, which shows a map of this branch of the watercourse and some portions of the adjacent branches.

B. Data Taken

The nuccas are labeled approximately in the order of their installation. The flows through the nuccas are indicated as a function of time in Figure 2. The heavy dashed line in Figure 2 represents the total instantaneous flow rate onto all fields from this watercourse branch as a function of time throughout the day.

The total amount of water entering this branch of the watercourse may be found by measuring the area under the line indicating the total flow available from the pucca watercourse, and adding it to the amount of water in the watercourse at 0600. The section of this watercourse, down to the point at which water was being taken out is approximately 1100 feet long. The average width of this watercourse is about 3 1/2 feet and its average depth at 0600 was estimated to be about 16 inches. Consequently, there was about 1.4 acre inches in the course at 0600. During the next 15 hours 65.6 acre inches of water flowed through the flumes at this junction for a total of 41.0 acre inches, the total supply considered. Summing the total area under the curve in Figure 2 indicates that 27.3 acre inches of water left the watercourse and entered the field from 0600 until the water ceased running after being turned off at 1500 that evening. In other words, 41 percent of the water reached the fields and 59 percent was lost through seepage, dead storage, overtopping and evapotranspiration in the watercourses.

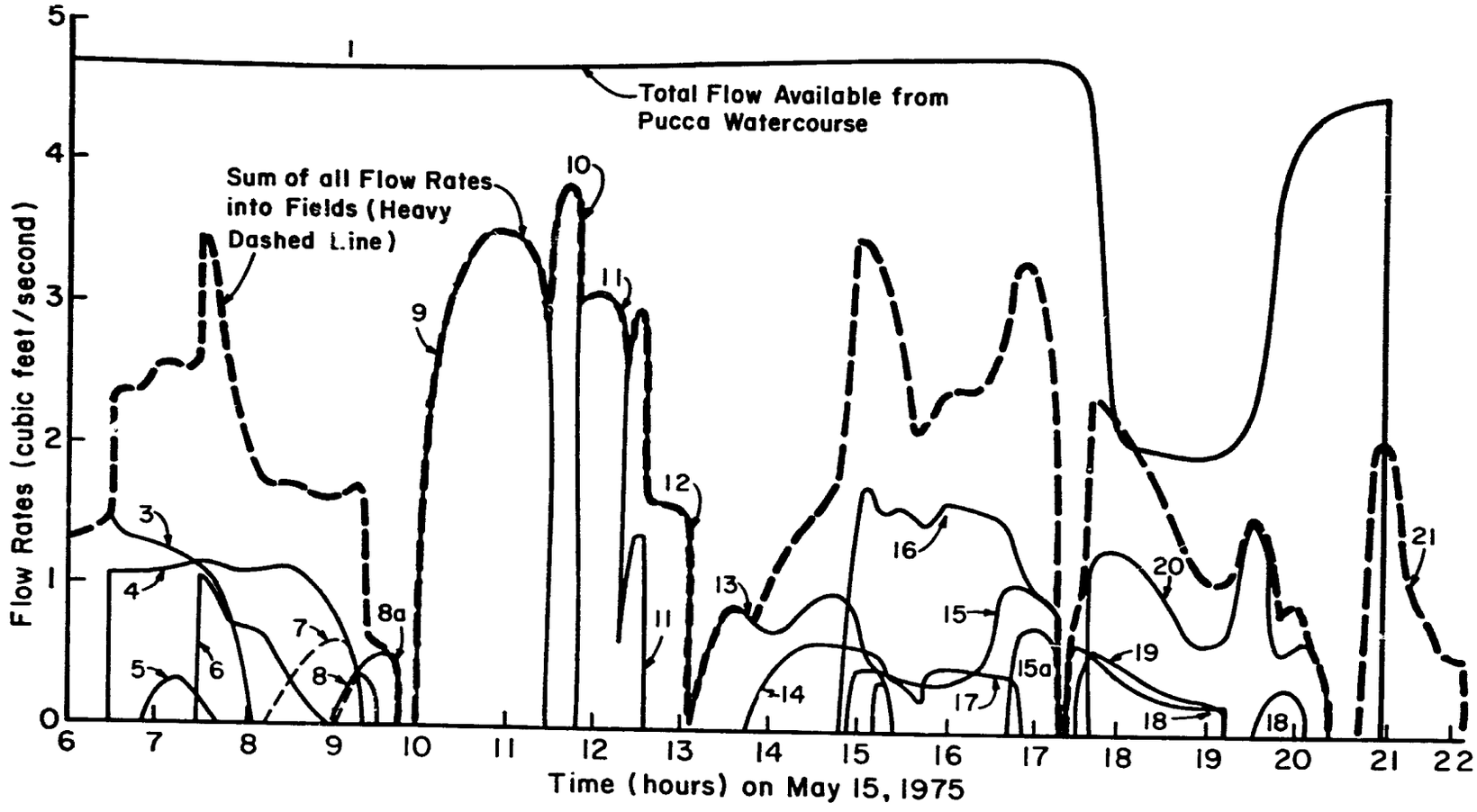

Figure 2. Flow rates into and out of the village branch of the watercourse (serving tubewell 78 on Thursdays).

Discussion

At one time we were tempted to consider part of the overtopping as being beneficial to wetted land. However, during discussion with one of the farmers in the upper reach he complained that his land was being damaged to a distance averaging almost 100 feet from the watercourse by seepage. He agreed to cut down trees along this watercourse and help us build banks which would stop seepage on the basis that this would be of considerable benefit to him. In other words the water lost not only loses its value, but actually takes on a negative value.

Along these and adjacent stretches of this watercourse, average loss rate at steady state have been about 40 percent. The higher loss rates found in this study of about 57 percent are discussed in terms of the operation of the watercourse as follows.

In the period from 0600 to 0630 the water level in the top reach of the watercourse was rising since lower nuccas had been closed and nuccas that had been opened were on higher elevations. The nucca at flume No. 4 was opened at 0630 and the flow through the nucca at flume No. 5 contributed to increasing flow from the watercourse to the field in the time from 0640 to 0730. At 0730 the nucca at flume No. 6 was opened resulting in the peak flow of over 3.4 cusecs. However, about 0750 a bund just beyond flume No. 3 on the main watercourse was opened and a large portion of the water began to flow down the watercourse, filling the section in the village area. By 0810 less than 1.8 cusecs of water were actually entering the fields. At 0815 a nucca began flowing at flume No. 7 which is just below the village. Nuccas at 2 small garden plots at flumes Nos. 8 and 8A ran for a short period of time after 0900. This flow after 0900 is essentially water which was in the watercourse draining out because at 0900 the gate allowing water into the village branch was closed and the water was shunted down the main watercourse to the trapezoidal brick lined section which leads down to flume No. 10.

The reason for this switch is that acres 22 and 23 of square No. 168 and acres 2 and 3 of square No. 174 are fairly high. The farmer can get water to these fields from the village branch of the watercourse but to do so he must repair damage and wear and tear from animals that has occurred along this bank for the last week or two. It is likely that he would have to work for 2 or 3 hours each irrigation turn to close the diversion and make the repairs needed to get his water to this land. Instead he chooses to shunt his water around through the brick lined sections. He brings the water into a sugarcane field in acre No. 2 of square No. 174 flooding this sugarcane field and allowing the water to go

out the right-hand side of this field back into the watercourse and irrigating portions of acre 22 in square No. 168. As indicated in Figure 2 he puts a large portion of the watercourse water which passes the junction at flume No. 1 into his field. However, a major portion of his sugarcane field is extremely chlorotic with leaves almost white in color and the general condition of the plants is poor, indicating that the plants are suffering from anaerobic conditions and that he is damaging his sugarcane plots by using the field as a watercourse channel.

A farmer who owns acre 13 in square No. 168 was to have received the water at 12 noon, but it did not actually reach his nucca (flume No. 12) until about 1215. It apparently took considerable water to fill up and soak the channels leading to flumes Nos. 13 and 14 which had previously been completely dry. These nuccas are on relatively high ground and the water level was building during this period of time.

The water was then turned into a sugarcane field in acre No. 16 of square No. 168. Flume No. 16 served the bottom half of this acre, flumes Nos. 15 and 17 served the upper half of this acre. The lower half of this acre was finished first. The farmer closed the nucca. Water built up in this section overtopping at several points until we convinced the farmer that he should open up another nucca at flume No. 15A adjacent to flume No. 15, which decreased the water level to approximately the normal operational level.

At 1715 hours the farmer opened up the watercourse to take the water the 400 additional feet down to the nuccas at flumes 18, 19 and 20. Despite the fact that this is only 400 feet of watercourse, (about 3' wide and 12" deep), figure 2 indicates that it took about 0.53 of an acre inch of water to wet up and fill this section. Filling would have taken about 0.33 acre inches, which indicates that 0.2 acre inches of water infiltrated into the wetted perimeter of this dry watercourse between 1710 and 1740. Since the wetted perimeter was less than 2000 square feet, the infiltration must have exceeded 3.2" in this 45 minutes. This rate of infiltration exceeds that of field soils of the area by a factor of about 5. However, inspection and excavation of the banks reveals many holes created by insects, rodents and roots. The highly porous nature of these banks lends credibility to these rates of infiltration. Independent measurements, using the ponding method, indicate infiltration rates of over 3"/hour after some sections of this watercourse had been wetted for two hours. Rates of flow out of individual holes were measured ranging from about 3 cubic feet per hour for a 1/2" diameter hole to 25 cubic feet/hour for a 2" diameter hole. Most of these holes originate in the sides of the channels and rather than going through the banks, they go down into the sandier sub soil. These holes are easy

to close and a study to determine water savings/time to close such holes should be conducted.

The tubewell feeding this watercourse was turned off at 1700 hours on schedule and the supply to this branch of the watercourse dropped to about 2 cusecs (canal water). This turn-off was a primary factor in the continued decline of the flow into the fields from 1830 hours until about 2020 hours. At this time the water was turned back into the watercourse which leads down to flume 21 serving acre 15 in square No. 168. The gap in flow between 2020 and 2045 hours is not due entirely, however, to filling that section of watercourse. By this time it was dark. One of our men observed that a farmer up the watercourse who had a fairly low field had cut a nucca and was irrigating this small tobacco field with a flow estimated at about 0.5 cusec. This "water thief" closed the nucca at about 2040. Additional water from the tubewell was beginning to come down the watercourse resulting in 2 cusecs going through the nucca at flume 21 at 2100 hours. There is a good possibility that the abrupt stop in flow through flume 21 at 2210 was due to another deliberate breach in the watercourse.

It is interesting to compare the flow which took place at the supply flow from 1920 to 2100 hours with the flow which occurred through flume 21.

Through flume No. 21, 1.4 acre inches went to the fields and a maximum of 0.6 acre inches may have been stolen, for a total of 2.0 acre inches applied to fields. From 1920 to 2100 hours, about 6.6 acre inches of water flowed into the watercourse through flume No. 1. Moreover, there was at least 2.0 acre inches of water stored in the 2700 feet of channel between flume No. 1 and the nucca at flume No. 21. Consequently, only 2.0/8.6 or about 21 percent of this "end of the turn water" reached the fields.

Conclusions

1. Summation delivery efficiencies of water to fields through watercourses are considerably less than those measured under steady state conditions.

2. The ability of these watercourses to soak up water rapidly during the initial wetting stages and the continual infiltration of "dead storage water" between times when the water is in that section of the watercourse and the high portion of end of the turn drainage water which infiltrates all play a role in reducing the summation delivery efficiency to low values.

3. Considerable water could be saved by scheduling the water at successive nuccas along the watercourse rather than moving back and forth between sections.

4. The farmer who diverts his water around through the pucca brick lined section appears to have increased his water supply to his fields in the vicinity of acres 22 and 23 of square No. 168 and 2 and 3 of square No. 174 by more than 50 percent (from a delivery efficiency of less than 41 percent to more than 70 percent). However, he is damaging his sugarcane crop by using a large portion of acre 2 of square No. 174 as a watercourse every week. He should be encouraged to construct a short watercourse which will prevent damage to this field and give him more water to use on other lands which need it. In the interest of saving water, his waribundi turn should be shifted to a time which is in sequence with the other turns on the trapezoidal brick section.

5. Most of the physical work performed by these farmers in their irrigation is in the building of bunds at diversion points. Most of this work could be eliminated and the number of weak points in the watercourse drastically reduced if these earthen bund junctions could be replaced by pucca junctions which would not be eroded. Considerable land is presently lost by excavations around these junctions, and crop damage due to leakage through resulting thin and weak banks often takes land out of production up to 50 feet from these junctions.

Appendix 14

WATER LOSSES IN STRAIGHT SECTIONS AND AT JUNCTIONS OF A WATERCOURSE

W.D. Kemper and M. Akram[1]

Many watercourses in SCARP areas carry flows of up to 5 cusecs. This flow is commonly diverted from one leg on that watercourse to another by a farmer whose only tool is a cusie. In the process of stopping a flow of this size by placing an earth bund across the channel a large portion of the earth placed in the channel is often eroded down stream. Erosion also takes place when soil is removed from a channel while the water is flowing. Even when farmers are reasonably careful to remove as much of the soil in the bund as they can, as much as 20 or 30 percent of the soil is washed downstream with the water. Sometimes this eroded soil is replaced in the bunds from soils dug from the bottom of the watercourse channel. This is particularly true if the farmer who owns the land adjacent to that junction has in it a high value crop and has let the other watercourse users know that he resents damage to his crop by borrowing earth from his field. However if the farmer owning the adjacent field is making the bund or if the farmer owning the adjacent field is too weak to protect his interests borrow pits grow along these junctions, often using hundreds of square feet of land which would otherwise bear crops.

Borrowing of soil from inside and/or outside of the channel in these junction areas often results in narrow banks and an expansion of the channel to two, or three or four times its normal width. As this tendency continues a farmer who wishes to minimize the labor involved does not build his dam across the wide section but goes downstream to where the channel is normal size. Borrowing in that section soon widens the channel, and this widening progresses downstream from the junction as time progresses.

The borrow pits along a junction are usually full of water when water is in the watercourse because the thin banks of the watercourse adjacent to these pits generally have many leaks and appreciable seepage. As a farmer or a water users association decides to improve their watercourse they need guidelines for determining what to do with their

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[1]C.S.U. Water Management Project Chief of Party and Mona Reclamation Experimental Project Assistant Agricultural Engineer, respectively.

limited resources of labor and capital. Repairing these junctions by building soil to them and installing pucca diversions is one of the first possibilities that farmers may consider. To give them guidelines as to how much water they might save by this junction improvement activity the following study was conducted on the upper section of a village branch of the watercourse serving tubewell 78 in the Mona Project area.

Procedure

On Wednesday, June 11, the section of the village branch shown in Figure 1 was studied. Due to a small leak through the nucca from the lined channel into this section there was at least an inch or so of water in most of the channel and at some points there were 8 or 10 inches. About two cusecs of water were turned into this channel and solid bunds were formed at each of the three junctions of the side branches at the points where the farmers currently install these dams. A solid bund was also formed at a bottom end of the seventh section. After about one and a half hours the bottom section was filled to a level which on the basis of erosion marks on the banks appeared to be approximately the operational level of this watercourse since this was near the top of the free board on some bunds. Section 7 was closed by putting a bund in just below the third junction. About ten minutes later the section at the third junction was at a level approximately the operational level and the bund above this junction was formed. This procedure was continued up the watercourse filling each section consecutively to approximately the operational level. Wooden rules graduated in tenths of an inch were anchored firmly in the soil in the bottom or sides of each of these sections and following the closure of the sections the heighth of the water in these sections was recorded as a function of time as indicated in Figure 2. The lengths of the channel sections were estimated from the acre lines and the width of the channel was measured at several places and the average width determined to the nearest half of a foot. The lengths of the junction sections were estimated by pacing and these measurements and estimates are shown in Table 1.

The rate at which the surface recedes, or the surface fall rate, was calculated from the slope of the curve at 0.5 inches below the operational level which is the zero elevation in Figure 2 and also for the slope at 2.5 inches below operational level which is the slopes at 0.16 feet in Figure 2. From these slopes the loss rates are calculated by multiplying the slopes times the area of water in each of the respective test sections to obtain the loss rate per section. Loss rates are also given in cusecs per million square feet of surface area. The loss rate in cusecs per

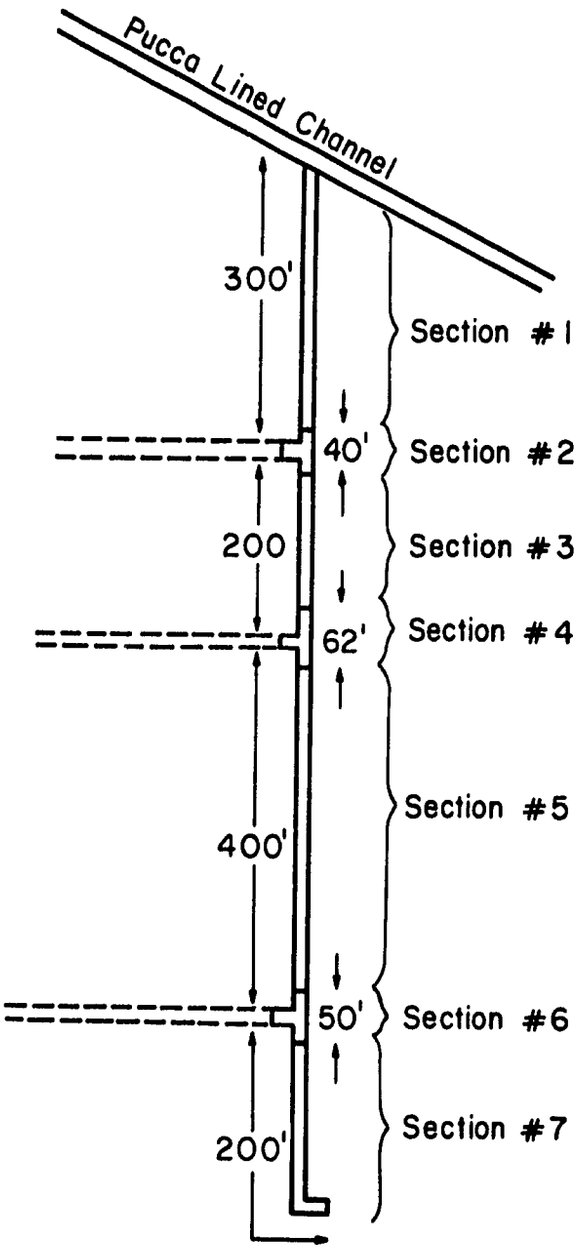

Figure 1. Outline of section of village branch tested for water losses in channel sections and at junctions.

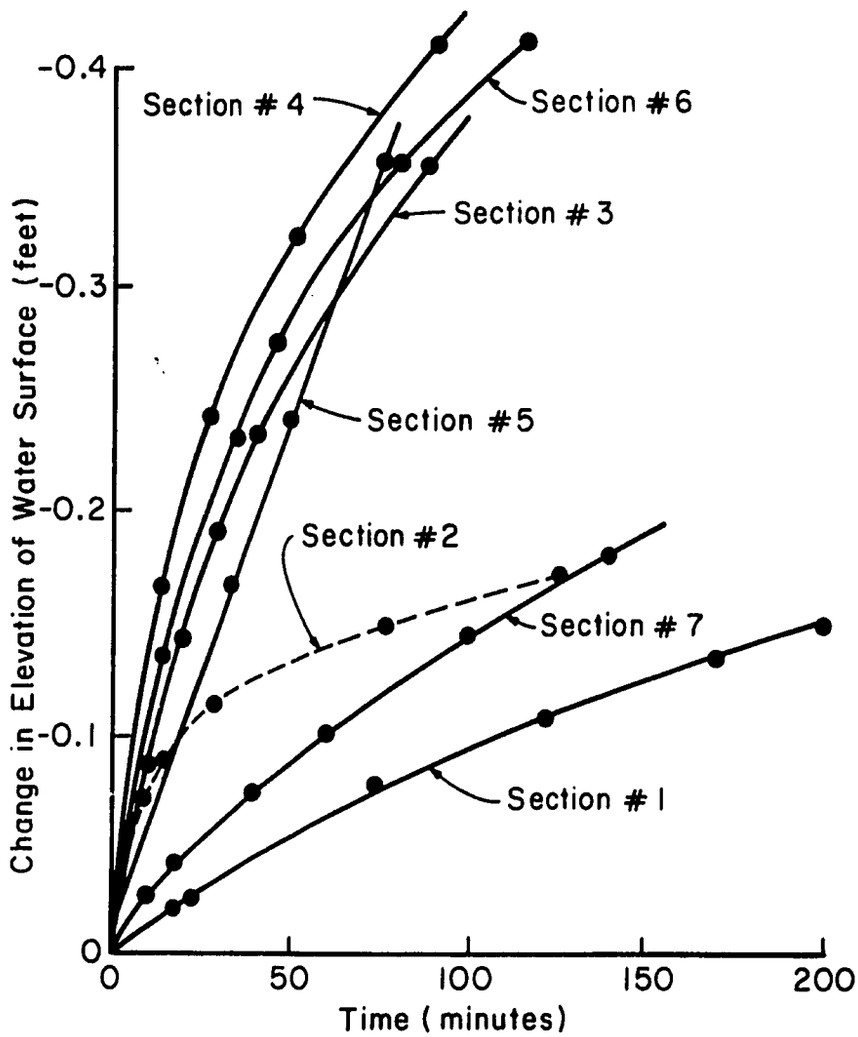

Figure 2. Rate of recession of water surface in water-course sections indicated in Figure 1.

Table 1. Dimensions and rates of loss of test sections indicated in Figure 1.

SECTION NUMBER	1 (Channel)	2 (Junction)	3 (Channel)	4 (Junction)	5 (Channel)	6 (Junction)	7 (Channel)	TOTAL
Length on main branch (ft.)	300	40	200	62	400	50	200	1252
Ave. width on main branch	3	4	4	6	4	5.5	5	
Area on main branch (ft.^{2})	900	160	800	372	1600	275	1000	5107
Length on side branch (ft.)	0	20	0	25	0	21	0	
Ave. width on side branch	0	7	0	6.5	0	6	0	
Area on side branch (ft.^{2})	0	140	0	163	0	126	0	
*Surface fall rate (ft/sec)	.000021	.000140	.00014	.00035	.000098	.000220	.000049	429
*Loss rate (cusecs/section)	.019	.042	.112	.187	.160	.089	.049	.658
*Loss rate (cusecs/10^6ft^2)	21	140	140	350	98	220	49	
**Surface fall rate (ft/sec)	.000003	.000010	.00007	.00012	.000080	.000120	.000016	
**Loss rate (cusecs/section)	.003	.003	.056	.064	.128	.048	.016	.318

*At 0.5" below operational level
**At 2.5" below operational level

million feet of wet perimeter may be estimated reasonably well by taking the loss rate shown in Table 1 per million square feet of water surface area and multiplying this by a factor of 0.65.

The test sections were filled to the point where water was within one half inch of overtopping in the sections where the banks were lowest. The next day this watercourse branch had its normal turn in the waribundi schedule and the site was revisited. The amount of water flowing out of the pucca lined channel into this branch was about 5 cusecs and the actual operating level was about one half inch above the levels used in the falling head measurement the previous day. The water was in fact overtopping at several places along this watercourse.

The total measured losses along this watercourse were 0.66 cusecs when the water level was one half inch below the operational level. The losses were 0.32 cusecs when the water level was 2.5 inches below the operational level.

During the actual irrigation operation a flume was installed at the point where the water comes from the pucca lined channel into this village branch and another flume was installed about 2500 hundred feet down this village branch. Of the five cusecs entering the village branch only 2.9 cusecs were reaching the 2500 foot distance indicating an average loss of about .84 cusecs per thousand feet of watercourse compared to about .52 cusecs as the average for the ponding method using this first 1200 feet as the test section. Extrapolation of the curves shown in Figure 2 to elevations about 4 hundreths of a foot higher than were used and estimating the slopes of seven curves at that level yields loss rates which are on the same order of magnitude as the average measured using flumes for the longer section.

On the other hand if the farmers had done just a bit more cleaning of grass from the bottom of the watercourse, the average operational depth of the water during the irrigation could have been dropped a half inch to the maximum level at which the loss was measured using the ponding method. The losses indicated in Table 1 should be representative of this slightly improved condition. However if the farmers were still lossing .66 cusecs of water per 1200 hundred feet of watercourse they should still be interested in improving this watercourse to:

1. Get more of the water to the fields where it is needed.

2. Reduce the seepage along the watercourse which has raised water contents of the soils to such a high level that total of several acres of land along this branch is practically out of production.

When 0.66 cusecs of water was being lost along this 1200 hundred foot section .34 cusecs was being lost from the regular channels and .32 cusecs was being lost from the three junction areas indicated. Since these junction areas only make up about 13 percent of the total length of the watercourse these junctions appear to be the logical place to start the improvement of this watercourse. Consequently it is suggested that earth be moved into these junction areas to fill the borrow pits and provide earth for building the banks of the watercourse to the proper cross sections (with about 6 inches of freeboard). Pucca diversions should be installed to avoid future borrowing of the soil areas and subsequent deterioration of the watercourse banks near the diversions.

Walking along the sides of these sections there are many obvious leaks which can be stopped with a few minutes of work. On the day following the ponding measurements, when the irrigation was taking place, a total of about two man hours of time was spent in closing some of the obvious leaks through the banks and the results of this repair work was an increase of flow at the lower flume of about .35 cusecs. Unfortunately, the measurements had to be terminated before the full effect of these closures had reached this bottom flume. However this short term effort did indicate that appreciable savings could be achieved by simple repair of the banks. Another opportunity for savings of water becomes apparent as we observe the lowered rate of loss when the water is 2.5 inches below operational level compared to when it is 0.5 inches below the operational level. Knowing the slope of this channel and using Manning's equation it is obvious that if the roughness coefficient (Manning's number) could be reduced to 0.04 by cleaning the grass and weeds out of the bottom of this watercourse the water would flow much faster and the operational level would be reduced by at least 2.5 inches.

A Plan for Improvement of this Watercourse Branch

Based upon the above findings the following plan for improvement of this watercourse is proposed:

1. The elevations of the soil on both sides of this watercourse and particularly the fields with the highest elevations will be determined along with the general profile of the watercourse.

2. Cross sections shall be designed along this watercourse along with the requisite pucca diversions and drop stretches which allow water to flow at an operating level which is at least six inches above the level of adjacent land and will assure enough head in this main branch to command all of the land served by this watercourse.

3. The watercourse should then be cleaned and the banks built up to at least six inches above the designed operational level with soil taken from within the watercourse, when this watercourse needs to be deepened and from adjacent to the watercourse when the watercourse does not need to be deepened. The best source of soil would be from adjacent fields which are in the process of leveling if this can be arranged.

If these junction areas can be improved, and proper cross sections including six inches of freeboard can be provided and the obvious holes plugged it appears that as much as 75 percent of the water lost from this watercourse could be saved.

The measurements taken prior to these improvements will be compared with measurements later this fall when the improvements have been made.

In so far as possible the farmers should be motivated to make these improvements. The extension people in Mona should be called upon to help make these contacts, explain the benefits and gain the farmers cooperation. This will require a coordinated effort by the engineers and extension people and methods for facilitating this coordinated effort should be devised. If such motivational attempts fail, beldars should be hired and utilized to make the improvements.

Appendix 15

IMPROVEMENT AND MAINTENANCE OF EARTHEN WATERCOURSES TO REDUCE WATERLOGGING AND INCREASE WATER SUPPLIES FOR CROP PRODUCTION[1]

W.D. Kemper, Wayne Clyma and M.M. Ashraf[2]

Summary

Losses of water are often particularly high at and near watercourse junctions due to borrowing of soil to construct earth dams across the channel, and consequent narrowing of the watercourse banks and broadening of the channel. Measurements indicate about half the water lost from watercourses is lost at or near these junctions. Improvement of these sections by bringing in soil from adjacent fields and remaking the banks to proper cross section can save up to 50 percent of the water lost. Regular maintenance programs, and the installation of pakka control structures at these junctions can maintain these savings. If labor is valued at Rs. 1/hour, the installation of pakka control structures at locations which must be opened and closed at least once each week can often be justified on the basis of labor savings. Pakka control structures can be installed at primary junctions at a cost of Rs. 250/structure or about Rs. 50000/per 540 acre watercourse.

Extremely low transmission efficiencies (in the 10 to 40 percent range) are commonly a result of silt and vegetation in the watercourse which have slowed the water and raised its level. Data shows that raising the level of water by 2" commonly increases losses by a factor of two or three. Although part of this increased loss is due to overtopping in some watercourses, the major loss is most commonly due to holes in the upper banks due to rodent and insect activity. Organized programs to clean and maintain watercourses observed to date apparently have potential to save water at a cost of ten to fifteen hours of labor per acre foot.

Reconstruction and packing of watercourse banks or making of new watercourses can reduce watercourse losses to a small fraction of their values in present watercourses. Losses can be reduced down to 0.01 to 0.15 cusecs/1000 feet depending

[1]Presented on October 14 at the International Conference on Waterlogging and Salinity in Lahore, Pakistan.

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on the texture of the soil and degree of compaction. Such reconstruction has been accomplished by farmers using kassies at rates varying from 1.0 to 10 feet per man hour depending on watercourse size, condition of the original watercourse and motivation, skill and strength of the farmer. On the watercourses observed to date, cost of increased water at the nucca as a result of such improvement are in the range of 10 to 30 hours of labor per acre foot of water saved.

Comparing costs of increased water supply at the farmers' field due to watercourse improvement (above) with the costs of pumped water (Rs. 40 to 100/acre foot) or the costs of water from new dams (Rs. 240 to 600/acre foot at the field) shows that watercourse improvement and maintenance is Pakistan's least expensive source of additional water for the farmer. Such improvement and maintenance will also be effective in reducing waterlogging and salinity and can utilize Pakistan's great rural labor resource.

Research to identify the most effective means for watercourse improvement and maintenance, and an organized program for informing farmers of the potential benefits and how they can be achieved could play a major role in increasing crop production so that Pakistan can take its proper place as a food exporting nation.

I. Introduction

The value of water to a farmer in Pakistan probably averages about Rs. 360 an acre foot (i.e. Eckert et. al., 1975). However the specific value of water can go up to Rs. 3600 when a critical irrigation is able to make the difference between 15 and 40 maunds/acre of wheat on a well fertilized field. The specific value of water can also become negative if its addition to the groundwater induces the water table to rise sufficiently to cause waterlogging and salinity, and consequent reductions in crop yields.

The cost of irrigation water in Pakistan also has a wide range. Water taken from the early barrages was obtained at a cost of only a few rupees per acre foot and abiana rates presently charges from farmers (equivalent to Rs. 12 to 24/acre foot at the mogha) are based largely on the low cost of this original water. Tubewell waters supplied by SCARP wells are currently costing the Irrigation Department about Rs. 50/acre foot at the well. Private tubewell operators are commonly charging their neighboring farmers from Rs. 40 to Rs. 120/acre foot at the well. Costs of irrigation water from reservoirs like Tarbela range from Rs. 120 to Rs. 240 per acre foot at the dam and because of transmission losses in the canal systems can be Rs. 240 to Rs. 600 per acre foot by the time the water reaches the mogha.

As the national demands for food and irrigation water increase, and additional land is still being taken out of production by waterlogging and salinization, it is time to evaluate the potential and the cost of gaining more water at the nuccas of Pakistan's farmers and reducing waterlogging through watercourse improvements. This paper is a preliminary evaluation based on the limited data currently available.

When the value of water obtained from watercourse improvement appreciably exceeds its cost, farmers should be alerted to this opportunity for profitable investment of their capital and labor resources.

II. The Magnitude of Water Losses from Watercourses

Early estimates used by Harza (1963), Tipton and Kalmbach (1967) and the World Bank (Lieftinch, et. al., 1968) in planning SCARP programs and other developments were that 10 percent of the water passing the mogha was lost in the watercourses. The averages of measurements of water losses taken by WAPDA, the University of Agriculture at Lyallpur, the Integrated Rural Development Program and the Agricultural Extension and Farm Training Center in cooperation with C.S.U. have been summarized in Table 1 which is taken from Clyma, et al., 1975.

Noting that watercourses augmented by tubewell water have greater losses indicating:

1. The farmers have not enlarged their watercourse to properly handle the water.

2. Having more water has allowed the farmers to be more careless with their supply, and/or

3. Tubewell water, pure or mixed with canal water has more tendency to erode and deteriorate and leak from watercourses.

From this table one can calculate (based on the sample of watercourses measured) that the average watercourse with 2 cusecs of canal water at the mogha looses about 26 percent of this water in going an average of 4000 ft. to the nuccas and discharges 1.48 cusecs of water at the nuccas. If a canal supply of 2 cusecs is augmented by two cusecs of tubewell water its average transmission efficiency drops from 74 to 60 percent and total discharge at the nuccas averages 2.40 cusecs. Only 0.92 cusecs of the 2 cusecs of added tubewell water is getting to the nuccas in the average watercourses measured in this size range. Augmenting a 3 cusec watercourse with 2 cusecs of tubewell water results in only .81 additional cusecs of water reaching the fields. Adding 2 cusecs of tubewell water to a 1 cusec canal supply results

Table 1. Average loss rates as a function of watercourse discharge with and without tubewell augmentation.

	TOTAL DISCHARGE (CUSECS)	LOSSES/1000 FT. CUSECS	LOSSES/1000 FT. PERCENT	AVE. LOSS/4000 FT. PERCENT
Canal	1	0.075	7.5	30
Water	2	0.13	6.5	26
Only	3	0.20	6.7	27
Canal	1	0.16	16	64
Plus	2	0.25	13	52
Tubewell	3	0.32	11	44
Water	4	0.40	10	40
		0.51	10	40

in 9.89 additional cusecs of water reaching the fields. In general, the increase in water delivered to the field is less than half of the water pumped in the watercourses measured to date.

However, on about 10 newly cleaned or reconstructed watercourses, where the nuccas were carefully closed, losses measured have ranged from 1 to 5 percent of the flow per thousand feet of watercourse (Clyma et. al., 1975 and Kemper et. al., 1975). It appears possible to keep losses from watercourses in the range from 1 to 5 percent/1000 feet by cleaning and maintenance and careful closing of all nuccas. Recent measurements by M. Afzal on a watercourse at the Mona Reclamation Experimental Project before and after cleaning showed a change in loss from about 15 percent/1000 feet to 5 percent/1000 feet.

The loss figures reported above were obtained using cutthroat flumes near the mogha and near the nucca and waiting until the water was neither rising nor falling and the flow was steady. Such measurements do not measure the "operational losses" involved in filling and changing water in these watercourses.

To gain a measure of the total losses in a watercourse, including these operational losses, Kemper et. al. (1975 b) conducted an "inventory study" in which they measured the total flow into a watercourse branch and out of the branch through the nuccas opened legally during the warabundi turn. Of the 5.6 acre feet let into the watercourse only 2.3 acre feet reached the fields which the farmers wished to irrigate. In other words, only 40 percent of the water reached the fields despite the fact that the average distance from the head of this branch to the nuccas was less than 2500 feet. Steady state measurements on the same watercourse have shown delivery efficiencies averaging about 60 percent in periods before and after this inventory study.

The watercourse branch used for this inventory study had somewhat higher losses than the average of the watercourses measured and to date this is the only watercourse on which we have such data. However this limited data indicates that total losses can be about 50 percent more than losses estimated from steady state measurements.

III. Cause and Reduction of Losses

A. Seepage, Leakage and Overtopping

Seepage down through the watercourse bed when the water is low in the channel is small as indicated in Figure 1B which is derived from Figure 1A which is drawn from data taken on a section of Branch I of the watercourse at Tubewell

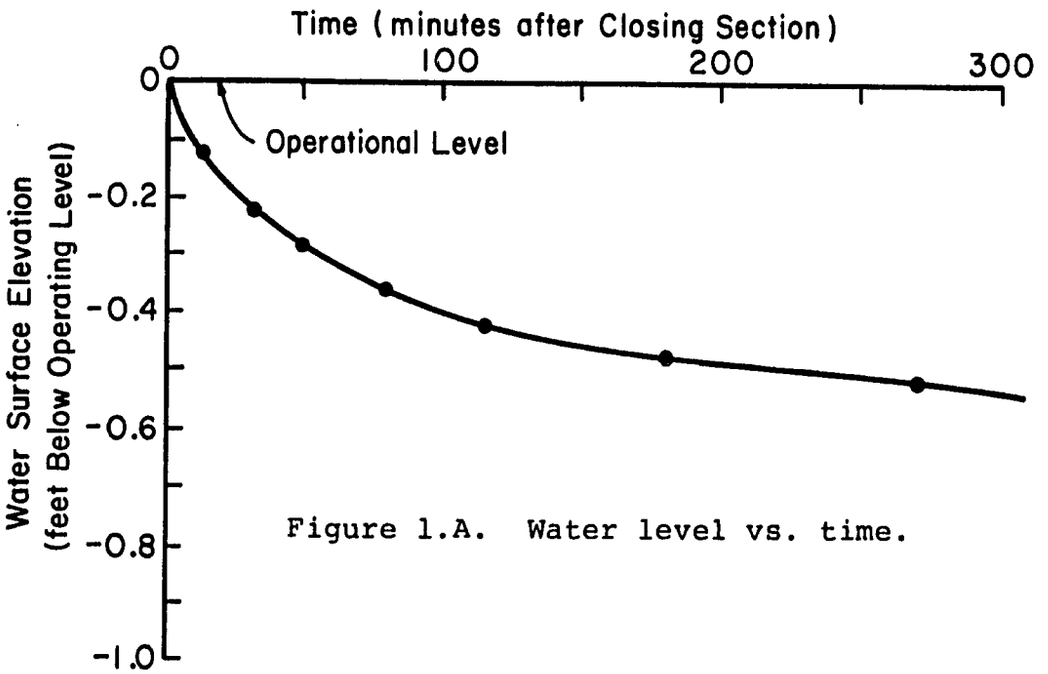


Figure 1.A. Water level vs. time.

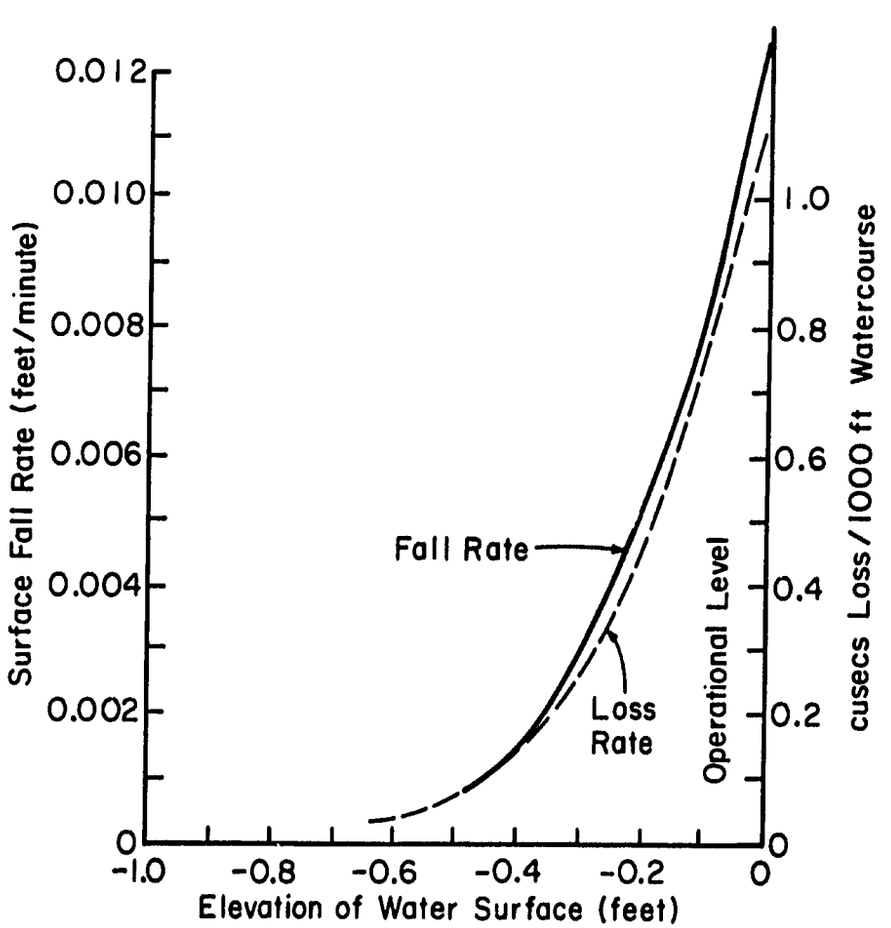


Figure 1.B. Fallrate and loss rate as a function of furface elevation.

#78 at Mona which carries up to 5 cusecs of water. When water was ponded on this watercourse at a level equal to that observed when it was carrying water to the farmers' fields there was extensive leakage and some spillage over the top of old nuccas and other low sections of the banks. When the level dropped a few hundredths of a foot the spillage stopped, but numerous small holes were still carrying water (leakage) through the banks, and water losses were still high. These holes are the result of decay of old roots and the burrowing activity of insects, worms, and rodents. Lowering the water surface to 0.4 feet below operational level reduced the loss rate to about 0.1 cusec per 1000 feet which is often an acceptable loss rate for a watercourse carrying 4 or 5 cusecs. Cleaning the grass and weeds from watercourses allows the water to flow faster so a given flow of water can take place in a smaller cross section. Reductions of 0.17 to 0.50 feet in surface elevations have been observed in operating levels following cleaning of watercourses. Using the ponding method on 35 watercourse sections in the Lahore and Mona areas, following lowering of the water surface by 0.17 feet, the loss rates were reduced on the average to less than 40 percent of their former values.

The uniformly low loss rates generally observed, even in sandy loam soils when the water level occupies only the bottom portion of the watercourse may be a result of accumulation in the bottoms of the watercourse of sufficient clay and silt from the canal water to keep the permeability low. The high permeability of the upper portion of the banks compared to the lower portion and the watercourse bottom is partially due to the lack of gravitational force to help hold and compact particles against the face of the vertical bank and the consequent falling away of finer particles.

Another characteristic of many watercourse banks is high concentration of roots and old organic matter resulting from piling the material cleaned from the watercourse on the grassy banks for many years. Traffic on the banks pushes this high organic matter soil mix downward and it often goes below operational water level as additional "cleanings" are piled on top and pressed down. The result is that the soils with the highest permeability in Pakistan are found in the banks of watercourses. It is common for the infiltration rate through upper portions of the banks to be 10 times the infiltration rate of water into adjacent soils that have been flooded.

B. Junctions and Pucca Diversions

Watercourses commonly carry flows of up to 5 cusecs. This flow is generally diverted from one leg on that watercourse to another by a farmer whose only tool is a kassi. In the process of stopping a flow of this size by placing an

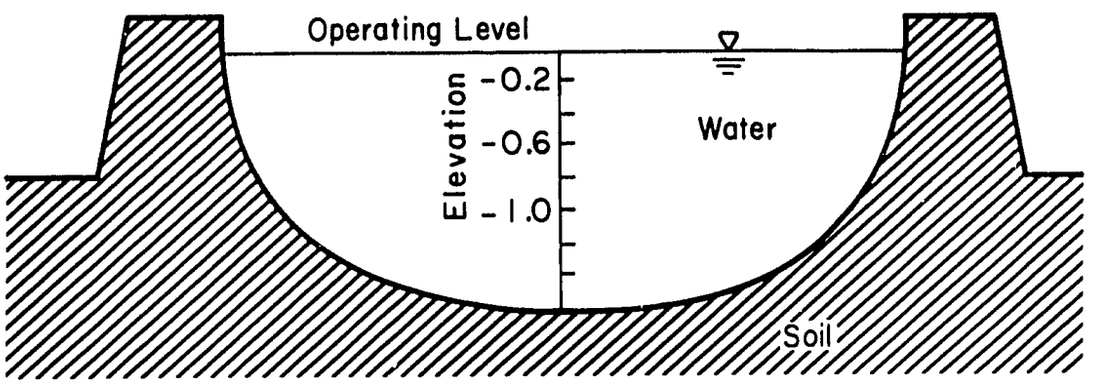


Figure 2. Approximate cross section of watercourse from which data in Figure 1 was taken.

earth bund across the channel, a large portion of the earth placed in the channel is often eroded down stream. Erosion also takes place when soil is removed from a channel while the water is flowing. Even when farmers are reasonably careful to remove as much of the soil in the bund as they can, as much as 20 or 30 percent of the soil is washed downstream with the water. Sometimes this eroded soil is replaced in the bunds from soils dug from the watercourse channel. This is particularly true if the farmer who owns the land adjacent to that junction has that land planted to a high value crop and has let the other watercourse users know that he resents damage to his crop by borrowing earth from his field. However, if the farmer owning the adjacent field is making the bund or if the farmer owning the adjacent field is too weak to protect his interests, borrow pits grow along these junctions, often using hundreds of square feet of land which would otherwise bear crops.

Borrowing of soil from inside and/or outside of the channel in these junction areas often results in thin banks and an expansion of the channel to two, or three or four times its normal width. As this tendency continues a farmer, who wishes to minimize the labor involved, does not build his dam across the wide and deep section but goes downstream to where the channel is normal size. Borrowing in that section soon widens and deepends the channel, and this enlargement of the channel and narrowing of the banks progresses downstream from the junction as time progresses.

The borrow pits along a junction are usually full of water when water is in the watercourse because the thin banks of the watercourse adjacent to these pits generally have many leaks and appreciable seepage.

Kemper and Akram (1975) measured the loss rates in these junction areas and found the loss rate per foot of bank to be almost five times as high in junction areas as along the normal sections. In the watercourse measured almost 50 percent of the loss was in the junction areas. Improvement of the junction banks to the same state as the rest of the banks could reduce the loss on this watercourse to 60 percent of its former value. The average steady state transmission efficiency on this watercourse was about 60 percent. Reducing losses to 60 percent of their former value is the equivalent of increasing transmission efficiency to 76 percent, which gives the farmers 76/60 = 127 percent as much water as they had previously at their nuccas.

The problem is that rebuilt junction sections begin to deteriorate as soon as the first earth dam has to be installed across this watercourse to turn the water. Consequently, though improving junctions can definitly increase water supplies at the nuccas, it requires large amounts of soil brought in to fill the borrow pits at regular intervals if the improvement is to be maintained.

The alternative is to install pakka control structures which allow the farmer to turn the water under conditions where little or no soil will be lost by erosion. Some of the control structures which are under test for these purposes are indicated in Figures 3 and 4. The bottom nucca in Figure 3 and the diversion structure in Figure 4 are both adapted to construction in katcha watercourses at installed costs of from Rs. 100 to Rs. 250 per pipe or per panel depending on the required pipe or hole size.

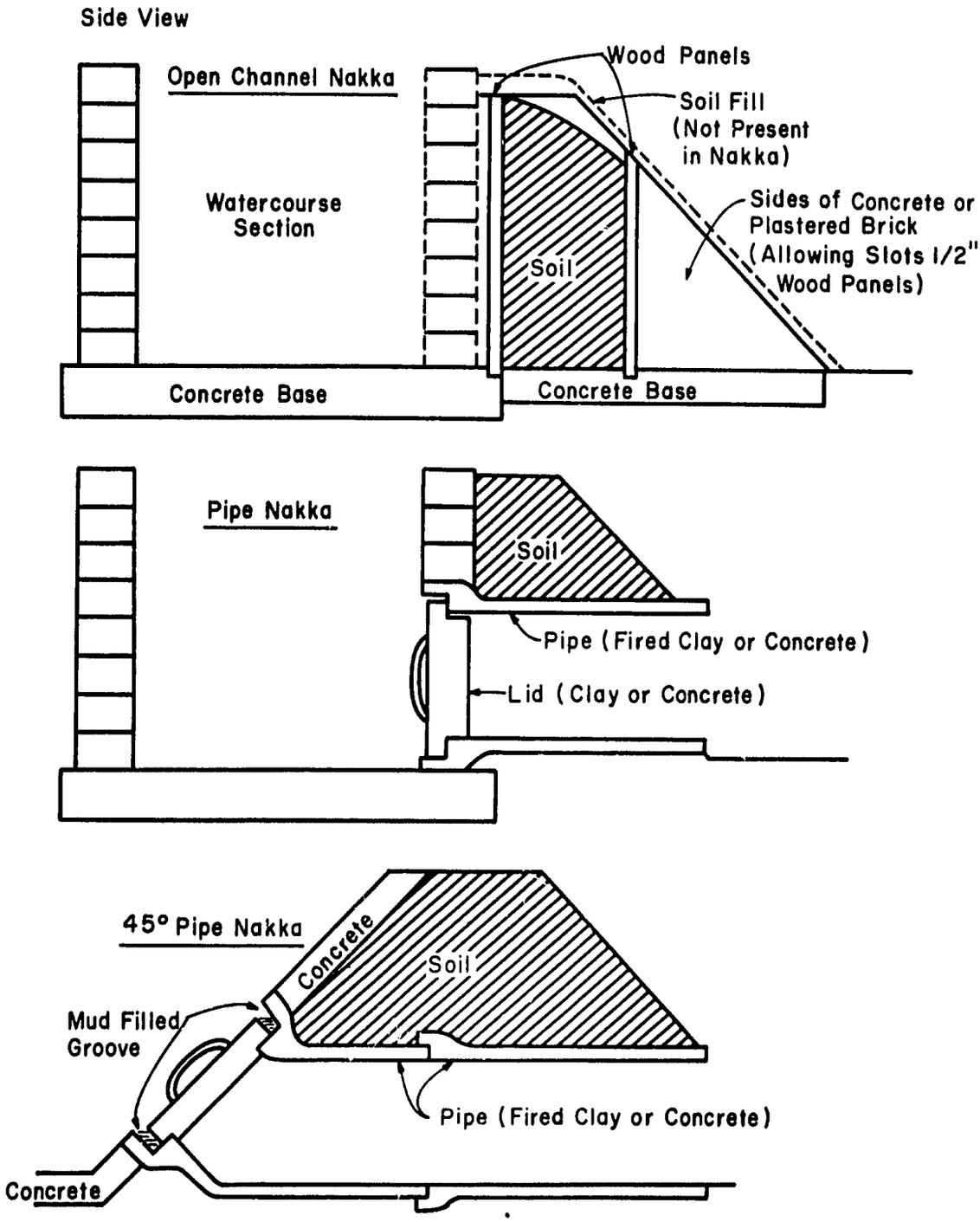


Figure 3. Nakka designs.

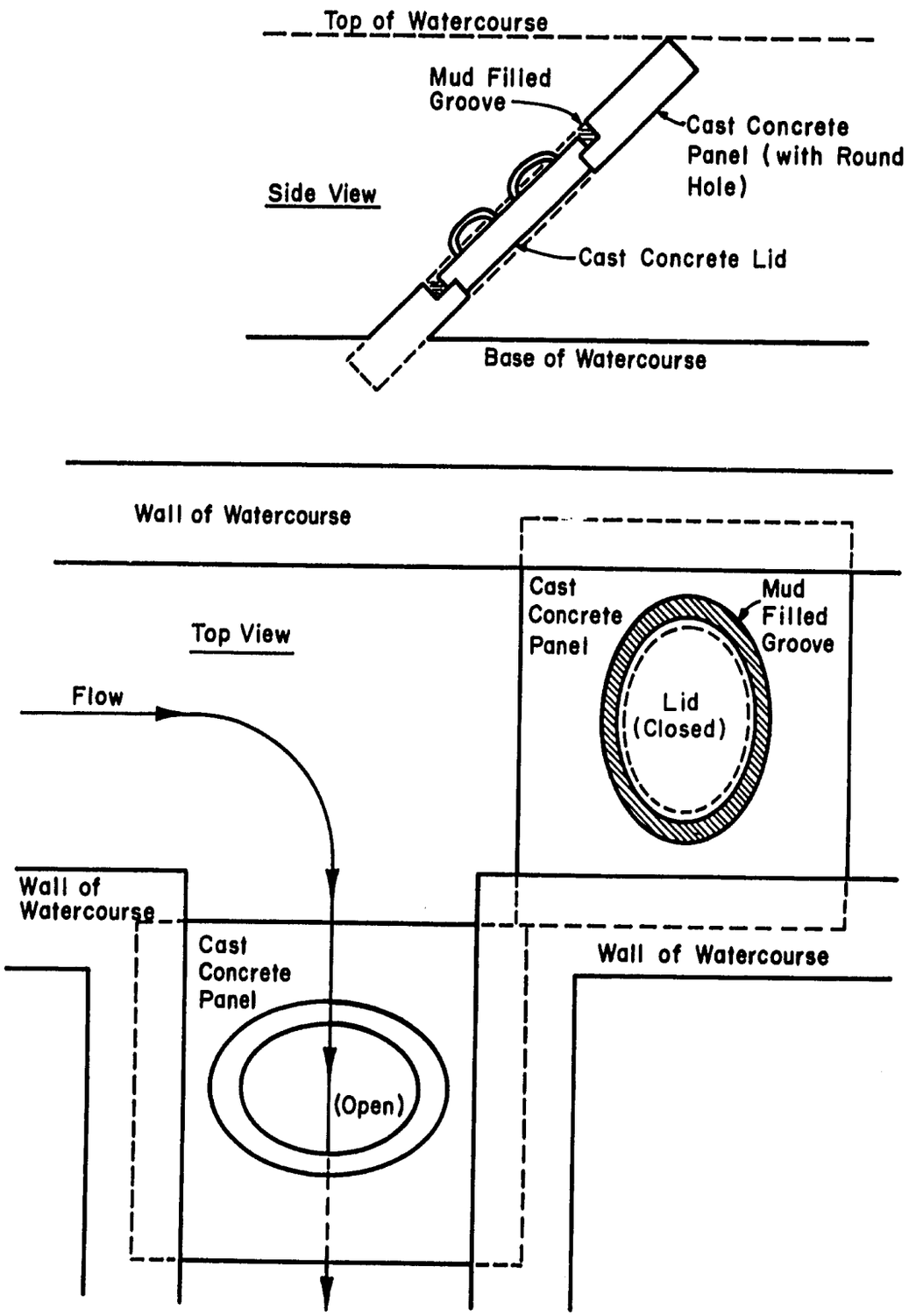


Figure 4. Diversion structure.

C. Operational Losses

In the limited trials to date, as much as 20 percent of the water coming into the watercourse may be lost in filling and wetting the watercourse, overtopping when water is let into a watercourse and no nuccas are open, spillage through nuccas that are accidentally left open, failure to build check dams in time, washouts of check dams and so forth.

Many of these spillage and overtopping losses can be avoided by care and good management on the part of the irrigator. The amount lost in filling the watercourse can be reduced to minimal values by engineering the bottom of the channel so it all slopes to a nucca where the water can be drained from the watercourse and used for irrigation or filling a pond.

The losses due to the initial rapid wetting of the watercourse banks can be eliminated only by pakka lining.

IV. Watercourse Improvement Programs

A. Regular Cleaning and Maintenance

Figure 5 is based on an observation in a 4000 ft. watercourse that before cleaning and maintenance, losses were about 15 percent per thousand feet, while after cleaning they were reduced to about 5 percent per thousand feet. This channel had not been cleaned for about 5 months and the cleaning and maintenance was initiated because the farmers had observed that overtopping of the banks was occurring. The overtopping in this section was due primarily to growth of tall grass in the section and secondarily to sediment settling from the canal water and earth dislodged from the bank to the bed at several points where animals crossed this watercourse frequently. If unsupported, the two data points in Figure 5 would not deserve the whole figure and this discussion. However, measured transmission efficiencies in several poorly maintained watercourses have been in the 20 to 40 percent efficiency range. The size and slope along these watercourses, used in Manning's equation indicate that if they were cleaned so the "roughness coefficient" was less than 0.05, the water level could be reduced from two to four inches, which according to observed relationships such as Figure 1, should substantially reduce water loss.

Cleaning and maintenance at 4 week intervals should allow improvement of the watercourse so that the rate of water loss is even less than that following a semiannual cleaning. Consequently, the top line of Figure 5 was drawn indicating a potential transmission efficiency ranging from 83 to 90 percent for a watercourse which is properly cleaned and maintained every four weeks.

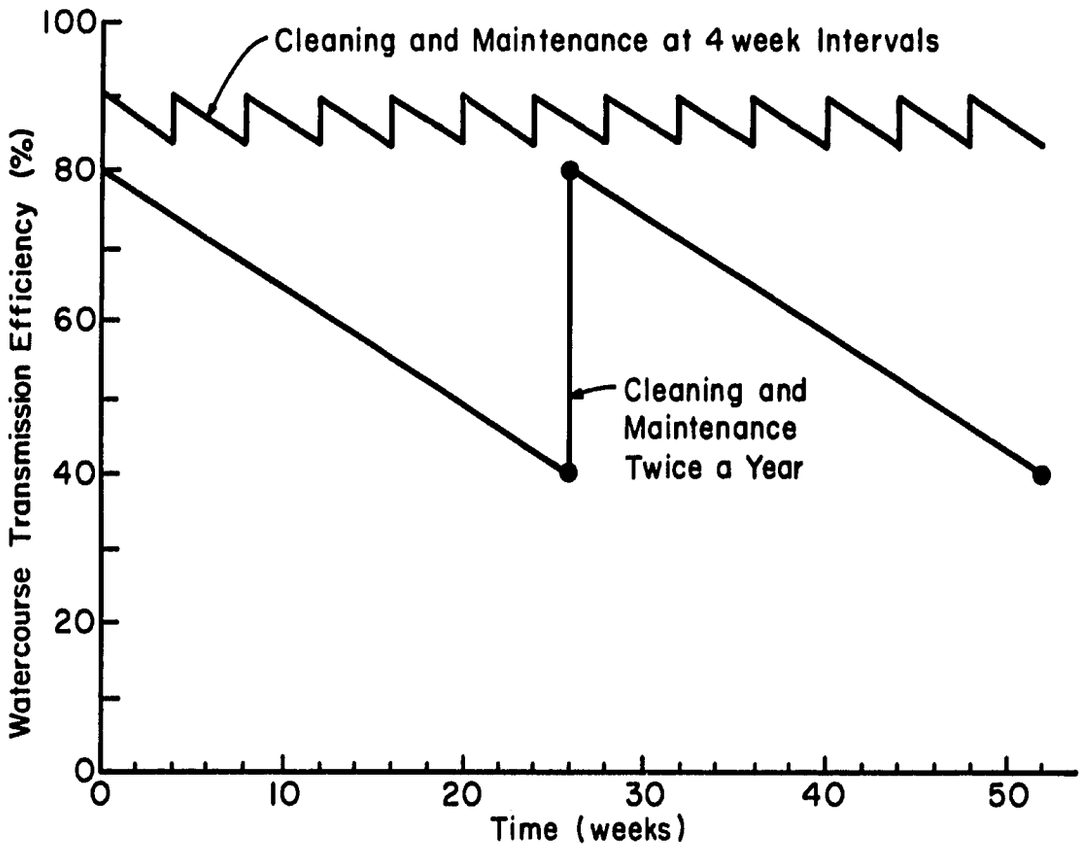


Figure 5. Potential effects of frequent (every 4 weeks) and semi-annual cleaning of watercourses.

In the 4000 foot branch watercourse where measurements were taken prior to and after cleaning, about 100 man hours were spent in this single cleaning and maintenance, indicating that a farmer can clean and do some maintenance on about 40 feet of watercourse per hour. The cleaning consisted of removing the grass from the bottom of the watercourse along with an inch or two of sediment, and some scaling of the sides which removed part of the grass. A large portion of the root system of the grass and some of the crowns were not removed which allowed early revegetation and served to prevent erosion (which had been a problem immediately following construction). Maintenance consisted of building up about 100 feet of banks which had been trodden down by livestock and eroded by spillage.

This watercourse is supplied with about 2 cusecs of canal water and 2.5 cusecs of tubewell water. An estimate of the cost of water saved by frequent cleaning and maintenance can be made as follows. If the farmers clean and maintain an 8000 foot watercourse every four weeks they will invest about 200 x 13 = 2600 man hours of time per year. Cleaning of this main channel twice a year would require at least 400 man hours, so the difference in time would be less than 2200 man hours. Assuming that Figure 5 indicates the water deliveries at the average mogha to nucca distance of 4000 feet the average transmission for monthly and semiannual cleaning and maintenance would be 87 percent and 60 percent respectively. The water savings due to more frequent cleaning would be about 27 percent of the total flow. Assuming that during a year the canal water flows for 300 days and the tubewell operates for the equivalent of 180 days, the total cusec days per year are (300 x 2) + (180 x 2.5) = 1050. Since one cusec day = 2 acre feet, about 2,100 acre feet flow per year. Saving about 27 percent of this water is equivalent to 567 extra acre feet of water delivered at the outlet to this cleaned section. The cost of this water is 2200 man hours/567 acre feet or about 4 man hours per acre foot of water. To get most of this water to his fields each farmer may have to expend about twice this amount of time on cleaning and maintaining the channels leading from this main branch to their individual fields. The labor cost to the farmer of this saved water appears to be about twelve man hours per acre foot, which is some of the least expensive water available in Pakistan today.

There are watercourses in Pakistan which have intensive cleaning and maintenance programs (e.g., Mirza et. al., 1975). For instance, in the watercourse serving tubewell MN-65 in the Mona project area, the 8000 foot main channel and 7000 feet of primary branches are cleaned cooperatively twice and once a month respectively. This cleaning requires 6900 man hours per year. Farmers' observations indicate that this cleaning increased the delivery about 0.4 cusecs for 290

days/year, yielding about 230 extra feet of water/year at a cost of about 30 man hours/acre foot. It is probably that this cleaning and maintenance could be less frequent and still maintain most of the benefits so the cost of the water could be reduced. However this land grows excellent Kinos, which are selling at an average annual rate of near Rs. 8000/acre. Adequate water is the primary factor limiting Kino acreage and consequently the value of the water to the farmers is many times its cost. Consequently, their current goal is to maximize their water supply rather than to minimize its cost.

Measurements are underway on this watercourse and others to determine the water savings and time involved in cleaning. Additional studies are also needed to determine time consumption and water savings resulting from specific cleaning and maintenance activities such as grass removal, bank building, closure of holes (rodent, insect and worm holes), compaction or puddling of the inner banks of the watercourse, overexcavation in sandy soils to allow settling of fine sediment to seal the perimeter, etc. When these facts are known, the farmers can be advised as to how they can most effectively spend the time which they have available for watercourse maintenance.

There is not yet sufficient data available to recommend an "optimized" cleaning and maintenance program. However, it is apparent from the limited observations taken to date that when water is in short supply, cleaning and maintaining that watercourse is commonly the most available and least expensive source of additional supply.

B. Construction and Reconstruction of Earthen Channels

1. Construction of New Earthen Channels

Reasons for the porous nature of the upper portion of old watercourse banks were discussed earlier. Kemper et. al. (1975) found that sections of new channels in loam soil had water losses which averaged less than 1/4 as large as losses in adjacent old channels. The average loss rate in the new sections was 0.02 cusecs/1000 feet from sections 2.7 feet wide and 0.7 feet deep. The difference between old and new channels was noted even when there was no overtopping or leakage from definable holes in the old watercourse banks. In replicated sections (30' long) of the side branch of a watercourse in a sandy loam soil Kemper et. al. (1975) measured the rates of loss indicated by the dashed lines in Figure 6. In the old sections the loss rate was 0.75 cusecs/1000 feet at the operating level. The farmers had built a new section close by. Banks of this new section were composed of loose soil and the roots and crowns of old sugar cane stalks, and loss rates at operating level in this "loosely built" section at operating level were 0.63 cusecs/1000 feet.

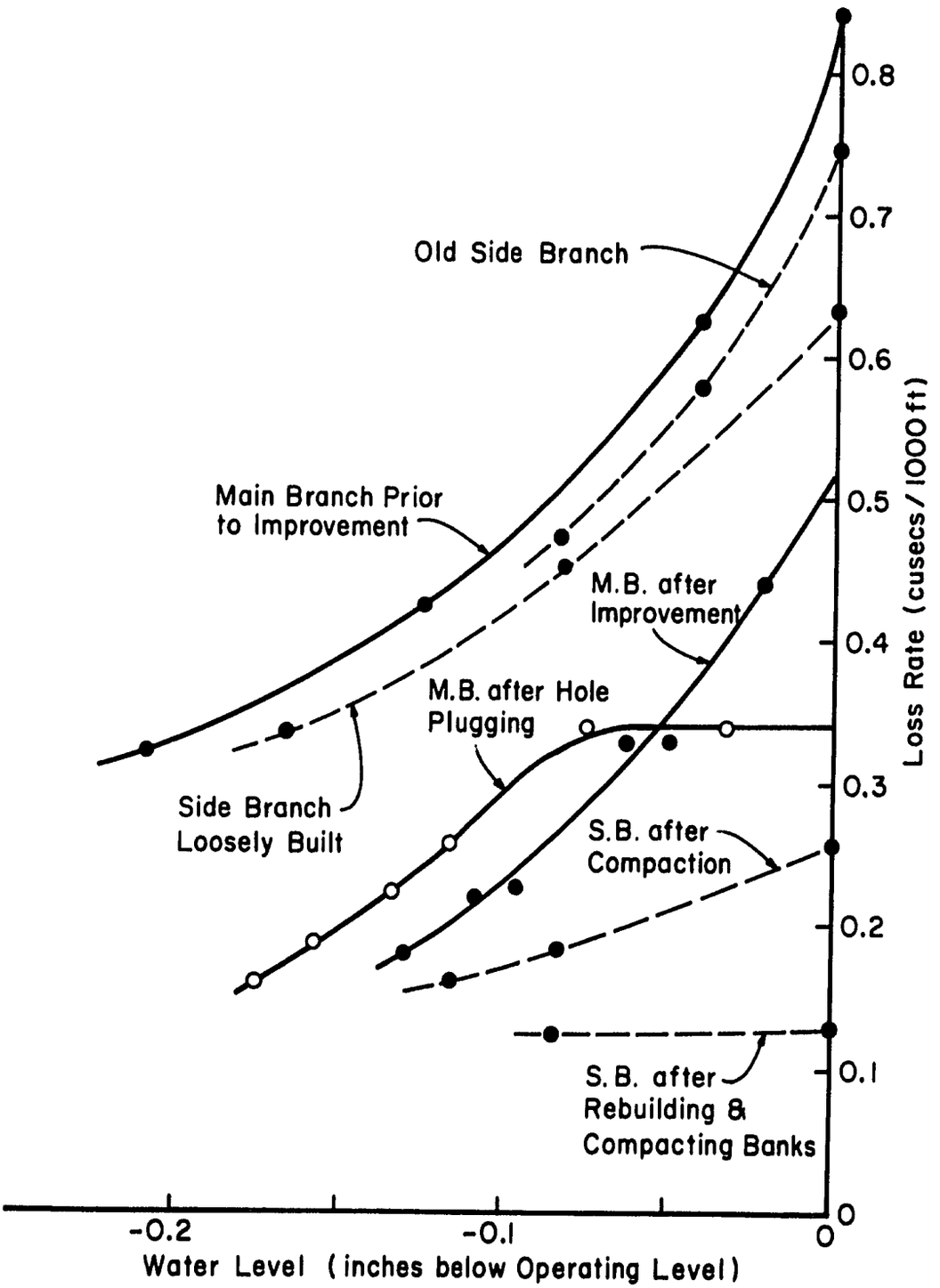


Figure 6. Watercourse losses as a function of water surface levels and the condition of the banks (in sandy loam soil).

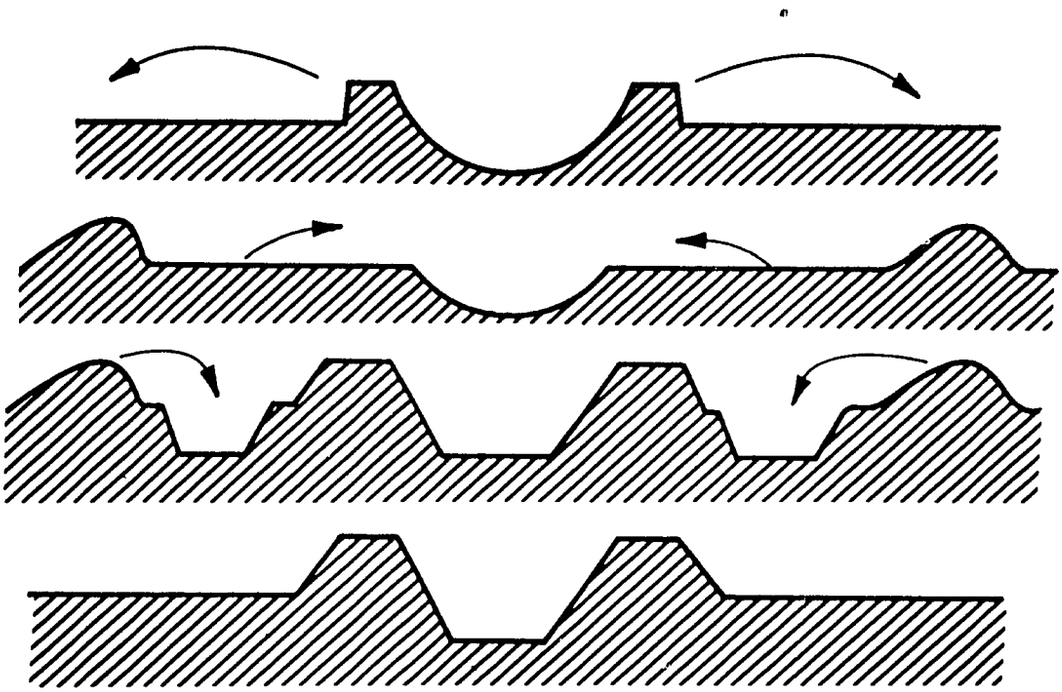
Sections of this newly built watercourse were compacted from the inside by stepping against them when they were in a moist condition. Banks of other sections were removed in a manner similar to that shown in Figure 7. Sandy loam soil (free from cane crowns etc.) was used to build new banks which were compacted by stepping on them while they were being built. The average loss rates at operating levels for the compacted and rebuilt compacted sections were .26 and.13 cusecs per 1000 feet respectively as shown in Figure 6.

Trout and Karim (1975) monitored the time taken by beldars to build a watercourse on which the bed level was excavated 12" below the ground surface, the top of the banks was 8" above the ground surface, the bed was 12" in width, the side slopes were 1:1 and the top of the banks were 12" wide. This required excavation of 2 cubic feet of loam soil from the channel per running foot which was placed on the banks and these banks were augmented by about .12 cubic feet of soil/ running foot taken from outside the channel. This channel was designed to carry up to 2.5 cusecs of water, and 0.3 man hours per foot were used in its construction.

Assuming 2 cusecs of water flows into such a channel for 12 hours of each week, 40 weeks a year and the loss is reduced from 10 percent to 3 per thousand feet, the yearly savings of water achieved by remaking 1000 feet of such a channel would be .07 x 480 x 2 acre inches of water or 5.6 acre feet. If the beneficial effects extend into the second and third years with an average of 1/2 their original savings the total savings would be 11.3 acre feet. The beldars monitored by Trout and Karim built an average of 3 feet of channel/hour. However farmers, more accustomed to kassie work and motivated by potential personal benefits moved an average of about 18 cubic feet of earth per hour in another watercourse building study and at that rate would build about 9 feet of this watercourse per hour. At the farmer construction rate it would take about 111 man hours to build a new watercourse of this cross section and 1000 feet in length while at the lower construction rate it would require up to 330 hours. Consequently, the cost of the saved water would be 10 to 30 man hours per acre foot depending on the efficiency of the earth movers.

2. Enlargement, Repair and Realignment of Old Channels

On one branch of the watercourse serving Tubewell 78 in the Mona project, farmers were contacted by extension agent (under the direction of Mr. Mohsin Wahla) and an agriculture engineer (Mr. Mohd. Akram) who told the farmers how much water they were losing and suggested that the farmers rebuild their watercourse. The farmers agreed to do this and worked during the last two weeks of August and the first weeks of



Steps Using Kassees:

1. Cut Off Banks and Move Away from Watercourse.
2. Borrow Soil from bear Watercourse and Compact in Layers about 3" Thick to Form New Banks.
3. Pull Soil from Old Banks into the Borrow Pit.

Figure 7. Labor intensive reconstruction of watercourse reconstructing a watercourse.

September rebuilding this watercourse according to the design developed by Mr. Akram. A total of about 1200 man hours was spent building banks, shaping the interior of the watercourse to the designed cross section and filling in borrow areas on the 2500 feet of watercourse for an average of about 0.5 man hours per foot of watercourse.

This 2500 feet of watercourse was designed to carry up to 5 cusecs of water and will have 16 pucca panels (similar to those shown in Figure 4), three new overpasses and one drop structure. These structures will cost an average of about Rs.250/each (installed). The total for pucca structures will be about Rs.5000, or an average of Rs. 2/foot of watercourse.

The initial losses in this branch watercourse as a function of level of water surface are shown in the top line of Figure 6. At operating level the old branch was losing 0.8 cusecs/1000 feet. Rebuilding consisted of digging soil from inside the channel to bring it to the proper depth and cross section. This soil was piled on the banks, along with soil borrowed from outside the channel to give them a top width of one foot side slopes of 1:1 and a freeboard above designed for operating level of six inches. These banks were compacted to some extent by over 6 inches of rain and foot traffic during the construction described above. The degraded junctions were filled in and pakka control structures similar to those shown in Figure 4 were installed.

When this improved branch was filled with water, at operational level it was still losing about 0.5 cusecs per thousand feet. At most of the points where there were observable leaks in the old watercourse banks the enlarged new banks were still leaking. About 3 man hours were spent with a belcha (shovel) per 1000 feet, closing the observable leaks. When the watercourse was filled again the loss at operational level had been reduced to about 0.34 cusecs per thousand feet. While this loss reduction (from 0.84 to 0.34 cusecs per 1000 feet) was adequate to justify the rebuilding, it is apparent from comparing the losses from this rebuilt section "after hole plugging" to the bottom dashed line in Figure 6 that removal of the banks and reconstruction (as in Figure 7) can further reduce these losses from 0.34 to down to less than 0.15 cusecs/1000 feet in this sandy soil. The pakka structures for water control eliminate soil borrowing that caused the large amount of leakage around junctions. The rate of leakage at these junctions, in the cases measured, averaged about 45 percent of the total loss or 18 percent of the total flow. The control structures used in these channels have practically no leakage if closed properly. However, there is still some leakage through the new earth banks that replace the old thin leaky banks, and the average farmer will not always properly close the improved control structures. A realistic

estimate might be that the loss in these junction areas is reduced from 18 percent to 5 percent of the total flow by installation of good pakka control structures and proper reconstruction of the banks in their immediate vicinity. The other advantage of the pakka nuccas is that they practically eliminate the weekly construction and removal of earth dams at these junctions. On a watercourse carrying up to 4 or 5 cusecs of water, 8 to 16 cubic feet of soil are needed in a dam which will properly stop this flow. Assuming an average of 10 cubic feet of soil used to make the dam and 8 cubic feet of soil recovered from the dam when it is removed, the farmers move 18 cubic feet of soil at each of these dams each week. Borrow pits at each dam grow at a rate of about 2 cubic feet per week or 100 cubic feet per year, and must eventually be filled with soil from the adjacent fields. During reconstruction of the watercourse banks, farmers were moving earth equivalent distances at a rate of about 18 cubic feet per hour. If the farmers' time is valued at Rs. 1.00/hour, as was done for the construction process a concrete control structure (pakka nucca) would save him labor worth about one rupee per week or Rs. 50/year. Refilling borrow pits from the fields costs about Rs. 2/cubic yard of soil if an efficient earth moving operation (tractor and scraper or bullocks and karah) is involved. Two cubic feet of borrow pits for 52 weeks would require about 4 cubic yeards of fill at a cost of about Rs. 8/year per dam site.

If the farmer can properly open and close the pucca nucca in 10 minutes, he will expend about 8.3 hours/year, or about Rs. 8.00 of labor operating the pucca nucca. The reduction in labor will amount to about 42 hours per year or Rs.50 per year per pakka nucca installed, which would amortize the cost of a Rs.250/nucca in 6 to 7 years depending on whether the interest rate is 7 to 10 percent per year.

It should be noted that a farmer does not actually spend 30 minutes closing a dam on a 4 to 5 cusec watercourse. One or two men work as fast as they can as the water keeps washing away the soil and usually manage to close the gap with a few large pieces of sod filled soil. This struggle may take only 5 to 15 minutes depending on the number of men and the stream size. However, at the end of this time they are generally ready for a 10 or 20 minute rest.

It is also true that farmers will find many ways to reduce the amount of soil in a dam. Keeping the dam very narrow and reducing the freeboard to practically zero are among these ways in spite of the fact that this results in an appreciable washout rate and accounts for an appreciable amount of the "operational losses" described earlier.

In general it appears that the cost of installing pakka nuccas on watercourses which carry 4 to 5 cusecs can be more than paid for in labor savings if earth moving is valued at

one rupee per 18 cubic feet of soil and the dam must be made and removed once a week. This means that the water savings resulting from elimination of these major points of weakness on the watercourses will generally be a clear profit. Assuming 4 cusecs of water flow, 40 percent steady state loss and 30 percent of this 40 percent = 12 percent of the total flow saved as a result of pakka nucca installation the farmers should receive 0.48 cusecs of additional water at their fields. Assuming this rate of flow for 250 days per year, a watercourse will deliver about 241 extra acre feet of water to the farmers per year. If these structures last for 15 years, at this rate of delivery the farmers will receive 3,615 extra acre feet of water as a result of their installation. On a representative watercourse commanding about 500 acres about 160 pakka nuccas appear to handle the main junctions. If these are installed for Rs. 250.00 each, the cost/watercourse for controlling water at these diversions is about Rs. 40,000.00.

The above calculations are based on work done or in progress on only a few watercourses and the results cannot be considered an average for all watercourses. However, even if the cost/benefits ratio is reduced by a factor of 2 for other watercourses, building pakka nuccas and improving earthen watercourse channels appears to be one of the best investments in Pakistan. Based on the limited data available, the following programs are proposed.

3. Programs Suggested

a. Improving Earthen Channels of the Main Channel and Primary Branches

(i) Specially trained water management advisers, measure the water losses and estimate the potential for improvement of watercourses and determine the interest of farmers in making the improvements.

(ii) If farmers are interested they will hold a meeting, form a committee and with the adviser consider the costs and potential benefits of improving their watercourse. If the Government pays the water management adviser and an engineer to advise the farmers, the cost to the farmers will be primarily their labor. Using the limited data available it appears that labor on the order of 20 man hours per acre of land served will be needed to give the average watercourses the proper cross section, slope and freeboard on the main channel and primary branches.

(iii) If the farmers are willing to commit this amount of time and tolerate and fill the resulting (and

existing) borrow pits, the design and schedule for improvement activities will be developed. The improvements will be scheduled to interfere as little as possible with needs for irrigation water. Arrangements should be made for tree removal and the main part of the work should be planned for a season when the farmers have time to spare from their essential farm operations.

(iv) One or two trained engineers (depending on the water course size) should be available to design and align the watercourse and guide the farmers in the construction, including emphasis on proper cross section of the channel and banks, and packing of the banks.

(v) These sections should be filled a day or more before they are to be used to "settle" the banks and allow detection and closing of observable leaks.

(vi) During the first day of use of each new section the engineers will inspect the channel to determine problems. For instance, if the water is flowing too swiftly and erosion is taking place at certain points, temporary checks made of loose brick or canvas should be installed to raise the water surface and reduce its velocity until the erosion can be prevented by grass cover, or by the installation of pakka drop structures.

b. Improving the Main Channel and Primary Branches Including Pakka Structures at Junctions and Crossings.

The same steps will be followed as in (a), but arrangements will be made by the farmers (with guidance from the water management adviser) to finance the construction of pakka nuccas at major junctions and culverts at needed crossing points. The purchase and installation costs of these pakka nuccas and culverts will be about Rs. 250.00 each and about 200 of them will be needed on watercourses serving 500 acres, for a cost of about Rs. 50,000.00 per watercourse or about Rs.100/acre.

Masons should be trained for installation of pakka structures and their pay and advancement will be based on the quality of their work. The amount of brick work can be reduced by almost 50 percent if the masons put good mortar into their work. This could reduce the cost of the nucca installation by up to Rs.50/nucca.

In a few pilot, or demonstration watercourses, the cost of these pakka installations will be considered a research expenditure. (Improvements in the nuccas are still being

made and are needed.) After these demonstration watercourses are constructed and the benefits and costs evaluated, the farmers should pay the costs, by direct subscription, or by increases in their water levies (e.g., Rs. 10 per acre per season for 12 seasons = 6 years.) However, the program should be initiated only on watercourses where the farmers are convinced and ready to pay the price. If the capital outlay appears too great for the farmers, they should consider the improvement without the pakka structures.

While borrow areas and associated losses will be minimized by the pakka control structures a well organized program of cleaning and maintenance will still be essential to maintain high delivery efficiencies.

c. Procedures for Minimizing Losses by Building New Compacted Banks on Watercourses

In areas where there is no other source of additional water and its value is high, additional steps to minimize water losses will often be economically worthwhile. Compacting and properly shaping the banks of a watercourse to reduce seepage appears to be able to save considerable water. This can be done at the same channel location using the procedures indicated in Figure 7, or by building a new watercourse at a new location. Packing of the new banks, and special efforts to close all rodent, insect and even worm holes will appreciably reduce losses. Single rodent holes, leading from the bottom of water channels to undetectable locations have been observed to carry away 0.01 to 0.04 cusecs continuously for periods of several hours.

Other than special care to the above details, the program for improvement should be similar to the programs outlined in (a) and (b).

d. Pakka Lining of Watercourses

The benefits of pakka lining include minimization of water loss, reduction in maintenance and increased control of the water. Eckert, Dimick and Clyma (1975) concluded that high costs of pakka lining prevent the cost benefits ratios of pakka lining from being as high as those that can apparently be achieved with pakka control structures and earthen improvement. However, in areas where groundwater is not suitable for use, other sources of water are not available and high value crops can be grown (e.g., Kinos @ Rs.8000/acre/year) the benefits can be sufficiently high to justify the costs of lining the main channels. It is probable that within the next 50 years, as crop production increases to meet increasing demands for food that most of the watercourses in Pakistan will be pakka lined.

Earthen improvements with pakka control structures are economical interim measures, which if properly maintained, can help the farmer develop the capital for many improvements including pakka lined watercourses.

V. Watercourse Losses and Waterlogging

A. Value of Lost Water

In some areas the water lost from a watercourse is not a complete loss since at least part of this water recharges the ground water, helps maintain or raise the water table, and is available for pumping back to the surface (at a cost of about Rs.50/acre foot at the well for government tubewells and Rs. 40 to 120 per acre foot for private tubewells). If the above figures based on the cost of water saved through watercourse maintenance on this single watercourse are within a factor of 2 of the actual average, it is apparent that water saved by cleaning watercourses is less expensive than pumped water.

In many areas where the water table is near the surface additions to the ground water increase the waterlogging and salinity of the surface soil, and in these areas the value of this water lost from the watercourses becomes negative.

B. Crop Damage

Elimination of overtopping and reduction of seepage and leakage also prevents damage to crops that grow along the main channels and branches of the watercourses. Walking surveys along watercourses serving Tubewell #91 in the Mona Project Area, and the Mohlenwhal Kurd watercourses near Lahore indicated that 15 and 6 acres of crops respectively were damaged to an extent of 50 percent or more yield reduction by water from these main channels. At T.W. #91 watercourse the damaged acreage included about 4 acres of Kinos. Most of the rest of the damage was done on wheat crops. Kinos from orchards in these areas were selling at about Rs.8000/acre and good wheat fields were producing about 30 maunds per acre selling at Rs. 40/maund. If our estimates of 50 percent yield reduction was close, the loss due to waterlogging from watercourse channels leakage was about Rs. 4000/acre on the Kinos and Rs.600/acre on the wheat, for a total economic loss of Rs.25,000.00 on these two watercourses. These data are too limited to even try to estimate an average for the Punjab, but do indicate that significant reduction in crop yields is resulting from surface wetting due to leakage from watercourses in Pakistan.

C. Distribution of Lost Water

Soil surfaces out to 100 feet from the watercourses are often wetted each time water runs in a primary branch of

a watercourse. These areas often will not grow cash crops and produce only a limited amount of fodder. However, the surface is almost always moist and evapotranspiration is probably close to the maximum most of the time. Trees growing along watercourses can also transpire amounts of water approximately equivalent to evapotranspiration from a strip of land as wide as the trees are tall. These substantial amounts of evapotranspiration must be subtracted from watercourse losses before the remainder of the watercourse losses can be relegated to ground water recharge.

Texture and permeability of the soil are a primary factor determining the portion of water going to the ground water. Since most of the leakage is from the upper portions of the watercourse banks, this leakage frequently travels over the surface and if the soils have fine textures and low permeability, may go many feet before being absorbed. On the other hand, in sandy soils a larger portion of the loss is direct downward seepage to the ground water and the leakage through the banks travels short distances before being absorbed in the soil.

Assuming a 550 acre watercourse, with 30,000 feet of main channel and primary branches, supplied by an average of 4 cusecs of canal and tubewell water for the equivalent of 250 days/year, the amount of water flowing into this watercourse is about 2000 acre feet per year. If 50 percent of this is lost in the watercourse, 1000 acre feet are lost per year. If the surface soil were moist for an average distance of 20 feet each way from the center of these main channels and primary branches (a liberal estimate) the number of acres of wet evaporating soil caused by this leakage from the watercourse would be 26 acres. Assuming an annual evaporation rate of six feet per year, about 156 acre feet of water per year would be an upper limit of what could be lost per year by this direct evaporation. Consequently, the majority of the 1000 acre feet lost from the watercourse still probably gets to the ground water where it causes a general rise in the water table.

D. Groundwater

Raising the water table nearer the surface can increase the portion of the plant needs that are drawn from the ground water. If a cusec of water running for 300 days a year is serving 250 acres and the watercourse is losing 40 percent of its water, or 240 acre feet per year, according to the estimates above less than 67 acre feet could be going directly to evapotranspiration and consequently over 170 acre feet/year will go to the ground water, or over 8 inches per year on an average over the 250 acres. If the drainage yield, or fillable pore space is 25 percent of the aquifer volume, and there were no removals or other additions to the ground water, the water table would rise 32 inches per year.

However, once the capillary fringe of this water table came within reach of plant roots, the crops transpire a large portion of this water, and further rises are curtailed. While such high water tables can provide some of the crop water requirements it is a precarious situation in the monsoon season in the northern parts of the Punjab where rainfalls of several inches may occur. If the water table is already only 36" below the surface and a 8" rain occurs over a wet week, the water table may rise to one foot or less from the surface, drown a major portion of the crop root system and reduce yield or even kill the crops. The SCARP system has generally pumped sufficient water from the ground water to lower the water table several feet, giving the plant roots a good chance to stay above the water table even in the monsoon seasons.

However, it should be emphasized that little water was actually added for the crops water requirements by the pumping plants in the SCARPS. The water table was practically static before the SCARP wells went in and it reached a new equilibrium after they were installed. Lateral transfers through the aquifer between SCARP and non scarp areas, resulting from lowering water table in the SCARP areas have been estimated and are generally practically insignificant compared to the amount of water brought in by the canals, or lost by transpiration. The plants were in a precarious position "pumping their own water" accumulating saline water in their root zones, and evaporation was pulling some of that saline water to the surface and keeping some of the soils from growing crops. After the SCARP wells began to pump, young plants with shallow roots could be provided with water as it was needed. However, as discussed earlier, about half of this pumped water is lost from the watercourses before it reaches the fields. It appears possible to save about 2/3 of this lost water by watercourse improvement in SCARP areas (at a cost considerably less than that of installing and operating new pumping plants) and help the present SCARP pumping plants achieve their intended potential.

However, the benefits of watercourse improvements which will reduce losses will be greatest in those areas where saline ground water contaminates lost water which finds its way downward. Here lining of the watercourse channels to reduce seepage to a minimum may be an economical practice since the value of water is high due to the lack of other sources of water. More careful application of irrigation water and land leveling will also help avoid "spot" over-irrigations. However the most "available" and least expensive source of water and means for decreasing the threat of a rising saline water table is to follow some of the above programs which will decrease water losses from watercourse.

REFERENCES

Clyma, Wayne; Ali, Arshad and Ashraf, M.M., 1975, "Watercourse Losses Proceedings CENTO Meeting on Optimum Use of Water in Agriculture" March 3-5, 1975.

Eckert, J.B., Dimick, N. and Clyma, W., 1975, "Water Management Alternatives for Pakistan A Tentative Appraisal", (C.S.U. Field Party Report)

Harza Engineering Co., Intl. 1963, "A Program for Water and Power Development in Pakistan 1963-1975". Supporting studies, "An Appraisal of Resources and Potential Development", A report prepared for WAPDA.

Kemper, W.D.; Clyma, W.; Akram, M; Hanif, M. and Pervez, I., "Watercourse Losses as Related to Composition of Banks", C.S.U. Field Party Status Report

Kemper, W.D.; Akram, M; Afzal, M.; Iqbal, M. and Cheema, M., 1975b, "Where Water Goes in a Watercourse", C.S.U. Report.

Lieftinck, Pieter; Sadove, A.R. and Creyke, T.C., 1968, "Water and Power Resources of West Pakistan: A Study in Sector Planning", Vol. 1., The main report published by World Bank and the Johns Hopkins Press, Baltimore.

Mirza, A.H.; Freeman, D. and Eckert, J.B., 1975, "Village Organizational Factors Affecting Water Management Decision Making in Pakistan", (C.S.U. Water Management Technical Report #35.)

Tipton and Kalmbach, 1967, "Regional Plan Northern Indus Plains: Development and Use of Water Resources of the Indus Plain", Vol. 1, Report prepared for WAPDA.

Trout, Tom and Karim, Ch., 1975, "Manual Construction of an Experimental Watercourse at Phullarwan Farm", C.S.U.Report.

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Mr. Moh'd Akram and Mr. Mohd. Afzal, Asst. Agr. Engineers at the Mona Reclamation Experimental Project have taken much of the data reported in this study and helped design the improved watercourses. Mr. Mohsin Wahla and the extension staff at MREP motivated the farmers and took the data on hours of time spent for various watercourse improvements. Dr. William Hart and Mr. Thomas Trout of the C.S.U. Agricultural Engineering Dept. were instrumental in developing and testing the pakka nuccas and assisted considerably designing the watercourse improvements. Our appreciation is extended to these men and many others who have contributed liberally of their time and ideas in the process of developing the concepts outlined in this paper.

APPENDIX 16

MANUAL CONSTRUCTION OF AN EXPERIMENTAL WATERCOURSE AT PHULLERWAN FARM

by

Tom Trout and Ch. Karim[1]

A 400 foot watercourse was constructed to deliver accurate flow rates under varying conditions to two acres of experimental plots. The channel is of sufficient size to carry 2.5 cfs at 1 fps. WAPDA beldars (manual laborers) with kusis (Pakistani shovel) were used to construct the unlined watercourse. The trapezoidal channel was constructed from a three inch pad laid during land leveling operations. The manual phase involved moving and shaping four cubic feet of soil per foot of channel. Two brick check structures and one canvas sock nucca were constructed in the watercourse.

The watercourse was laid out and shaped with the help of a rope, and elevations of the bottom and banks were continually checked with a surveyor's level. All design specifications were met to within one inch.

Because soil conditions were too wet to use a sheepsfoot compactor, the beldars were continually encouraged to compact each 3 inch layer of bank by tramping with their feet. The beldars were not accustomed to this practice nor did they readily adapt to it, and compaction on most of the watercourse was poor. In one section, where the newly completed banks served as a path for carrying bricks, compaction was adequate. It is suggested that some type of manual compaction tool, such as a heavy rod with a flat plate at the bottom, be provided for future manual construction work.

At the completion of the construction the channel was filled to within one inch of the bank tops, or three inches above design depth and nine inches above the field level to check the strength of the banks. Major leaks developed through the fill dirt around the check structures, through an animal hole and in two places through the banks. Minor seepage occurred in many places. The one foot wide saturated banks became soft and were difficult to walk on without destryoing the shape in several places. After two days the banks were again tested, both dry and with the channel filled with water, and were found to be adequately strong. The only leak developed at an animal hole. Apparently, the saturated conditions of the banks created during the first filling acted to compact and strengthen the banks.

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Losses from the channel were measured after it had been in use for two weeks. Measurements were made by ponding water in the channel and measuring the water surface area and rate of water level decline at the operation depth. The loss rate in the first 200 foot section was .039 cfs/1000 ft, or 0.32 in/hr through the wetted perimeter. In the second 200 foot section, where 10 kacha nuccas had been previously cut through the walls, the seepage rate was 0.032 cfs/1000 ft. or 0.28 in/hr. About 900 cubic feet of water was used to fill and wet the 400 ft. watercourse over a period of 40 minutes.

Construction materials and labor costs are given in the following table. The costs include no design, or transportation and planning costs or time. With the control structures, the construction costs averaged Rs. 1.42 per foot of channel ($0.14 per foot). Excluding the control structures the watercourse cost would be Rs. 0.81/foot.

Table 1. Watercourse construction costs.

1) Pad Construction: 32 yd^3 of soil fill

3.2 hours of tractor and driver time @ Rs. 35 = 112

2) Channel Construction: 60 yd^3 of soil moved and shaped

88.5 beldar hrs @ Rs. 1.5/hr =	Rs. 130
12 supervisor hrs @ Rs. 3.0/hr =	Rs. 36
10 engineer hrs @ Rs. 4.5/hr =	Rs. 45
Total	Rs.211 or Rs. .53/ft

3) Check and Nucca Construction: 2 check structures and 1 nucca

300 bricks @ Rs. 0.25/brick	= Rs. 75
1 bag cement @ Rs. 25/bag	= Rs. 25
Sand	= Rs. 5
4 check planks (wooden)	= Rs. 60
Canvas and pipe	= Rs. 25
Total materials	Rs. 190
1 mason for 1.5 days	= Rs. 40
1 beldar for 1.5 days	= Rs. 16
Total cost of structures	Rs. 246

Total cost of channel = Rs. 569 or Rs. 1.42/foot

Appendix 17

WATERCOURSE LEAKS

W.D. Kemper[1], M. Akram, M. Afzal and M. Iqbal[2]

On December 27, 1974, the watercourse serving Tubewell 91 at Mona was surveyed and found to have 120 leaks through the banks in 8000 feet and an additional 40 leaks at improperly closed junctions. The tubewell was on during this time. Twelve days later this same watercourse was surveyed and found to have only 20 leaks through the banks when the tubewell was off. In general the operating level of the watercourse had dropped about 3 or 4 inches and consequently it was concluded that 100 of the 120 leaks through the banks had their entrance in the area on the banks between the operating levels when the tubewell was on and when it was off.

While the tubewell was off, flumes were installed at the top of this watercourse and at a point 8000 feet from the top and 2 man hours were spent in plugging 14 of the 20 observable holes from the inside of the watercourse. The other 6 were not plugged because the inlets were not easily found and it was estimated that the loss through these 6 remaining holes was less than 0.001 of a cusec per hole. The result of plugging these 14 holes was a reduction in loss and increase in delivery at 10,000 feet down the watercourse of about .14 cusecs which was an increase from .69 to .83 cusecs of water flowing into the field.

Due to other work schedules, it was impossible to get back to this watercourse to conduct a study of the effects of plugging the holes that were leaking when the tubewell was on. It is assumed that these holes were of about the same size as those plugged on the day when the tubewell was off and since there were 6 times as many holes when the tubewell was on, the total reduction in leakage would have been about 6 times .14 = .84 cusecs and the additional water delivered at a distance of 8000 feet down the watercourse would have been about 0.84 cusecs. This water would have high value at the bottom end of this watercourse where there is considerable acreage of land which is not cultivated because of the deficient supply of water.

The reaction of farmers as they observed our brief hole plugging efforts, was "Why worry about those little holes?

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[2]Assistant Agricultural Engineers, Mona Reclamation Experiment Project, WAPDA, Pakistan.

They have been flowing for many months and are not growing bigger." Since this tubewell was running about 50% of the time during the year these farmers were probably losing an average of about 1 acre foot per day for over 300 days per year. Assuming a value of this water of Rs. 350/acre foot as estimated by Eckert et. al.,(1975). The value of the water that could have been saved by plugging these holes in the banks was over Rs.100,000 per year.

Realizing this high value of water lost and the fact that farmers apparently underestimate its value, it is of interest to make calculations to show whether our decision to leave 6 small holes not plugged because their inlets were not easily found was economically defensible.

These small leaks probably did not flow more than about 10 gallons of water per hour which is about 0.0003 of a cusec. Experience in plugging similar holes on other watercourses indicates that a good laborer can dig through the bank from the outside following the hole, find the inlet and pack the soil back into the excavation so the leak is stopped in an average of about 15 minutes per hole. The longest time taken to find and stop such a hole was one-half hour. These amounts of time must be balanced against the value of the water saved to determine whether such efforts at stopping and stoppage are worthwhile.

Figure 1 shows the value of the water saved assuming that the leaks are stopped for one year. The numbers on the left hand side of this figure indicate the value assuming the value of water is Rs. 330 per acre foot which is close to that estimated by Eckert et. al., (1975). The figures on the right hand side indicate the value of the water saved if it is assumed that this water has a value of only Rs.100 per acre foot which is the approximate cost of water pumped by SCARP tubewells. This cost of pumped water is based on a cost of pumping of Rs.50 per acre foot at the well and the fact that an average of one-half of this water is lost by leakage before it reaches the fields.

From Figure 1 the following conclusions can be drawn:

1. On the main watercourse the value of the water saved will exceed the value of the labor (assuming labor at Rs. 1.00 per hour and that the maximum time for stopping a hole will be one-half an hour) for leaks which have low rates in excess of 0.05 gallons per hour. In qualitative terms the value of the water saved will exceed the cost of the labor used in stopping the leak for any detectable leak on a main watercourse.

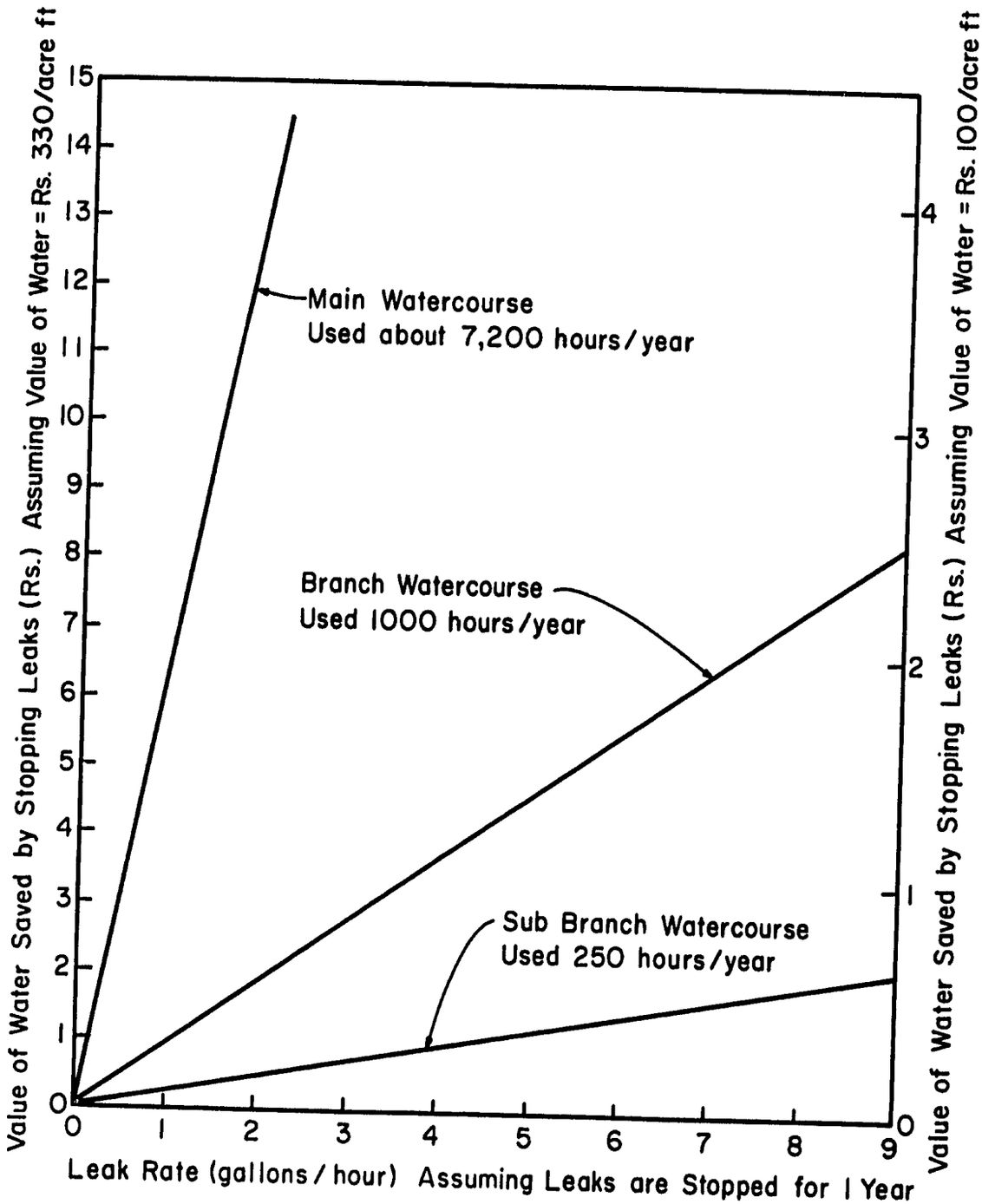

Figure 1. Value of water saved by stopping leaks in various sections of watercourses.

2. On branch watercourses leaks with flow rates greater tahn 0.5 of a gallon per hour can be stopped for costs which are less than the value of water saved.

3. On some branches where the water flows in the watercourse for only about 4 hours per week, leaks whose rate of flow is greater than 3 gallons per hour can be stopped for costs which are less than the value of the water which will be saved.

4. It is estimated that the 6 holes left unplugged on tubewell 91 watercourse had flow rates averaging .0003 cusecs which is about 10 gallons per hour. In deciding to neglect these leaks rather than close the holes at a cost of 0.5 man hours per hole, we were passing up an opportunity to bring a return of Rs. 70 worth of water for 0.5 man hours of labor, assuming water to have a value of Rs.330/acre foot. If the value of water is as low as Rs. 100/acre foot, the return for 0.5 man hours of labor plugging these 10gpm holes on the main watercourse would be about Rs. 20 worth of water.

In general, we underestimated the value of the water saved and stopped our hole plugging efforts while they were still returning benefit/cost ratio of 40 to 140 depending on whether a value of Rs. 100 or Rs. 330 is ascribed to an acre foot of water.

Labor used in closing leaks of this same size on branch watercourses with water only 1000 hours/year would result in a benefits/cost ratio of 10 or 3.3 assuming values of 330/acre foot or 100/acre foot respectively.

The general recommendation that may be extracted from these calculations is that any observable leak should be stopped on main and branch watercourses even if up to one-half hour must be expended on excavating through the bank following the hole, and compacting earth back into the excavation to fill the hole.

Seepage faces are commonly observed as wet zones along the outside of banks. Measurements of infiltration rates through such seepage faces have been from 5 to 10 times infiltration rates into adjacent soils in flooded basins. These seepage rates through banks are commonly 1 to 4"/hour. Assume a seepage face 6" high and along a watercourse, loosing water at a rate of 2"/hour per foot of such seepage face. Removal of the porous bank and replacing it with fresh compacted soil can generally be accomplished at a rate of about two feet of bank per hour, and such treatment will generally reduce the infiltration rate to less than 1/3 of its former value. Consequently, an hour of work can save about one gallon of water per hour. According to Figure 1, on main watercourses the value of the water saved by repairing and compacting the banks to eliminate seepage faces will

be about Rs.1/hour of labor spent. In other words, the cost of the water saved will be about 0.07 hours/0.02 acre foot per year, or 3.4 hours of labor per acre foot of water saved.

On branch watercourses the cost of saving water by compacting banks to reduce seepage losses will be of the order of 25 man hours/acre foot of water if the effect lasts for a year. This indicates that bank improvement will be worthwhile even on sub branches where water flows only 6 hours per week, in which case the saved water would cost about Rs.100/acre foot.

On the basis of such calculations it is concluded that because of the low cost of labor in developing countries there are highly profitable returns to labor used in the improvement of watercourses. These efforts can bring water to the farmers at a labor cost of 1 to 100 Rs/acre foot of water, whereas new storage dams and pumping from ground water result in costs of water at the field varying from Rs.100 to Rs.500.

These opportunities for improving their water supplies should be brought to the attention of farmers. Farmers are spending much more for water by running jalars, building and operating their own wells or buying water from private tube-well operators, than they would spend to obtain similar amounts of water through watercourse improvement.

To educate farmers to these opportunities will require special training of extension personnel, and the development of measurement and demonstration techniques.

References

Eckert, Jerry B., Niel Dimick and Wayne Clyma, 1975, Water Management Alternatives for Pakistan A Tentative Appraisal, C.S.U. Field Report.

Appendix 18

COMPACTED CORES TO REDUCE LEAKAGE THROUGH WATERCOURSE BANKS

W. D. Kemper and Mohammad Akram[1]

Summary

Rate of water loss was reduced by more than 75 percent by compacting soil cores in watercourse banks. Labor used was 0.06 man hours per foot of watercourse. Benefits appear to exceed costs by a factor of over 30.

Background

Previous measurements of watercourse losses using the ponding method indicated that most of the loss was through the upper portions of the bank. Digging cross sections through many banks has indicated that the upper portions of these banks were riddled with insect, worm and rodent holes and measurements have shown that these banks have low bulk densities and high permeabilities. Lowering the water surface in these watercourses by about 2 inches commonly reduces the loss rates to less than 1/3 of their previous values. With these facts in mind it seems likely that compacting a core of soil in the middle of these banks might appreciably reduce loss of water through the banks.

The site chosen for this study was the upper end of Branch I of the watercourse serving tubewell MN-78 in the Mona project area. This watercourse was losing about 0.84 cusecs of water in the first 1000 feet prior to being rebuilt by the farmers. In the process of this rebuilding the banks were brought up to the proper cross section and overtopping was eliminated. However, a large part of the leakage persisted and the average loss following rebuilding was still about 0.50 cusecs per 1000 feet.

About five man hours plugging the major obvious leaks reduced the loss rate to less than 0.4 cusecs. The remaining leaks were fairly difficult to find and close. The top section of this watercourse was chosen for study because there appeared to be more leakage in this top section than in the watercourse as a whole.

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[1]C.S.U. Water Management Research Party Chief and Asst. Agric. Engineer, Mona Reclamation Experimental Project, WAPDA. This study was supported in part by funds from USAID contract AID/ta-c-1100 and USAID/Islamabad project agreement 204,73-5.

Procedure & Results

The watercourse was filled to the operating level, three separate sections were closed with bunds and the rates at which the water surface receded in each section was determined as indicated in Figure 1. The rate at which water was being lost was calculated from the slope of the recession curve when the water surface level was at the operating level and those figures are given in Table 1. Section 3 had the highest loss rate at 0.66 cusecs per 1000 feet. Section 2 had the lowest loss rate at 0.44 cusecs per 1000 feet and Section 1 was intermediate with 0.61 cusecs per 1000 ft.

Table 1. Effect of compacted soil cores in the banks on watercourse losses.

	Rate of water loss in cusecs/1000 feet	
SECTION #	FIRST FILLING	SECOND FILLING
1*	0.61	0.11
2	0.44	0.37
3	0.66	0.50

*Compacted soil cores were formed in the banks of Section #1 between the first and second filling.

Following these measurements, compacted cores were formed in the banks of section 1 in the manner indicated in Figure 2. The sod and soil were removed, using shovels or kassis, from the inner sides of the banks down to near the surface level at which water flows in this watercourse under operating conditions. A hand compactor (weighing 15 pounds, with a head 2" wide and 4" long attached to a 4' long pipe handle) was then used to displace the soil from a slot 2 to 3" wide. As the soil in the bottom of this trench was pounded downward it was displaced to a depth averaging about 4 or 5" below the bottom of the excavated trench. This depth was variable, ranging from only about 3" where the soil was fairly hard to more than 8" where the soil was soft. After this soil had been displaced the slot was filled with moist soil and this fill soil was compacted again. This process was repeated until the volume from which the soil had been displaced was filled with a compacted core. The soil and sod excavated from the top of the bank was then replaced and pressed into place by foot. The result of this operation was a compacted core of soil about 3" wide and 6 to 12" deep with the top of this core being an inch or so above the operating level of the water.

Building such a core into the bank of a 72 foot section of this watercourse involved the efforts of 5 men working

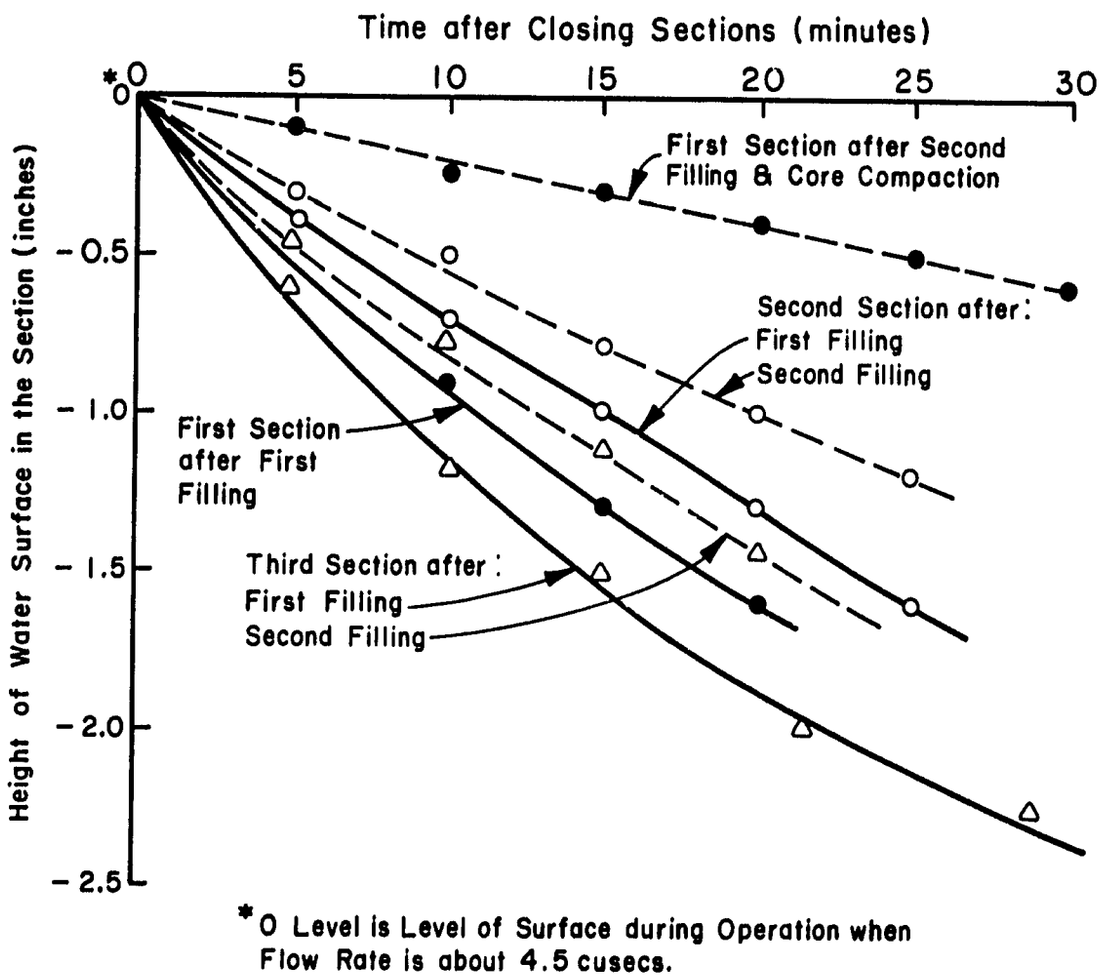

Figure 1. Water recession in test and check sections of compacted soil core study.

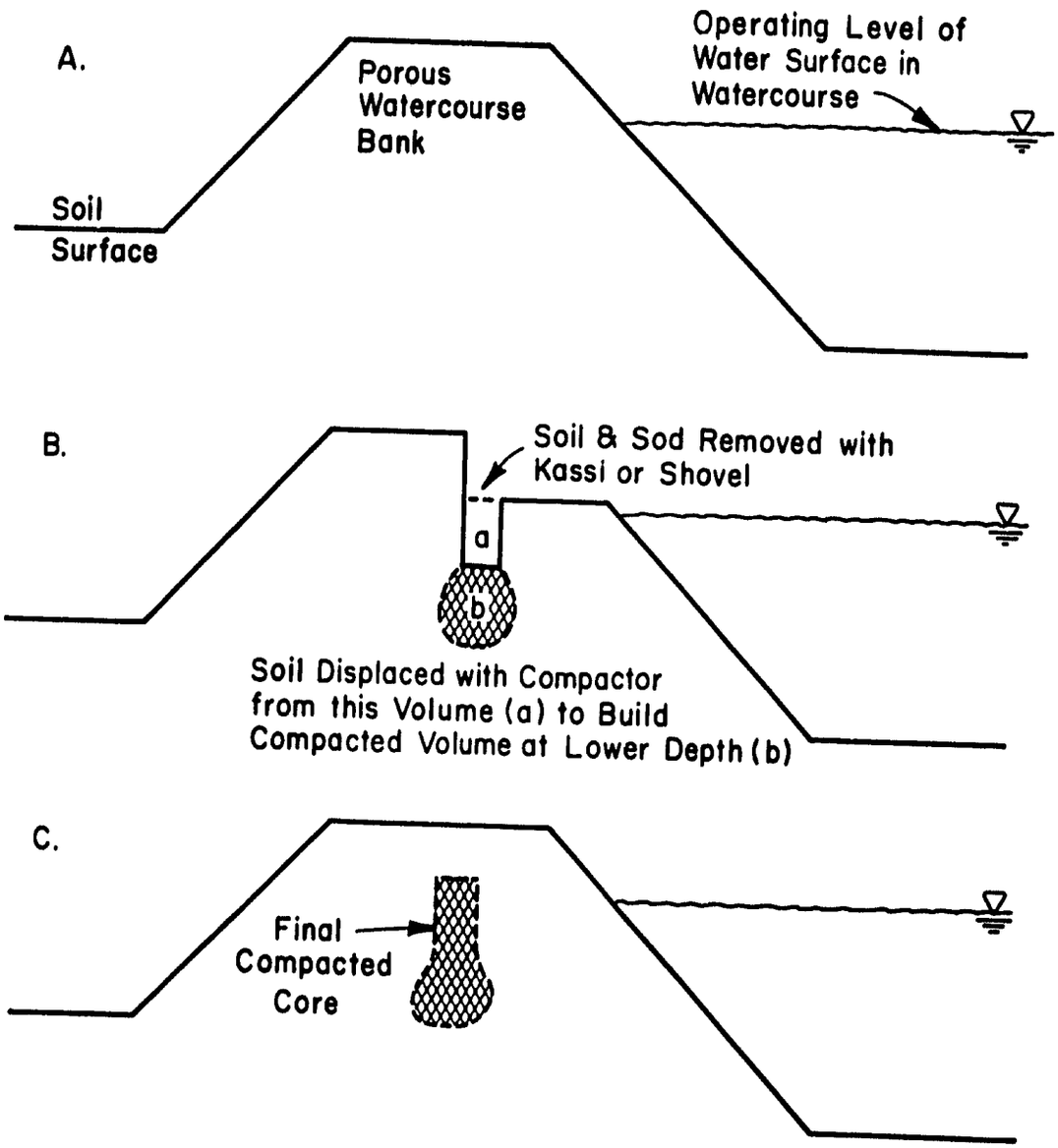

Figure 2. Steps used in forming compacted cores in watercourse banks.

stenuously for slightly less than 50 minutes for a total of about 4 man hours of labor to do this 72 feet. This is an average rate of about 18 feet per man hour. However these men were working considerably harder than the average man works in Pakistan and a reasonable production rate from healthy farmers or beldars would probably be nearer 10 feet of watercourse per hour for this type of compaction of cores in the bank (it should be pointed out that in the improvement of 10 feet of watercourse, 20 linear feet of core was constructed.)

After the core was in place in the test section, the watercourse was filled again to operating level, the bunds which separated the various sections were reformed and the rate of loss was measured again. Section 3, which was one of the checks, still had the highest rate of loss with 0.50 cusecs per 1000 feet and section 2, the other check section, had the second highest loss at 0.37 cusecs per 1000 feet. In general the rate of loss in these 2 sections decreased to an average of about 79 percent of their values following the first filling, probably as a result of the soil having wetted up and the infiltration rate decreasing with time. In section 1 in which the compacted core has been installed the loss rate decreased from 0.61 to 0.11 cusecs per 1000 feet for a decrease to only 18 percent of its former value. If its rate of loss had decreased at the same rate as that of the 2 test sections it would have been losing 0.48 cusecs per 1000 feet. Consequently, it appears that the installation of the compacted core reduced the rate of water loss from this watercourse to about 23 percent of what it would have been without the compacted cores.

Benefits and Cost Comparisons

Assume that the reduction in seepage through this bank as a result of compacting this core will last for 1 year and that the compaction is done in a branch watercourse where the water runs for 24 hours each week, reducing the loss from 0.48 cusecs per 1000 feet to 0.11 cusecs per 1000 feet. This loss reduction results in a savings of water of about 0.74 acre foot in each 24 hours for which this watercourse is filled. If this watercourse is filled 40 times in a year, the total savings in a year will be about 30 acre feet of water.

Current computations indicate that government tubewells now being installed will pump water at a cost of about Rs. 50.00 per acre foot. Data collected by Clyma et. al., 1975 on losses of water from watercourses serving tubewells indicate that less than half of the pumped water reaches the field. Consequently, the cost of the water reaching the field from the tubewell is over Rs.100.00 per acre foot. Assuming Rs.100.00 per acre foot, the value of the water saved in a year by the watercourse compaction efforts will

be about Rs.3,000.00. It was calculated previously that a man can compact this soil core in a watercourse at a rate of about 10 feet of watercourse per hour. Consequently, it would take about 100 man hours to put this type of compacted soil core in 1000 feet of watercourse. Consequently the investment of 100 hours of labor (currently costing about Rs.100.00) would bring a return of Rs.3,000.00 worth of irrigation water.

Actually estimates (e.g., Eckert et. al., 1975) indicate that the average values of irrigation water to the farmers of Pakistan is Rs.350 or Rs.250 per acre foot depending on whether the land has or has not been leveled. If a section of a main watercourse is selected for this computation where the water runs 5 or 6 days per year, and these values of water are used the benefits/cost ratios can go well over 100.

Potential of Compacted Soil Cores in Watercourse Banks

Compacting cores in watercourse banks is an alternative to removing permeable banks and building them again with fresh soil which is compacted as it is placed in the banks. Both of these methods have been successful in reducing loss to less than 25 percent of the previous values. Removing and replacing the banks has required 0.3 to 0.7 hours of work per foot of bank whereas compacting the soil cores in the center of the bank in this trial required about 0.1 man hours of labor per foot of watercourse. Further refinement of these estimates on man hours and water saving is needed. It will require testing on a broad range of soil textures and using the range of types of man power available in the Punjab. However, it does appear that compacting cores in the banks of the watercourses is one of the most productive work opportunities available for unemployed rural labor. This opportunity is not restricted to any specific season. It can be done whenever the labor is surplus; moreover cores can be compacted in the banks without inactivating the watercourses and disturbing the water supply.

The soil in these watercourse banks was a loam, and apparently compacted to low permeabilities rather easily. The question arises as to whether similar compaction can cause similar reduction in the infiltration through sandy soils. Tests should be run on compacted cores in watercourse banks in such soils. However the probabilities apper good in view of data collected by the senior author on infiltration into loam sand soils on the Eastern Shore of Maryland, U.S.A. These soils had infiltration rates averaging 5.0 inches per hour following fodder harvest in areas where there had been no traffic. In areas where the wheels of trucks had compacted the soil during the harvest operations, the infiltration rates had been reduced to an average of 0.10 inches/hour. Since the degree of compaction (pounds of force/square inch) with our hand packer and the truck wheels would be comparable,

it appears likely that compacted soil cores in sandy watercourse banks will cause a major reduction in water loss. As discussed previously (Kemper et. al., 1975) the bottoms of watercourses are somewhat self sealing, particularly when carrying sediment laden canal water, and most of the water loss appears to occur through the upper portions of the banks.

References

Clyma, Wayne, Moh'd Ashraf and Arshad Ali, 1975 "Watercourse Losses", C.S.U. Water Management Report.

Eckert, Jerry, Niel Dimick and Wayne Clyma, 1975, "Water Management Alternatives for Pakistan A Tentative Appraisal", Colorado State University Water Management Field Report.

Kemper, W.D., Wayne Clyma, Moh'd Akram, Moh'd Hanif and Iqbal Parvez, 1975, "Watercourse Losses as Related to Composition and Condition of Banks", Colorado State University Water Management Team Status Report.

Appendix 19

PUCCA NUCCA LOSSES ON WATERCOURSE D OF TUBEWELL 78

Tom Trout and M. Akram[1]

The losses through the pucca nuccas or improved watercourse outlets, installed in watercourse D, a kacha improved watercourse of tubewell 78 in the Mona Reclamation Porject area were measured to determine the percentage of total water losses that may be attributed to nuccas. The watercourse has five 12 inch pipe nuccas, many of whose lids are broken, that are sealed with mud; and six 20 inch panel nuccas, three of which are sealed with mud and three with a sponge rubber ring.

PROCEDURE

Loss measurements were made volumetrically. Where possible, a metal pan 1 ft. x 2 ft. x 0.33 ft. was used to collect water as it passed through the nucca, for a certain length of time. The volume collected was determined from the pan dimensions and depth of water collected. If more accuracy is desired in future work, a graduated cylinder could be used.

If there was sufficient overfall at the nucca outlet, the leakage could be collected directly in the pan. This was the method used for nuccas numbered 4, 7, and 8. If the outlet was submerged or inaccessible, a bund was built across the watercourse near the outlet, a small head created in the bunded area, and overflow from the area was collected in the pan. This was the method used for nuccas 2 and 6. There will be slight losses from the bunded area, but these losses should be insignificant.

A third measurement method that was tried, and which is workable for large leaks, was to bund a short length of the watercourse below the nucca and measure the depth increase in the area with time with a staff gauge. This rate of depth increase, multiplied by the bunded water surface area, gives a volume collected with time. The head increase in the bunded area should be maintained as low as possible to minimize the influence of the reduced head across the nucca on the leakage rate. The seepage losses from the bunded area could be significant, especially if the rate of depth increase is small.

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RESULTS

The results of the measurements are given in Table 1.

Table 1. Pucca Nucca Losses From D. Watercourse

Nucca	Type	Measurement Method	Losses (gpm)	Losses (cfs)
2	12" pipe	bunded overflow	3.14	.007
2	" "	" "	3.43	.008
2	" "	bunded area	3.58	.008
3	" "	no visible leakage	--	--
4	" "	direct collection	2.31	.005
4	" "	" "	2.17	.005
5	" "	bunded overflow	00	000
6	" "	" "	0.07	.000
7	20" panel	direct volumetric	1.42	.003
7	with mud	" "	1.57	.004
8	" "	" "	17.02	.038
9	" "	" "	00	000
10	20" panel	" "	00	000
11	with rubber	" "	00	000
12	" "	" "	00	000
	TOTAL		24.21	.054

DISCUSSION

The leakage through only one nucca, a panel nucca with mud seal, exceeded .008 cfs. It was improperly sealed, and the leakage was easily stopped by a passing farmer. There was no leakage from the panel nuccas with rubber seals.

Total losses from the 11 nuccas of the 4900 ft. watercourse were .054 cfs., or 1% of the total flow of 5.5 cfs. Seventy percent of these losses were from one nucca.

The lids of the 12" pipe nuccas are all of the original casting which involved wooden forms (which warped slightly) and no reinforcing. These are all scheduled to be replaced by lids made with machined steel forms and steel reinforcing of the lids. This should greatly extend the durability and reduce the water losses at these nuccas.

An admissible water lossage through nuccas should be determined for a watercourse before nucca design is chosen. Although no leakage is ideal, a total loss through nuccas of from 1 to 5% of the total flow should be allowable. On the studied watercourse with 11 nuccas and a flow of 5 cfs., a loss per nucca of .004 cfs. and total nucca losses of .05 cfs. would result in 1% total losses. Five percent nucca losses would allow 0.25 cfs. total losses and .023 cfs. average water loss per nucca.

When water loss values are known for various nucca designs, an economic analysis of nucca benefits and costs could be made to assist in nucca selection for a watercourse.

Appendix 20

CHECK AND GATE DEVELOPMENT FOR PAKISTAN AND OTHER LESSER DEVELOPED COUNTRIES

William E. Hart[1]

Low-cost gates and checks, capable of being constructed locally in a lesser developed country (LDC) have been under development in Pakistan, and in Ft. Collins for later use in Pakistan. The criteria for determining that the developed gate or check is satisfactory are the following (Hart, 1975[1]).

(1) The design flow rate is delivered within a desirable differential head range. The maximum upstream water surface elevation must not be so large as to cause drawdown at the nakka and upstream of it does not cause erosive velocities in the channel.

(2) The nakka is easily and simply operated. Farmers will probably not accept a nakka that requires more effort to open and close than does a simple earthen nakka. They do not like excessively heavy gates. Any complicated procedure would be unacceptable.

(3) The nakka can not be accidentally opened. A major source of water stealing is earthen nakkas which have "accidentally" opened. Once a nakka is opened or closed, it must take an identifiable, intentional action to alter its position.

(4) The nakka is essentially leakproof when closed. Although it may be impractical to insist on total leakproofness, certainly a low level of flow should be maintainable. As a starter, it might be required that the total leakage from all nakkas combined along a watercourse should not exceed 1 percent of the total flow into the watercourse. Applying this criterion to the TW 78 watercourse at Mona, one finds that the main watercourse plus the last branch has a total length of 12,300 ft. (7,500 plus 4,800). There are a total of 21 nakkas on the main watercourse and 5 nakkas on the last branch. The total flow from the mogha, plus that of the tubewell,

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[1] Hart, William E. 1975. Final Report, TDY assignment in Pakistan, June 18 to August 2, 1975. Water Management Research Project, Dept. of Agricultural Engineering, Colorado State University, 40 plus 11 p, mimeo.

amounts to 4.7 cfs. The allowable loss from a nakka would thus be about 0.002 cfs (0.9 gpm).

(5) The cost is reasonable. The actual cost is the annualized cost, and should consider maintenance, depreciation, etc. One can arrive at an "allowable" initial nakka cost by considering the information given by Eckert et al, (1975*). They indicate an initial cost of about Rs 44 per ft for a brick lined, rectangular watercourse, discharging 4.7 cfs (slope unknown). There is a nakka, on the average, every 475 ft (12,300/26). Considering one check per three nakkas, there are a total of 35 checks and nakkas. If 1 percent of the watercourse cost is allotted for nakkas and checks, this would allow a unit initial cost of approximately Rs 157 each. (It is tacitly assumed that the nakkas and watercourse have similar maintenance and depreciation charges.) Nakkas for less expensive watercourses must necessarily be of lower cost.

(6) Nakkas should be durable. Even though maintenance and replacement costs might be low, nakkas giving frequent trouble, or requiring repairs, will be odious to the farmer and therefore unacceptable.

(7) Nakkas and checks should have provisions for overtopping. If a watercourse overtops when nakkas and gates are operated in an improper sequence, this can cause erosion of banks and, eventually, destruction of the subgrade, thus hastening deterioration of the watercourse. Is is well to provide nakkas and checks that will allow overtopping of water within the watercourse, or into branch watercourses, rather than over the sides of the watercourse. Thus, the top of a panel or gate might be 2 or 3 inches below the top of a watercourse bank.

Conforming to the above criteria, five distinct types of nakkas and checks have been developed, or are under development, in Pakistan and Ft. Collins. The primary material in each of these is concrete, which is available locally in quantity. Although somewhat costly, it is the least expensive of any suitable material. Each of these units is discussed in turn in the following paragraphs, and the progress of their development, in both Pakistan and Ft. Collins, is indicated.

(1) Pipe Nakkas

The basic pipe nakkas consists of a piece of reinforced

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[1]Eckert, Jerry, Niel Dimmick and Wayne Clyma, 1975. "Water Management in Pakistan -- A Tentative Appraisal", Water Management Research Project, Colorado State University, 59p, mimeo, June.

or non-reinforced concrete pipe, of 12 inches to 20 inches inside diameter, with a 45-degree bend near the entrance, and a lid which fits into the opening. It is essential that the lid and seat be circular to close tolerances. This has been accomplished through the use of machined metal forms.

Sealing to date has been by two methods. In the first, "clean" mud is pressed into the opening between the outer circumference of the lid and the inner circumference of the pipe opening. This groove must be about 3/4 inch wide and 1 inch deep and will give a leakproof closure if properly packed with mud. However, closure fails after the mud has dried and is rewet. Depending upon the operating schedule of the watercourse, this may or may not be serious.

The other method of sealing has been through the use of a sponge rubber gasket which is affixed to the lid with contact cement. The gasket cross section may be round or of some other shape (such as a near-square one tried at Mona). The location and shape of this gasket is still under field evaluation, but sponge rubber gaskets appear to be quite feasible. A test made at the manufacturer's shop showed that they stopped leaks completely. One unknown at the present time is their life expectancy under actual farming conditions. They may deteriorate due to the weather, or due to mishandling, or they may malfunction if dirt gets on the seat of the pipe.

In any case, it is essential that the lid surface which receives the gasket, and the seat, be smooth and planar. This is accomplished when the aforementioned forms are used in the fabrication of the lid and seat.

Pipe nakkas have been installed in earthen watercourses with and without cutoff walls. The cutoff wall was added when soil piping occurred along the outside of the pipe. However, a cutoff wall is only a palliative for improper packing of soil There is reason to belive that proper packing is sufficient in itself. Even after soil piping has started, it can sometimes be eliminated by further packing of soil. Anti-seep collars are another possible solution to soil piping problems.

(2) Circular-opening Panel Nakka and Panel-and-Pipe Nakka

The pipe nakkas described above have proven quite successful. However, they are made primarily for taking water out of an earthen watercourse into a branch. Similar sealing principles can be applied to the case of removing water from a lined watercourse, or as a control structure for multiple diversions. For these purposes the circular-opening panel nakkas was developed. It consists of a rectangular panel,

approximately 3 ft x 3.5 ft x 3 in. in the center of which is a circular opening for the lid. These units have been used as check structures in channels and as outlets from earthen channels. They are ordinarily set at approximately 45 degrees to the vertical, utilizing the lid's weight to hold it in place. This panel can also be combined with a piece of pipe to make a field assembled pipe nakka called a panel-and-pipe nakka. In this case the panel is cast with six reinforcing bars protruding from its rear face, so spaced that they match the outside circumference of a pipe of appropriate size when that pipe is cut at 45 degrees and butted up against the panel. The two pieces are joined in the field with concrete and mortar. To date, this assembly has been little used.

(3) Sewer Pipe Nakka

Mr. Hussain of the Hussain Pipe Works (Sargodha) is considering a new concept for a pipe nakka. It will use a standard piece of sewer pipe (reinforced or non-reinforced) which has been "bent" in the manner described previously. However, the sealing will be along the inside diameter of the pipe, which is slightly tapered at the entrance. A groove will be provided in the male portion of the lid, and this will receive a solid rubber 0-ring. The lid is forced into the pipe, compressing the 0-ring and providing the seal. If successful, this will be the least expensive of all the pipe-type nakkas so far investigated.

(4) Rectangular Concrete Nakka

A concrete rectangular nakka has been developed. It consists of a 1-inch thick rectangular gate. It seats in a concrete opening which is U-shaped, or which may be an open rectangle to allow a place for storing the gate when it is not in the closed position. This gate can be sealed by a flap, or rubber gasket, or mud. As is the case with pipe and panel nakkas, there must be good quality control and dimensional stability in the construction of these units. It is particularly important that the gate and seat each be planar surfaces if rubber gasket closures are to be used. Otherwise, sealing is not possible and there will be leaks. These units are still under development, but one installed on a watercourse in Pakistan has been successful. A precision form is being constructed in Ft. Collins.

The main application of these units is in rectangular pukka channels. However, with the construction of a suitable bulkhead they could be used as checks or nakkas in channels of other shapes, whether kucha or pukka. As outlets from watercourses they can be combined with a bulkhead or a short length of brick-lined channel.

(5) Sock Nakka

A sock nakka consists of a flexible tube attached to a pipe. The pipe leads through a ditch bank or a bulkhead. The sock can be on either the upstream end or the downstream end of the pipe. If on the upstream end, the nakka is opened by turning the sock inside out and extending it through the pipe. The nakka is closed by pulling the sock back through the pipe and fastening it closed. A rubber band (cut from an old inner tube) can be used as a retainer. Such a band is also used to hold the sock to the pipe if the sock is made of canvas. If the sock is made of an old inner tube, the attachment is made by stretching the tube over the end of the pipe. The sock can also be attached to the outlet end of the pipe.

Two of these units were tried in the field. The inner-tube sock, because of its bend, provided excessive head loss and was unsatisfactory. The inner tube was replaced with canvas, and this appeared to work satisfactorily but because of lack of water control in the channel upstream and downstream of the installation, no definitive conclusions could be made as to leakproofness. The sock was stolen the first night after its installation on the pipe. This configuration because of its low cost, can be a practical one if the thievery problem is overcome.

Relative costs for installations incorporating the above nakkas or checks, for approximately equivalent discharges (3.5 cfs) at expected heads (0.5 ft), are as follows:

12-inch pipe or circular-panel opening	Rs 99
12-inch sewer pipe	Rs 91
12-inch rectangular concrete	Rs 61
12-inch sock	Rs 66

More detailed costs are given by Hart (1975)*.

*Hart, William E. 1975. Final Report, TDY assignment in Pakistan, June 18 to August 2, 1975. Water Management Research Project, Colorado State University. 40 plus 11 p, mimeo.

Appendix 21

THE INSTALLATION AND USE OF CUTTHROAT FLUMES FOR WATER MEASUREMENT

Methodology Series Number One

Waryam Ali Mohsin, Wayne Clyma, Alan C. Early[1]

A considerable amount of work has been done on the development of water measuring devices including flumes, weirs, and flow meters. The latest in the series is the Cutthroat flume. The Cutthroat flume has certain beneficial operating characteristics as described below:

1. Water measurement is satisfactory under both free and submerged conditions.

2. Head loss through the flume is low, even less than the long-used Parshall flume.

In summary, it gives satisfactory accuracy for water flow measurement in the flat gradient channels of Pakistan. Furthermore, it is easy to construct because of the flat bottom required. Due to the above mentioned advantages the Cutthroat flume should be widely accepted and used by all who are involved in water management work in flat-gradient channels of Pakistan.

1. Theoretical Considerations:

a) Flume Selection: Make sure that the proper throat size is selected. Flow measurement is not as accurate at low heads or at very high heads. Tables are available for each throat width to help in this regard. Judgment of the quantity of expected flows is required for selection of a flume to meet specific measuring requirements. Tables 1 and 2 can be used as a guide to the selection of flume throat width for the 1.5 foot flume lengths commonly used in on farm water management research, and other flumes of various larges sizes.

b) Flume Dimensions Check-up: Always measure all of the flume dimensions to insure that the flume has been constructed properly. If dimensions of the throat vary more than 1/16th of an inch reject the flume. Check also for general appearance of the flume. The walls should be vertical, and perpendicular to the flat bottom. The converging and diverging sections should be fabricated according to the

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TABLE 1. FREE FLOW CALIBRATION TABLES FOR 1.5 FOOT CUTTHROAT FLUMES

HA	CUTTHROAT FLUME SIZE					
	1 INCH	2 INCH	4 INCH	6 INCH	8 INCH	12 INCH
.10*	.00	.01	.01	.02	.03	.04
.20*	.02	.03	.06	.09	.13	.19
.30*	.04	.07	.15	.23	.30	.46
.40*	.07	.14	.28	.42	.56	.85
.50*	.11	.22	.44	.68	.91	1.37
.60*	.16	.32	.66	1.00	1.34	2.03
.70*	.23	.45	.92	1.39	1.87	2.83
.80*	.31	.60	1.22	1.86	2.49	3.78
.90*	.39	.78	1.57	2.39	3.21	4.86
1.00*	.49	.97	1.97	3.00	4.03	6.10

TABLE 2. FREE FLOW CALIBRATIONS FOR SELECTED CUTTHROAT FLUMES

(VALUES LISTED ARE DISCHARGE IN CFS.)

H_a ft.	41NX3FT	81NX3FT	121NX3FT	161NX3FT	81NX6FT	161NX6FT
.10	.02	.04	.07	.09	.06	.11
.20	.08	.15	.23	.31	.17	.35
.30	.16	.32	.49	.66	.34	.69
.40	.27	.55	.83	1.12	.55	1.11
.50	.41	.83	1.26	1.68	.79	1.60
.60	.57	1.16	1.76	2.36	1.07	2.16
.70	.76	1.54	2.33	3.13	1.37	2.79
.80	.97	1.97	2.98	4.00	1.71	3.47
.90	1.20	2.45	3.71	4.97	2.08	4.21
1.00	1.46	2.97	4.50	6.03	2.47	5.01
1.10	1.74	3.54	5.36	7.19	2.89	5.86
1.20	2.04	4.15	6.29	8.43	3.33	6.76
1.30	2.36	4.81	7.29	9.77	3.80	7.72
1.40	2.71	5.52	8.36	11.20	4.29	8.72
1.50	3.07	6.26	9.49	12.72	4.81	9.76
1.60	3.46	7.05	10.69	14.32	5.35	10.86
1.70	3.87	7.88	11.95	16.01	5.91	12.00
1.80	4.30	8.76	13.27	17.78	6.49	13.18
1.90	4.75	9.68	14.66	19.64	7.09	14.40
2.00	5.22	10.63	16.11	21.59	7.72	15.67

specifications. Check also all the welded joints. If welds are found improper, the flume should be rejected at once.

c) Gauge Installation: Check the gauges. Gauges and inlets to the stilling wells reading upstream head (H_a) as well as downstream head (H_b) should be checked against the specifications. If the flume is equipped with stilling wells, check the water level next to staff gauges as compared to level in the stilling wells in standing water with the flume properly leveled. Incorrect installation will cause erroneous discharge measurement.

d) Orientation for leveling: If the flume has to be installed in a channel with water flowing in it, make sure that two longitudinal and transverse locations on the flume top are parallel with two similar locations on the flume bottom. As close to the flume throat as possible, preferably on the converging section of the flume, place the wooden level (6" long) in transverse direction on the bottom or floor of the flume and bring the bubble to the center level position. Likewise bring the flume to level position in the longitudinal direction. Find the same transverse level position somewhere on top of the flume either in the throat region, or on the cross piece at the start of the converging section or on the cross piece at the end of the diverging section. Mark this position for later leveling the flume in flowing water. Likewise for longitudinally leveling, place the level on top of walls of converging or diverging section of the flume. Wherever the bubble comes in the center, mark that position on the top of the walls. Always use these two marked positions to level the flume if it has to be installed in the flowing water, otherwise always use the floor or bottom of the flume to insure that the flume is installed in a level position. Check occasionally these predetermined positions with reference to the flume bottom, as the flume may become deformed after a long interval of use.

2. Installation and operational considerations:

Experience has revealed that installation of a flume in the channel for flow measurement does not make a farmer happy. Generally he complains that the flume has eaten half of his water. If the channel has a flat gradient with very little freeboard and the flume has been installed for free flow conditions, considerable water will be stored in the watercourse above the flume. This creates a very uncontrollable situation both for the farmer and the person who is trying to make discharge measurements. The upstream section of the channel often in this case overtops causing much spillage. The farmer does not like this situation. Moreover, until steady state conditions are achieved the measured discharge is much less than the actual discharge passing through that point without the flume installation. These

types of difficulties and many others force the development of proper installation techniques, which in turn facilitate obtaining accurate measurements and minimize the farmers' complaints about our friend, Mr. C. T. Flume, for eating his water.

Following steps will help a great deal while making discharge measurements in the field:

1. Please introduce yourself to the farmer and explain to him very politely your mission.

2. Please do not approach the farmer bureaucratically as an officer would; treat him as the important person which he is.

3. Please try to develop very friendly relationships with all farmers concerned.

4. Please remember that the farmer in whose watercourse the flume is installed is very important to us; we cannot accomplish much without his cooperation.

5. Please try to convince the concerned farmer that our mission is to help him to achieve better water management.

6. Please do not make false promises to win his favor, e.g., getting his mogha bigger or something else which cannot be fulfilled. This would adversely affect our relationships with the farmer in the future.

7. If we fail to make a farmer understand our program, it is better not to argue with him and wait until another farmer starts irrigating before starting measurements.

8. Always remember that most of the channels in Pakistan have flat gradient beds with very little freeboard. Take some time to decide about the site for flume installation. With the Cutthroat flume good discharge measurements can be made even under submerged flow conditions. However, the submergence should not exceed 90 percent if possible. A higher submergence would reduce the energy loss, but the problem of the upstream section being overtopped could be minimized alternatively through careful installation and/or by building up the bund of the upstream channel. But where conditions permit, e.g., steep-gradient conditions with much freeboard, installation should be for free flow conditions.

9. The flume should be placed in the center of the channel. It should be parallel to the direction of flow of water in the channel.

10. The sides and bottom and around the flume should be properly sealed so that there are no leaks beside as well as under the flume bottom. Sandy soil conditions impose a serious problem for leaks. Plastic sheets or cloth used as a cutoff wall in the surrounding soil can be used to overcome this problem.

11. The flume should be properly leveled both in longitudinal as well as in transverse directions. For this purpose the flume bottom can be used while installing it in a dry channel. For installations in flowing water conditions the two reference points, (already marked on the flume topside) can easily be used.

12. Before recording readings of the upstream as well as downstream gauges, always check for leaks along the side and underneath the flume. The inside bottom of the flume should be checked and cleaned of any sediment or trash as this will cause H_a to increase and result in an erroneous reading. Also make sure that the flume is still in level position both longitudinally as well as in transverse directions. If leaks are observed stop them and if level is disturbed, relevel the flume. Repeat this process before recording each reading of the gauges.

3. Interpretational Considerations:

Recording the gauge readings and determining the discharge from the rating tables is the easiest step in the flow measurement process. Who can answer with full confidence that flow measured with this flume is quite correct? To answer this question confidently requires more than simply recording the readings of gauges.

Experience has shown that on flat-gradient channels the flume has to remain installed for a considerably longer period of time before it reaches steady-state flow conditions than for steep-gradient channels. Short period installations often lead to wrong conclusions. The section through which the water flows is restricted to a much smaller width with the flume as compared to the section width without the flume. This imposes a problem of water storage in the upstream section of the channel resulting in a smaller volume of flow for the initial periods of flume installation. Sufficient time should be given to allow the ditch storage to stop so that the flow through the flume is the same as the normal flow through the watercourse. Or in other words, one should

wait long enough after the flume is installed so that equilibrium conditions between inflow above the flume and outflow through the flume are established. This can be noted very easily with the volume of flow becoming constant (the H_a gauge reading does not change with time) if the conditions on the upstream section of the channel do not change.

4. Water Measurement Applications:

The Cutthroat flume is a flow measuring device. It is simple in construction, is easy to install and gives reasonable accuracy in flow measurement both under free flow and submerged flow conditions.

Proper water management plays a vital role in the economic utilization of water resources. For better water management, it is very essential to know the rate of flow through any water flow system and to know how much flow enters a specific field.

These questions are best answered by using a Cutthroat flume at various locations in a water conveyance channel. Select any convenient length of a conveyance system. Install the flume at the starting point and another flume at the end of that selected length. The ratio of the second flow volume to the first flow would give us the conveyance efficiency of that system. Use the second flow volume to determine the depth of water applied to a specific field. In the above example the first flume is installed as close to the mogha as possible and the second flume is installed as close to the required field as possible. From the depth of water applied calculations of the water application efficiency can be made. Some suggestions are given below on evaluation of delivery and application efficiencies.

Measurement Installations:

The first flume should be installed close to the mogha. The most important point about the first flume installation is mogha submergence. By mogha submergence is meant the reduction in mogha discharge due to water backup in the channel because of the flume installation. The effect can be noted by installing another flume about 1000 feet below the first flume. If after pulling out the first flume no change in flow is observed at the second, then one can be confident that our first flume is not submerging the mogha. If some increase in flow occurs at the second flume then a location at a slightly greater distance from the mogha must be used for the first flume. Keep adjusting the location of the first flume until no change occurs in the flow through the second flume after pulling out the first flume.

Before installing the flume near the mogha, record the

water surface elevations in the distributary and in the upstream section of the watercourse just below the mogha. If these two elevations differ by less than 0.5 feet, one should check as described above to see if flume installation has submerged the mogha. After the flume installation, there should be no change in the water surface elevation of the distributary. The upstream section of the flume should show some increase in elevation. The flume should be installed in such a position that the increase in water level in the watercourse is as small as possible when there is danger of submerging the mogha. In doing all this highly submerged flow conditions which would endanger our measurement accuracy should not result. The flume should not be installed at more than ninety percent submergence. If the channel downstream from the mogha has a steep gradient, then the chances of the mogha being submerged with flume installation are small, but if the channel is of flat gradient, then mogha submergence is a serious problem.

The volume of flow which passes through the mogha or the flume installed close to the mogha has to go somewhere through the conveyance system to be utilized for irrigation purposes. How much of this discharge is being effectively used for irrigation purposes is another area of interest for the water management specialist. If some of this mogha discharge does not reach the fields then one may ask where does it go. These and many other questions force a person who is interested in better water management to further investigate the situation.

Determination of volume of flow past certain length of conveyance system requires installation of another flume. This flume must be installed as close to the fields being irrigated as possible, making certain that no spillage losses are caused in the upstream section of the channel.

The discharge measurement made by this second flume will serve five purposes:

1. To determine the conveyance efficiency of the system.

2. To determine the overall losses of water of the conveyance system.

3. To evaluate the depth of application of irrigation to a specific field.

4. To evaluate the application efficiency to specific fields (with several additional measurements).

5. To evaluate the overall irrigation efficiency of a particular irrigation system.

All the above listed evaluations make this water measurement

the most important element of the entire study. Erroneous measurement will jeopardize the whole water management investigation.

The following steps will help to a great extent to get this measurement with reasonable accuracy.

1. After the second flume is installed make sure that one person is deputed to walk along the channel back to the first flume which has been installed near the mogha. This person should make note of spills, stealing, nakka leaks, trading between the farmers, nakka failures, water diversions into other branches and anything special which would affect the discharge measurement at the second flume. He should be instructed to keep record of all those happenings with time.

2. When the second flume is installed the flow reduces for the initial periods of installation. In flat gradient channels a lot of water gets stored in the upstream section of the channel as the channel section gets constricted due to flume installation. Sufficient time should be given to dissipate this storage otherwise false conclusions are likely to be drawn. Wait long enough after the flume installation to achieve steady flow conditions. This can be noted when the flow rate becomes constant if there are no changes in the upstream section of the channel.

Water Delivery Efficiency - Water delivery efficiency is the ratio of the flow at the second flume to the flow at the first flume. For example if the discharge at the second flume equals 1.2 cusecs and for the first flume equals 1.8 cusecs, the delivery efficiency is:

$$E_d(\%) = 100 \frac{(\text{flume } \#2)}{(\text{flume } \#1)} = \frac{(1.2)}{(1.8)} 100 = 67\%$$

Watercourse Losses - Watercourse losses consist of seepage from the watercourse to the groundwater and spills which occur from leaky nakkas, overtopping of the sides of the watercourse, etc. Losses may be measured or reported in several different ways. One method of reporting the loss is the percent loss which is:

$$\text{Loss } (\%) = 100 - E_d\ (\%) = \frac{(\text{Flume 1} - \text{Flume 2})}{(\text{Flume 1})} \times 100$$

$$= \frac{(0.6)}{(1.8)} \times 100 = 33\%$$

Another method for reporting loss is as cusecs per unit length of channel and assuming the distance between the above flumes is 2,400 feet is:

$$\text{Loss} = \frac{\text{Flume 1 - Flume 2}}{\text{Length of Channel/1000 ft. (ft.)}} = \frac{0.6}{2.4} = \frac{0.25 \text{ cusecs}}{1000 \text{ ft.}}$$

Using cusecs/1000 ft. as a measure of loss permits the direct comparison of the loss rate for different channels and lengths of channel. The loss rate of watercourses does appear to increase with increasing discharge and decrease with increasing length of watercourse, so a third method of reporting loss may also be considered.

Probably, the most correct method for reporting loss is in terms of a seepage rate. The loss between two locations on the watercourse is measured. The length of the section and the wetted parimeter at several locations in the watercourse is measured. The average wetted perimeter is calculated and the loss may be reported as (using five feet as an assumed average wetted perimeter):

$$\text{Loss} = \frac{\text{Flume 1 - Flume 2}}{\text{(length)(wetted perimeter)}} = \frac{0.6}{(2400)(5)}$$

$$= 51.84 \text{ in/day} = \frac{2.16 \text{ in.}}{\text{hr.}}$$

Water Application - The water application to a field is determined by the flow rate, the time of application and the area of the field as follows:

$q^t = dA$
q = flow rate in cusecs
t = time in hours
d = depth of application in inches
A = area of field in acres

If the flow at flume 2 near the field averages 1.2 cusecs during the time period of 2.25 hours, and the water is being applied to a field at 150 ft. x 200 ft., which is approximately 0.69 acres, then the water application is:

$$d = q^t/A = \frac{(1.2)(2.25)}{0.69} = 3.9 \text{ in.}$$

The amount of water applied to the field was 3.9 acre-in./acre.

Application Efficiency - The application efficiency is computed as the amount of water stored in the soil or the soil moisture deficiency divided by the amount of water applied to the field. Determination of soil moisture deficiency may be accomplished by several procedures, the most simple of which is soil moisture sampling. If the soil moisture deficiency was 2.3 inches, then the application efficiency for this example equals:

$$Ea = \frac{\text{(Amount of water stored in the soil)}}{\text{(Amount of water applied to the field)}} \; 100$$

$$= \frac{(2.3)}{(3.9)} \; 100 = 59\%$$

Irrigation Efficiency - The irrigation efficiency is determined as a product of the delivery efficiency and the application efficiency. It is a measure of the effectiveness of the water used that is available at the mogha. For the examples already cited, the irrigation efficiency is calculated as:

$$E_i = E_d \times E_a = 67 \times 59 = 40\%$$

Additional information may also be derived from these basic flow measurements but these are some important examples.

IRRIGATION EVALUATION GUIDELINES - The following are some practical guidelines making irrigation efficiency evaluations:

1. Plan ahead - contact farmer at least a day in advance to confirm his schedule and plans - recontact to reconfirm early on the day of the scheduled evaluation.

2. Soil Moisture Sampling - Be careful of:
   - exact depths used with King-tube
   - covering the cutting edge with finger ASAP after removing from ground
   - closing plastic bag as soon as sample is placed therein
   - weighing the sample on the evening of the same day as sample was taken
   - conducting SMD on sample after weighing the sample
   - exposing the sample to sun only after weighing and conducting SMD procedure
   - reweighing the sample immediately after exposure to the sun
   - collecting samples together to composite sample to have mechanical and soil moisture characteristic analyses completed at a later data
   - taking care of scale (weighing)
   - cleaning King-tube periodically

3. Water Measurement - Be certain that:
   - flume is leveled and remains so at all readings
   - time of each reading is recorded
   - notes are made of all changes in area irrigated and time changes were made
   - breakages of watercourse and bunds are noted with time of occurance and duration of leakage and actions taken by the farmer to correct problem

4. **Field Book and Notes - be certain to inlcude the following on the page of every evaluation:**

1. Date
2. Observer(s)
   Time start & stop
3. Location (Sq. No. & Acre No.)
   Sketch map
   H_a & H_b & discharge
   Crop & height
4. Mogha number
5. Distance from mogha
6. Farmers name
   Date of last irrigation
   Area of field (dimensions)
7. CTF dimensions

1-7 Top of page; 0 items in table; [] separate page

5. Inquiry - Question person irrigating with regard to:

How did he decide tc irrigate the crop today? For instance: (1) appearance of crop, (2) appearance of soil, (3) time since last irrigation, (4) digging in the soil, (5) weather and season;

How did he choose this field crop today when he has many fields to irrigate and a limited supply of water? Why?

What are his watercourse losses?
What are his field losses?
How deep does water go?
How much water is he putting on field?
How did he decide when to shut off water to the field?

GUIDELINES FOR CUTTHROAT FLUME INSPECTION

Precision in water measurement is dependent upon the production of flumes within precise tolerances. The following is a guideline, fill-in table and check list, for cutthroat flume inspection. All measurements of flume dimensions must be within 1/16 inches or .005 foot of the specified length or 0.5 degree of the specified angle to be acceptable for field use. Flumes which do not meet these standards will be rejected.

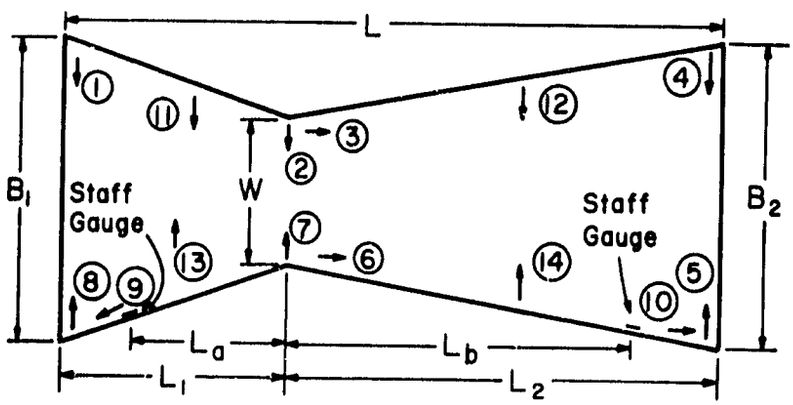

Table of Linear Dimensions (Tolerance: 0.005 foot)

	Specification	Top	Middle	Bottom	Other
W	_____	_____	_____	_____	_____
L	_____	_____	_____	_____	_____
$B_1 = W + L/4.5$	_____	_____	_____	_____	_____
$B_2 = W + L/4.5$	_____	_____	_____	_____	_____
$L_1 = L/3$	_____	_____	_____	_____	_____
$L_2 = 2L/3$	_____	_____	_____	_____	_____
$L_a = 2L/9$	_____	_____	_____	_____	_____
$L_b = 5L/9$	_____	_____	_____	_____	_____
H	_____	_____	_____	_____	_____
H_a	_____	_____	_____	_____	_____
H_b	_____	_____	_____	_____	_____

Table of angles measured: angles measured from vertical wall (or staff gauge) to the floor of flume in the direction corresponding to the arrows in the diagram above: tolerance: 0.5 degree.

	Specification	Measured		Specification	Measured
1.	90°	_____	9.	90°	_____
2.	90°	_____	10.	90°	_____
3.	90°	_____	11.	90°	_____
4.	90°	_____	12.	90°	_____
5.	90°	_____	13.	90°	_____
6.	90°	_____	14.	90°	_____
7.	90°	_____	15.	90°	_____
8.	90°	_____			

General Qualitative Measures & Observations

_____1. Staff gauge calibrations precisely at distances L_a and L_b from throat respectively (distance measured to the center of the markings).

_____2. Staff gauges installed perpendicular to the floor of flume.

_____3. When installed with stilling wells, the centerline of holes for water entry must be precisely at distances L_a and L_b from throat. (Tolerance: .005 foot)

_____4. When installed with stilling wells, the staff gauge in each stilling well must start at exactly the same datum (floor of flume) in the stilling well as in the respective converging and diverging sections.

_____5. Sides must be perpendicular to the floor throughout converging and diverging sections.

_____6. Sides must be plane surfaces, free of buckles and bulges.

_____7. Bend of metal in throat section must be sharp and perpendicular to the floor along the direction of flow.

_____8. Angle iron top cross pieces at converging center and diverging sections should be parallel to the floor in the respective section.

_____9. Angle iron top pieces at sides of flume should be parallel to floor of flume.

____10. Floor of flume should be flat plane surface free of bulges.

____11. Bolts holding staff gauges should not protrude into the flow.

____12. Welds should be done on the outside of flume and should not contact the inner perimeter or influence flow.

____13. Painted surface should be smooth without rough areas or streaked finish.

____14. Top edge of staff gauges should not protrude above top edge of flume and top edge of calibrations should correspond with measurements made inside the flume (tolerance: 0.005 foot).

Appendix 22

MEASURING TUBEWELL DISCHARGES BY THE PURDUE COORDINATE METHOD[1]

Tom Trout and Alan Early[2]

The discharge rate from many tubewells of Pakistan can be estimated by the Purdue Coordinate Method. The method entails measuring the fall in a given length of a stream of water flowing freely from the end of a horizontal pipe. The method is applicable when the tubewell discharge flows freely, the outlet pipe is straight for a distance of at least six diameters and is horizontal, and the end of the outlet pipe is round and accessible. The method applies to the general case, whether the pipe flows full or partially full. Figure 1 indicates the measurements which must be made for this estimation procedure; Q is the discharge in cubic feet per second (Qsecs), D is the inside diameter of pipe in inches, X is the horizontal coordinate to measuring point in inches, Y is the vertical cordinate to measuring point in inches. The measuring point is the average location at which the horizontal jet touches the vertical ordinate at a pre-specified abscissa distance from end of pipe, 0", 6", 15" or 18".

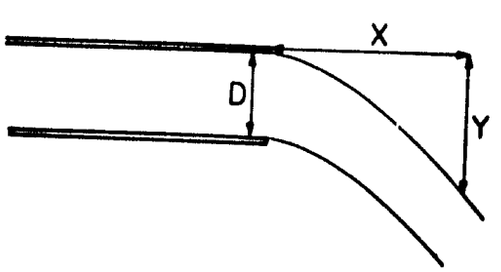

Figure 1. Definition of Measurements for Estimation of Tubewell Discharge

Stock from Purdue University, prepared graphs, presented in the U.S.B.R. Water Measurement Manual (1967), for

[1] Adapted to Pakistan conditions from Water Measurement Manual, U.S.D.I., Bureau of Reclamation, 1967.

[2] Graduate Research Assistant and Agricultural Engineer, Colorado State University, Water Management Research Program in Pakistan.

experimental measurements of the coordinate method. A table taken from these graphs is presented in Table 1, for 3, 4, 5 and 6 inch pipe diameters and for X coordinate values of 0", 6", 12", and 18 inches.

The procedure for measurements is as follows: With a small engineering or carpenters level, check the tubewell discharge pipe for level and note if level is sloping up or down to discharge side. Then with a carpenter's square, or folding rule, or any calibrated right angle rule, measure the vertical distance from the top of the pipe to the top of the falling stream, 6 inches, 12 inches or 18 inches from the end of the pipe, as shown in Figure 2. If the pipe wall

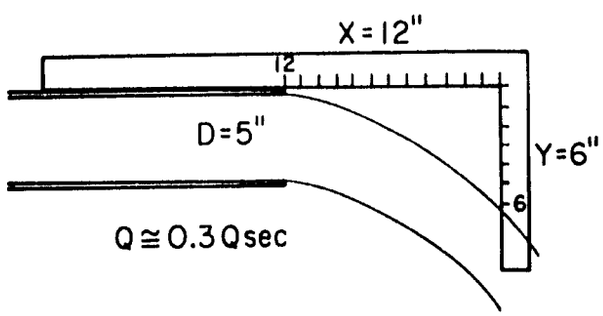

Figure 2. Cordinate Method Measurements Using Carperters Square

thickness is significant, subtract it from the vertical distance. Measure the inside diameter of the pipe in both the vertical and horizontal direction and calculate the average diameter. From these measurements, the discharge can be read directly, or linearly extrapolated, from the values in Table 1. If the outlet pipe slopes slightly upward toward the outlet, the table values will be high; if it slopes slightly downward, they will be low, so round the value up to next tenth of a Qsec. The table values are expressed to the nearest hundredth of a Qsec, but since this is an estimation procedure only, the recorded values should never be expressed to more precision than the nearest tenth of a Qsec. If the pipe has a discharge with a depth less than eight-tenths of the diameter of the outlet, the vertical distance Y should be measured at the end of the pipe and the part of the table for X =) should be utilized.

If the tubewell is driven by a diesel engine, be certain to record the counts per minute of the diesel exhaust and record as revolutions per minute. The farmer will often speed up the engine if he knows someone is measuring its discharge, but then reduce the speed again when that person moves away. Be certain to record this behavior if it occurs.

Table 1. Discharge from horizontal round pipes (cfs) after U.S.B.R. Water Measurement Manual (1967) Figure 92. p. 202 and 203.

Diameter Y (in)	Horizontal Coordinate X = 0" 3"	4"	5"	6"	X = 6" 3"	4"	5"	6"
0.5	.13							
1.0	0.12	0.29	0.59	0.94	0.40	0.76	1.27	1.78
1.5	0.08	0.22	0.49	0.81	0.33	0.65	1.07	1.56
2.0	0.04	0.17	0.38	0.71	0.29	0.56	0.91	1.36
2.5	0.02	0.11	0.30	0.56	0.26	0.49	0.81	1.24
3.0		0.05	0.20	0.45	0.22	0.45	0.74	1.11
3.5			0.12	0.33	0.20	0.40	0.67	1.00
4.0			0.07	0.27	0.19	0.37	0.61	0.95
4.5					0.17	0.33	0.57	
5.0					0.16	0.30		

	X=12" 3"	4"	5"	6"	X=18" 3"	4"	5"	6"
1.0	0.71	1.27	2.23	3.12				
1.5	0.61	1.05	1.80	2.67	0.84	1.56	2.56	3.68
2.0	0.53	0.92	1.56	2.34	0.75	1.34	2.12	3.12
2.5	0.47	0.85	1.38	2.09	0.67	1.20	1.92	2.79
3.0	0.42	0.78	1.27	1.94	0.60	1.07	1.78	2.56
3.5	0.39	0.72	1.16	1.78	0.57	1.00	1.65	2.40
4.0	0.37	0.67	1.07	1.67	0.53	0.94	1.54	2.28
4.5	0.35	0.64	1.00	1.56	0.51	0.89	1.45	2.17
5.0	0.33	0.61	0.96	1.47	0.49	0.85	1.38	2.06
5.5	0.32	0.58	0.91	1.40	0.47	0.81	1.33	1.96
6.0	0.31	0.56	0.87	1.34	0.45	0.78	1.27	1.89

Since there is a variation between the theoretically predicted and empirical results, it would be worthwhile to check the method for tubewell outlets by taking coordinate measurements and measuring discharge with a Sparling meter for various pipe diameters and discharge rates. The method which gives results which compare most closely with the experimentally measured data can then be used, or new graphs can be prepared and used.

For other diameters of tubewell discharge pipes the theoretical relationship for this flow condition, based only on inertial and gravity forces, can be used to calculate discharge as

$$Q \text{ (cfs)} = .0063\ D^2 \times \sqrt{I/Y}$$

with all symbols as previously defined.

Appendix 23

DIFFERENTIAL LEVELING FOR BENCH MARK SURVEY OF THE WATERCOURSE[1]

Methodology Series Number Six

Wayne Clyma and Alan Early[2]

Differential leveling is the process of finding the differences in elevation of any two points. It usually requires several setups of the instrument along a general line between the two points. Each setup requires a rod reading on a point of previously determined elevation and a rod reading on a point of unknown elevation. A bench mark survey is conducted to provide a widely spaced series of points (pucca nakkas, culverts, bridges, etc.) of known elevation from which a topographic survey is conducted at a later date.

THEORY OF LEVELING

Leveling is the process of determining the elevations or differences in elevations of points. Figure 1 illustrates the basic procedure.

A level is set up at a location approximately half-way between a bench mark (B.M.) and a turning point (T.P.). A bench mark is a relatively permanent natural or artificial object bearing a marked point whose elevation is known or assumed. A turning point is a temporary bench mark for the purpose of continuing a line of levels. Portable turning points are provided for field watercourse surveys and topographic surveys.

For example, referring to Figure 1, if the elevation of the bench mark ($B.M._1$) is assumed to have an elevation of 100.000 meters, the elevation of the turning point ($T.P._1$) can be determined by leveling. First the instrument is set up approximately half-way between $B.M._1$ and $T.P._1$ and is leveled. A rod reading is taken on $B.M._1$ of 2.40. This rod reading is termed a backsight (B.S.). A backsight is a rod reading taken on a bench mark or turning point of known elevation. It is the vertical distance between the B.M. and the line of sight of the instrument. The line of sight of the instrument is almost always higher than the B.M. or T.P.,

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[1]Adapted from "Agricultural Surveying for Soil and Water Conservation", by Wayne Clyma, Oklahoma State University, USAID Contract in Ethiopia, 1966.

[2]Agricultural Engineers, Colorado State University Water Management Research Project in Pakistan.

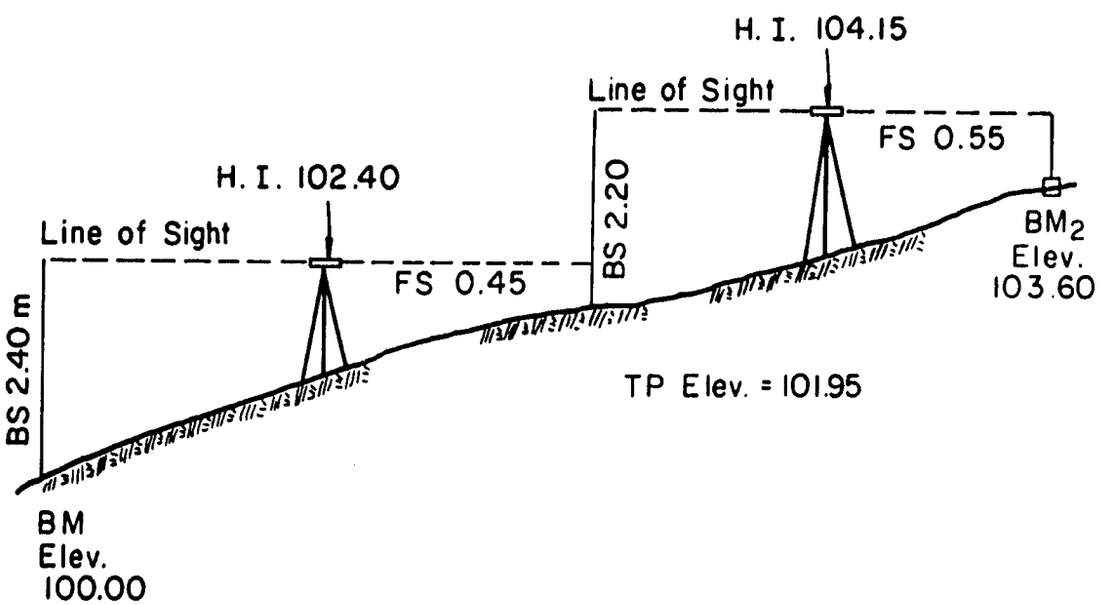


Figure 1. Theory of differential leveling.

therefore, the backsight is almost always positive and could be described as a plus sight.

The height of instrument (H.I.) is the elevation of the line of sight when the instrument is level. This corresponds to the line of sight of the instrumert and is obtained by adding the backsight to the elevation of the B.M. or T.P. In Figure 1, the B.S., 2.40, is added to the elevation of $B.M._1$, 100.00, to obtain the H.I., 102.40. Turning the telescope to bring into view the rod held on $T.P._1$, a rod reading called a foresight is obtained. A foresight (F.S.) is a rod reading taken on a turning point of any other point of unknown elevation for which the elevation is to be determined. The foresight is almost always substracted from the height of the instrument and could be described as a minus sight. In the example of Figure 1, the F.S., 0.45, is subtracted from the H.I., 102.40, to obtain the elevation of T.P., 101.95. Thus, by a process known as leveling, we have determined the difference in elevation of two points. The students may now use his knowledge of leveling to check the elevations shown in Figure 1, and determine the elevation of $T.P._2$.

From the above definitions, we can derive two equations that are quite beneficial in leveling. These equations will be repeated numerous times during a leveling exercise and the student should become thoroughly familiar with them. They are:

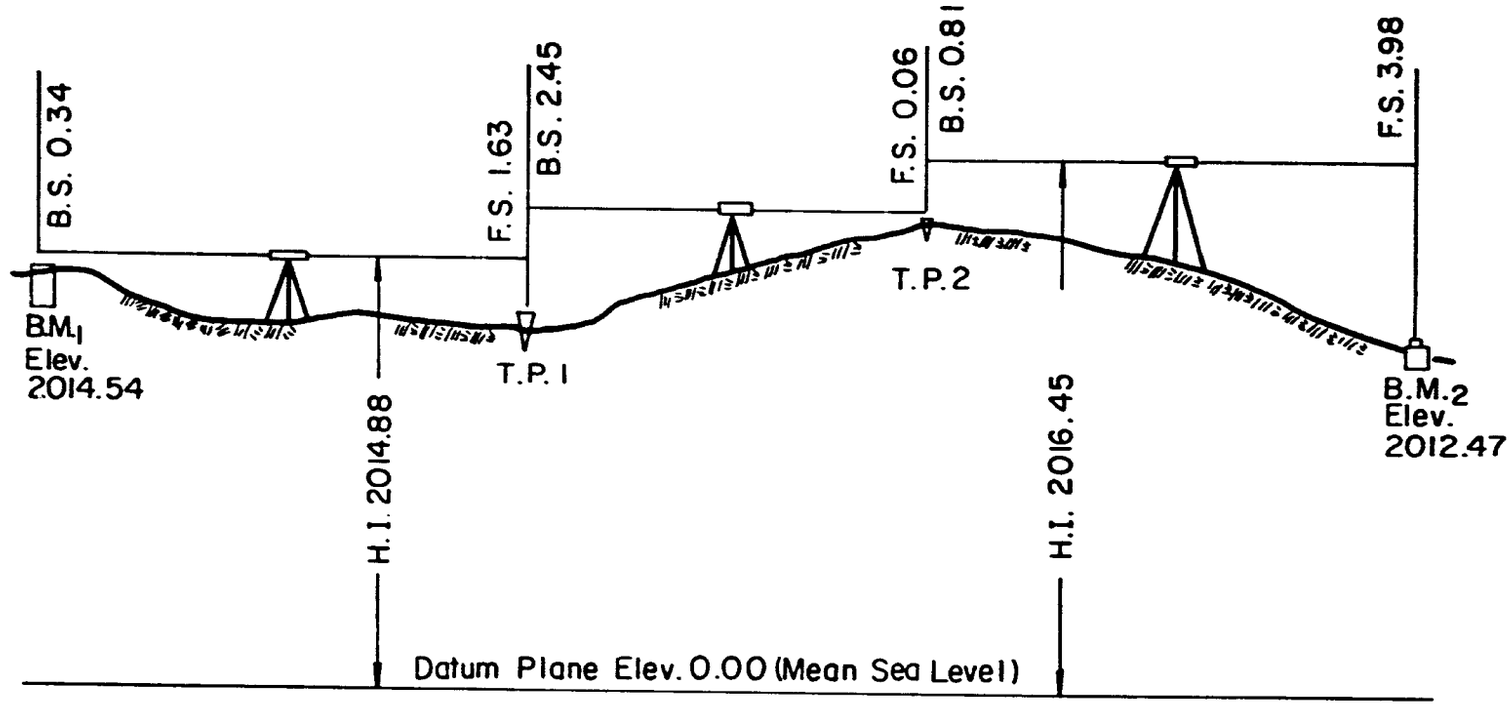
Elev. + B.S. = H.I.
H.I. + F.S. = Elev.

Note that if a backsight is taken on a B.M. or T.P. located on the roof of a tunnel or on the ceiling of a room with the instrument at a lower elevation, the backsight must be subtracted from the elevation to obtain the height of instrument. Also, if a rod reading is taken on a pipe or some other object higher than the instrument, the foresight must be added to the height of instrument to obtain the elevation.

PROCEDURE FOR DIFFERENTIAL LEVELING

Several procedures and precautions should be observed for accurate differential leveling. Refer to Figures 2 and 3 for sample rod readings and a sample set of notes for a differential leveling exercise.

To begin a differential survey, the rodman holds a rod on $B.M._1$ while the levelman goes forward a convenient distance (not over 100 meters for a Bostrom-Brady farm level) and sets up the level. The distance from the instrument to T.P. The levelman takes a reading on the rod and determines where the middle crosshair strikes the rod, in Figure 2 at 0.34. This is a backsight and the notekeeper records 0.34 in the B.S.



DIFFERENTIAL LEVELING

Figure 2. Illustrating the procedure for taking backsights and foresights of differential leveling.

DIFFERENTIAL LEVELING
FOR BENCH MARKS
Alemaya College Campus

Sunny, calm

Haily S. & N
Tewolde W.
Aug. 18, 1965

Sta	BS	HI	FS	Elev.	
BM_1	0.34	100.34		100.00	$B.M._1$: the southern bolt on the pole
TP_1	2.45	101.16	1.63	98.71	nearest to the irrigation lab.
TP_2	0.81	101.91	0.06	101.10	about 5 m. from eastern side
BM_2	3.98	101.91	3.98	97.93	door
TP_3	0.09	101.19	0.81	101.10	
TP_4	1.98	100.71	2.46	98.73	$B.M._2$: Steel rod on the N.E. corner of
BM_1			0.69	100.02	the cattle guard into the live-
BS =	9.65	FS =	9.63	0.02	stock area across from poultry.

Error of closure =

9.65 - 9.63 = 0.02 check

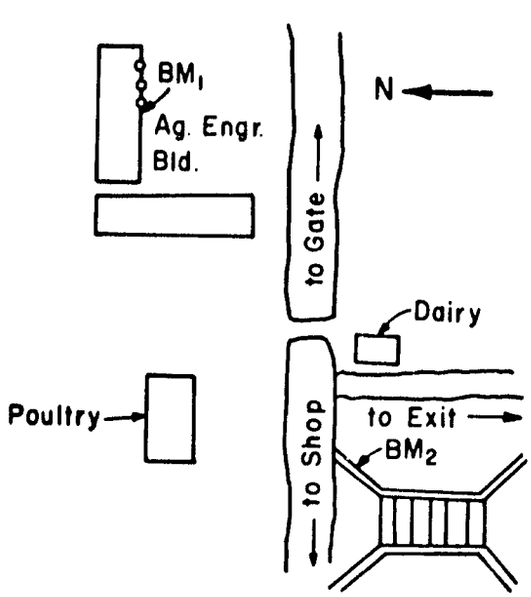


Figure 3. Sample differential leveling notes.

column of the notes. Now the H.I. is determined by adding the B.S. to the elevation of the B.M., 100.00 + 0.34 = 100.34, and is entered in the notes in the H.I. column. For the convenience of the student, a plus sign can be placed above the B.S. column and a minus sign above the F.S. column to indicate how that column is used in note computations.

After the B.S. has been obtained, the rodman steps the distance from the B.M. to the instrument and then steps the same distance away from the instrument in the direction of $B.M._2$. This pacing is one of the acceptable methods of balancing the horizontal distances between the backsight and the foresight. This distance can also be measured by stadia, but the accuracy obtained by taping is not considered necessary. The effects of refraction, curvature of the earth, and lack of instrument adjustment are thereby eliminated. On slopes a zigzag path may be taken to utilize the longer rod length available on the downhill sights.

CLOSED SURVEYS

To verify the accuracy of the leveling, a return check must always be made. That is, the line of levels must be continued from $B.M._2$ back over a slightly different route to $B.M._1$, the initial starting point. To make the return check independent of the first line of levels, after the F.S. is taken on $B.M._2$, the student should lift up the level and re-level it so that the H.I. will be at a slightly different elevation. This results in a B.S. on $B.M._2$ different from the F.S. and should result in a better check of the line of levels. When the student has returned to $B.M._1$, he has completed a closed survey. All leveling exercises should be closed surveys so that a check of the accuracy of the survey can be made. Figure 4 gives a sample traverse for a bench mark survey of a watercourse. Note that all available permanent structures are used as bench marks. These bench marks must be marked with both a water proof marker and with a nail or screwdriver scratch for permanence. Figure 5 provides the sample survey notes for the traverse of Figure 4. Note the double tabling of points which are both turning points (T.P.) and bench marks (B.M.). Portable turning points are labeled PTP.

ERROR OF CLOSURE

If there have been no errors made in a closed survey or if the errors have compensated, then the elevation determined for $B.M._1$ by the return check will be the same as the original elevation of $B.M._1$. Generally these elevations are not the same because of errors in rod readings or instrumental errors.

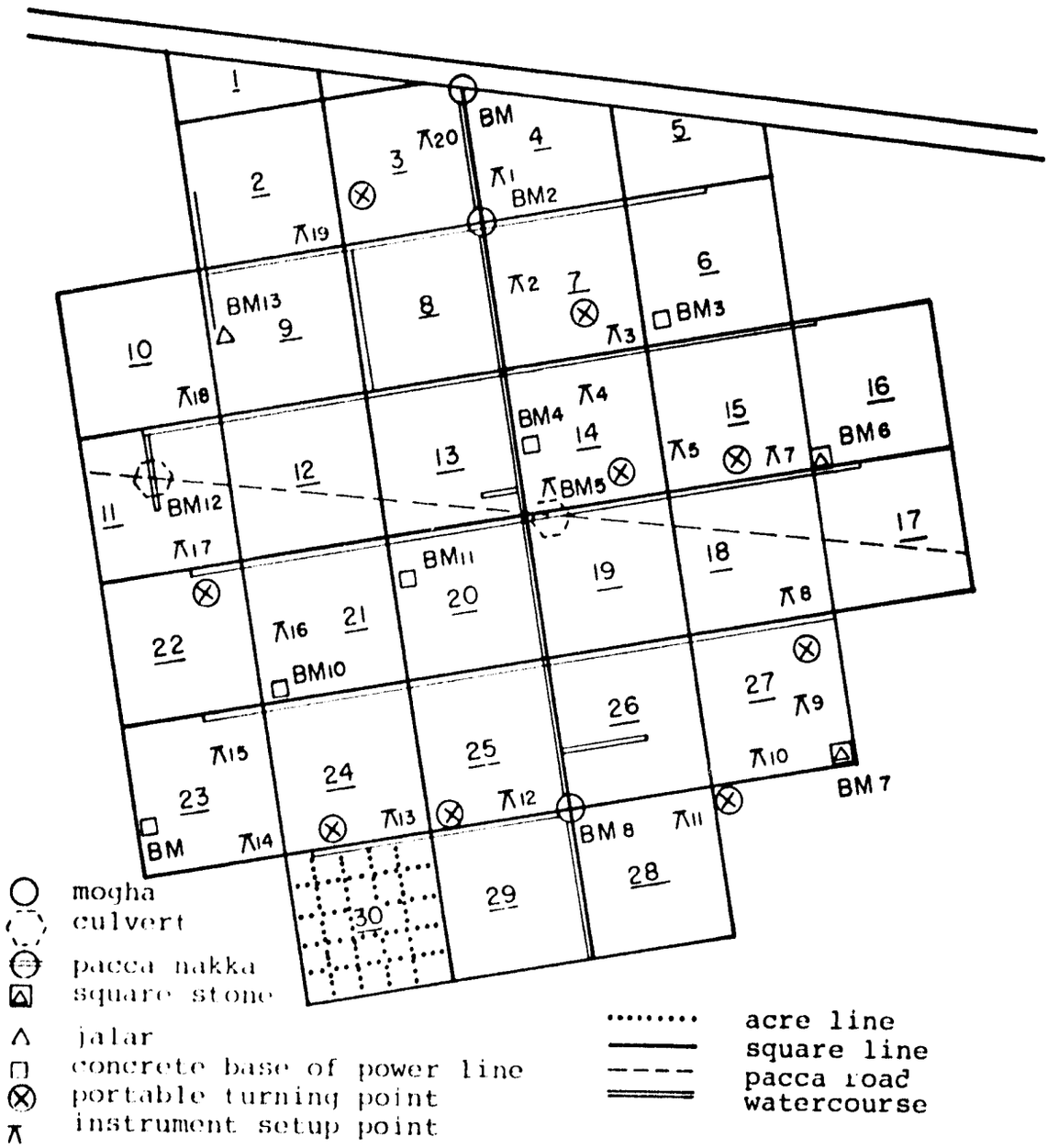


Figure 4. Sample traverse for bench mark survey of water-course.

WATERCOURSE BENCH MARK SURVEY
BY DIFFERENTIAL LEVELING
Chak 110/JB, Lyallpur

Sunny Waryam
Hot Zahid
Calm August 18, 1975

Sta.		BS	H.I.	FS	Elev.	
	BM_1	3.02	103.02		100.00	
TP_1	BM_2	4.22	103.17	4.07	98.95	Mogha Scratch Mark - Upstream Side
TP_2	TP_2	3.89	102.05	5.01	98.16	Pacca Kanna Corner of Squares 3,4 7 and 8
TP_3	BM_3	6.87	104.85	4.07	97.98	
TP_4	BM_4	4.48	102.44	6.89	97.96	Sq. 6: CBPL* - Scratch
TP_5	BM_5	4.32	101.75	5.01	97.43	Sq. 14: CBPL - Scratch
TP_6	TP_6	5.10	101.60	5.25	96.50	Sq. 13, 14: Concrete culvert - upstream
TP_7	TP_7	4.88	101.50	4.98	96.62	
TP_8	BM_6	3.37	99.61	5.26	96.24	
TP_9	TP_9	3.85	99.28	4.18	95.43	Sq. 15,16,17,18: Square stone - scratch
TP_{10}	BM_7	4.71	99.98	4.01	95.27	
TP_{11}	TP_{11}	4.85	99.56	5.27	94.71	Sq. 25,26,28,29: Square stone - scratch
TP_{12}	BM_8	5.17	99.44	5.29	94.27	
TP_{13}	TP_{13}	4.37	98.81	5.00	94.44	Pacca Nakka Corner of Squares 25, 26, 28, 29
TP_{14}	TP_{14}	3.99	98.28	4.52	94.29	
TP_{15}	BM_9	4.00	98.37	3.91	94.37	
TP_{16}	BM_{10}	6.02	100.77	3.62	94.75	Sq. 23: CBPL - scratch
	BM_{11}			/5.91/	94.86	Sq. 21: CBPL - scratch
TP_{17}	TP_{17}	6.27	101.77	5.27	95.50	Sq. 20: CBPL - scratch
TP_{18}	BM_{12}	5.33	102.82	4.28	97.49	
TP_{19}	BM_{13}	4.81	103.74	3.89	98.93	Sq. 11: Concrete Culvert:Scratch-Downstream
TP_{20}	TP_{20}	4.68	104.72	3.80	99.94	
	BM_1			4.51	100.11	Sq. 9: Steel frame on Jalar Base - scratch
BS =		98.20	FS =	98.09	0.11 = Elev. Diff.	Mogha

Error of closure = 98.20 - 98.09 = 0.11

*Concrete Base of Power Line - CBPL

Figure 5. Watercourse benchmark survey notes by differential leveling.

The amount by which the original B.M. elevation and the B.M. elevation observed upon the return check fail to agree is called the error of closure.

Allowable errors of closure for a survey is a function of the accuracy of the instrument and the length of the survey or the number of times the instrument is set up. For a Bostrom-Brady level, the allowable error of closure equals 0.01 meters per two instrument setups (0.01/2 setups). For the notes shown in Figure 3, there were four instrument set-ups so the allowable error of closure was 0.02. The actual error of closure was 0.02 so it is within the limits of error for the survey. For general leveling purposes with available equipment, the allowable error in English units, feet, is given by:

$$\text{allowable error} = 0.007\sqrt{\frac{\text{length of traverse in feet}}{100}}.$$

If the sample traverse for Figure 4 were 20,000 feet then the allowable error is 0.0989 or 0.10 foot. Bench mark surveys which do not meet this standard must be completely resurveyed until the error of closure is less than the allowable error. The survey whose notes are provided in Figure 5 does not meet the standard and must be repeated.

CHECKING THE LEVEL NOTES

The computations of the level notes should always be checked by comparing the difference between the sum of the backsights (B.S.) and the sum of the foresights (F.S.) with the differences between the initial and final elevation of the B.M. used to close the survey before leaving the field. This computation checks the notes for arithmetical accuracy. The two differences must agree or an arithmetical error has been made. No set of leveling notes is complete without an error of closure computation and check of the arithmetical accuracy of the notes, before leaving the field.

USE OF THE BENCH MARK SURVEY

The bench mark survey when completed to the required standard of accuracy becomes a basis for additional field surveys that are completed subsequently. The pucca bench marks can then become starting points for any portion of the profile leveling survey of the watercourse and of the topographic survey of the watercourse. This set of benchmarks is then a set of known elevations to facilitate the completion of these other surveys.

PRACTICAL CONSIDERATIONS

While profile leveling, benchmark or topographic surveying, the need for intermediate turning points arises frequently. The placement of the staff rod on the ground or

on the bed of a watercourse can lead to errors of major magnitude, if when the rod is rotated in contact with soil changes in rod elevation occur. To avoid this problem and source of inaccuracy, portable pucca turning points are provided for field use. Figure 6 below shows this simple surveying item. It is nothing more than a four-inch square piece of #14 or #16 sheet metal with one inch corners bent down at 90° from face to form four legs and with a rivet in center to hold the chain handle to bottom side. The rod is rotated on the rivet after portable turning point is forced into ground.

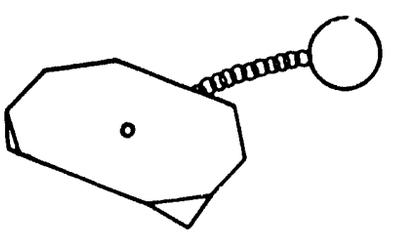


Figure 6. Portable Pucca Turning Point.

Appendix 24

FIELD AND WATERCOURSE ORIENTATION MAPPING USING PLANE TABLE AND PEEP-SIGHT ALIDADE[1]

Methodology Series Number Seven

Wayne Clyma and Alan C. Early[2]

The plane table and alidade, Figure 1, are frequently used instruments where layout maps are needed of irregular field and watercourse orientations. This offers the advantages of preparing the map while the surveying is done and permits checking the watercourse and field layout as shown on the map with the actual layout. Also, where the design of, for example, a farm pond is completed as soon as a map has been prepared, the design can be completed and staked all in one operation. No return trip to an office to prepare the map, make the design, and then another trip to the field to stake the dam, pond, and spillway is necessary. The principal disadvantage of using the plane table and alidade is the extra field time necessary. When bad weather occurs, no work is possible.

The basic equipment for the plane table and alidade method of mapping consists of a tripod, drawing board, alidade equipped with peep-sight alignment hairs, tape and pencil, paper, and scale for preparing the map. Paper is fastened to the board and positions are plotted on the paper by sighting through the alidade for direction, and determining the distance by taping.

The Plane Table

The plane table (Figure 1) is a rectangular board (1) usually 18" x 31" (46 x 79 cm.) with a means for attaching it to a tripod. The top surface of the board is provided to attach a sheet of mapping paper.

The Alidade

The alidade in Figure 1 has two peep-sight brackets (3) with the vertical hairs separated by 18 inches distance. The alidade has a linear, usually brass base (4) that supports it

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[1] Adapted from "Agricultural Surveying for Soil and Water Conservation", by Wayne Clyma, Oklahoma State University, USAID Contract in Ethiopia, 1966.

[2] Agricultural Engineers, Colorado State University Water Management Research Project in Pakistan.

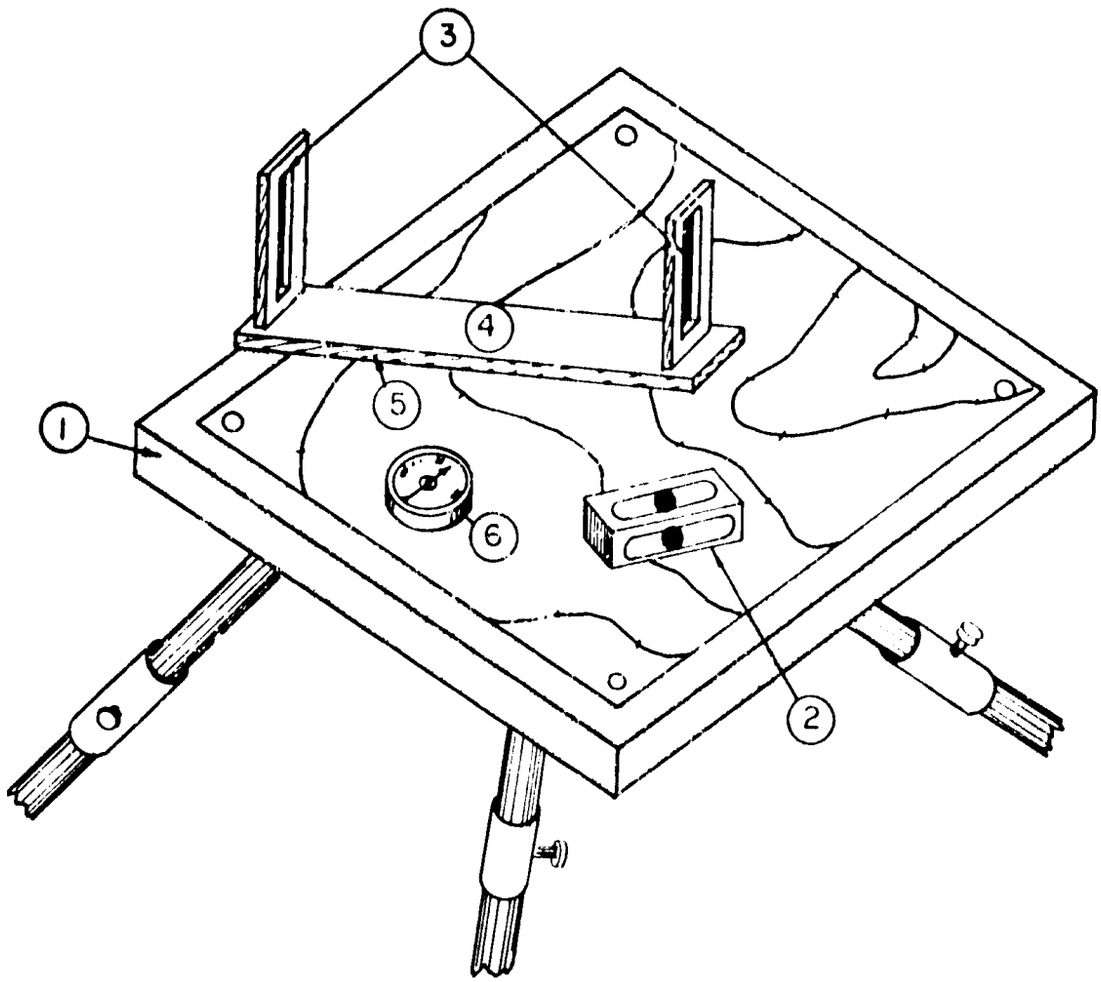

Figure 1. The plane table and alidade.

when resting on the table. One edge of the support (5) is usually beveled and this is the sighting edge. A separate, small magnetic compass (6) is provided for proper orientation of the plane table.

Setting up the Plane Table

The tripod and plane table are set up at an appropriate central location with respect to the line of sight for field layout or watercourse to be mapped. Using the level bubble (2) on the separate level provided, the table is leveled. Leveling the table is frequently difficult. The table is then rotated in a horizontal plane until magnetic north is the top of the map or until another reference direction has been selected. The location of the instrument is designated on the map either arbitrarily or by using other known points to determine instrument location. A map can then be prepared using the alidade to sight locations and the tape to determine distances.

Alidades of other types can be used to determine both elevation and stadia distances. Because of the difficulties of maintaining a precisely leveled table, the student may find it advantageous to use the plane table for locations and the farm level for elevations. This procedure may seem like an unnecessary duplication of instruments and equipment. However, use of the level eliminates most of the difficulties of keeping the table level for good elevation control. Where a plane table and alidade are available, a level is usually available. One experienced surveyor for both level and table can usually keep two experienced rodmen busy.

Orienting the Plane Table

Location of the instrument on the map that is to be made is usually accomplished by two methods: (1) compass and (2) backsighting.

To orient the table by compass, the alidade is placed in the direction that is desirable for a north-south line. The table is then rotated until the compass needle points to magnetic north. The board is clamped and a line is then drawn on the paper for future reference and for periodically checking the orientation of the board.

Orientation of the board by backsighting requires that two points be located in the field. They may or may not be located on the map. If not located on the map, then the orientation of the line is assumed for best use of the paper for constructing the map. Distances in all directions may be estimated and then scaled to make sure that the scale selected will permit all the area to be mapped to be included.

Rod readings are observed on the ground or bed with portable pucca turning point adjacent to the stake or chaining pin for the intermediate shots. For turning points all rod readings are taken on top of a stake if the stake is used or on the portable pucca turning point if chaining pins are used. When placing the rod adjacent to a stake for an intermediate shot, the student should always try to select "average ground." That is, the rod should not be placed in a hole nor should it be placed on top of a small hill or clod. The location should represent the average of the ground surface immediately around the stake.

For an example of a ground surface profile and corresponding rod readings, see Figure 1 and Figure 2. After the instrument has been leveled, a rod reading is obtained on the B.M. and H.I. computed. In the example a B.S. of 1.02 gives an H.I. of 101.02. A rod reading is then obtained near 0 + 00 for the first shot, at 0 + 38.03 for the second shot and so forth until station 0 + 72.56 has been read. A turning point is then necessary so a T.P. is selected and a foresight of 1.60 is obtained on top of the stake. The instrument is carried to a new position along the line, releveled, a B.S. of 0.98 obtained on $T.P._1$, and a new H.I. computed. We are now ready to take additional intermediate shots along the profile line. This process is continued until the profile is completed. A complete set of profile leveling notes is shown in Figure 3.

Closed Surveys

In profile leveling, as in differential leveling, a closed circuit of levels must be made to check the accuracy of the survey. This is done as in differential leveling by running a line of differential levels back to the bench mark from which the survey was begun.

Error of Closure and Checking the Notes

The method of checking the note computations and computing the error of closure is shown in Figure 3. Note that for a profile survey the foresights and backsights used for computing the error of closure are only those which were taken on the B.M.'s and T.P.'s. The intermediate rod readings are not used in the computation for error of closure. The only method of checking the intermediate rod readings is to rerun the entire profile.

Plotting Profiles

Profiles are usually plotted on paper and the result called a cross section. Special profile paper can be obtained which simplifies plotting, but any ruled paper can be used.

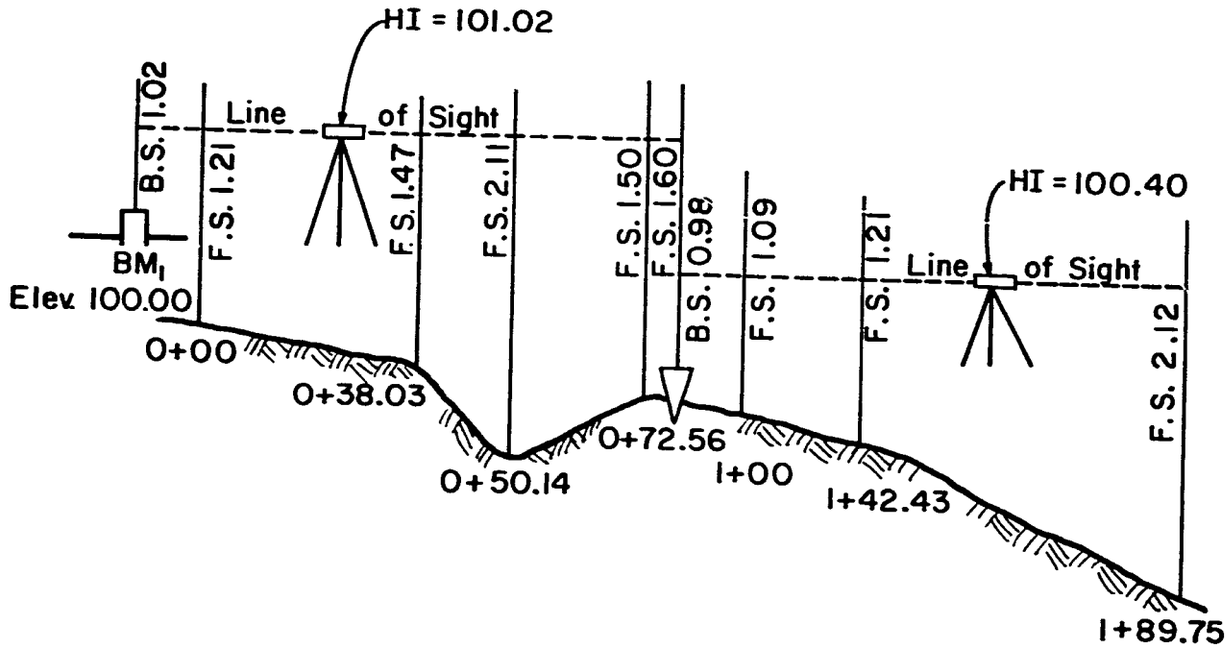

Figure 1. Rod readings for profile leveling.

PROFILE LEVELING				
Station	BS	HI	FS	Elev.
BM_1	1.02	101.02		100.00
0 + 00			1.21	99.81
0 + 38.03			1.47	99.55
0 + 50.14			2.11	98.91
0 + 72.56			1.50	99.44
TP_1	0.98	100.40	1.60	99.31
1 + 00			1.09	99.31
1 + 42.43			1.21	99.19
1 + 39.75			2.12	98.28

Figure 2. Left side of notes for profile shown in Figure 1.

PROFILE FOR AG. ENGR. CULVERT

Station	BS	HI	FS	Elev.
BM_1	1.62	101.62		100.00
0 + 00			0.51	101.11
0 + 4.12			0.86	100.76
0 + 8.75			1.14	100.48
0 + 12.50			1.39	100.23
0 + 15.96			0.92	100.70
0 + 20.58			1.65	99.47
0 + 27.85			1.98	99.64
0 + 30.00			2.16	99.46
0 + 36.90			2.39	99.23
0 + 39.42			2.25	99.37
0 + 42.30			2.76	98.86
TP_1	0.23	99.70	2.15	99.47
0 + 48.14			1.26	98.44
0 + 58.56			1.91	97.79
0 + 60.00			1.95	97.75
0 + 65.83			1.93	97.77
0 + 69.90			3.05	96.65
0 + 72.18			3.44	96.26
0 + 72.65			3.60	96.10
0 + 73.19			3.48	96.22
0 + 76.49			3.30	96.40
0 + 81.55			3.50	96.20
TP_2	0.54	96.93	3.31	96.39
0 + 83.15		96.93	1.27	95.66
0 + 85.30			1.49	95.44
0 + 88.10			1.56	95.37
0 + 90.00			1.83	95.10
0 + 93.40			1.90	95.03
0 + 97.31			2.21	94.72
TP_3	3.32	99.70	0.55	96.38
TP_4	1.72	100.93	0.49	99.21
BM_1			.92	100.01
BS =	7.43	FS =	7.42	100.00
Error of closure = BS - FS				
	= 7.43 -		7.42	
	= 0.01			0.01 Check

Cloudy, shower Tewolde W.
October 7, 1965 Mehary T.
BM_1: An x mark on the retention wall at the north side of the Agric. Engr. building about 2.60 m. above the first step, under a lamp post.

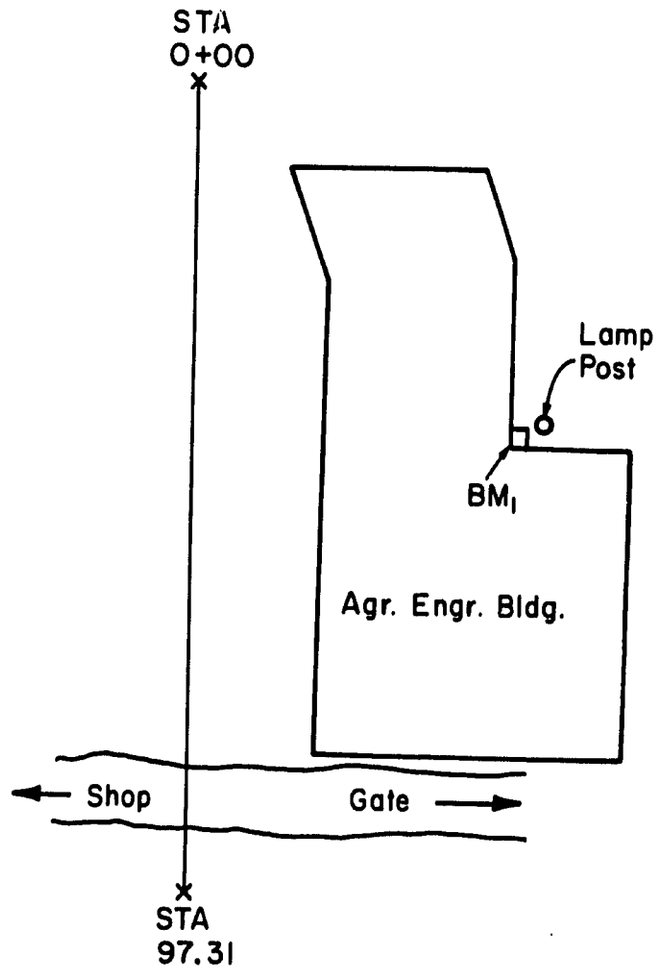

Figure 3. Sample notes for a profile leveling exercise.

The vertical scale of a profile is generally exaggerated with respect to the horizontal scale in order to make differences of elevation more pronounced. This is because vertical differences in elevation are usually much less than the horizontal distance covered by the profile. The exaggeration is usually on a ratio of 10:1. That is for a horizontal scale of 1:500 (i.e., 1 meter equals 500 meters or 1 foot equals 500 feet), the vertical scale would be 1:50 (i.e., 1 meter equals 50 meters or 1 foot equals 50 feet). Since the points plotted on the paper from the profile represent "average ground" it is usually the practice to draw smooth lines (not straight lines) from point to point.

The plotted profile is used for many purposes, such as:

1. Determination of the depth of cut for a drainage or irrigation watercourse.

2. Determination of the fill for a farm pond.

3. Selection of the grades for a drainage ditch, irrigation watercourse or culvert.

Rate of grade, gradient, or just grade is the rise or fall in meters per 100 meters. Thus a grade of 2 5 percent means 2.5 meters difference in elevation per 100 meters horizontally or 2.5 feet in 100 feet. Ascending grades are plus; descending grades are minus. The selection of a grade line for a project involves the principles of engineering design.

The term "grade" is also employed to denote the elevation of the finished surface of an engineering project.

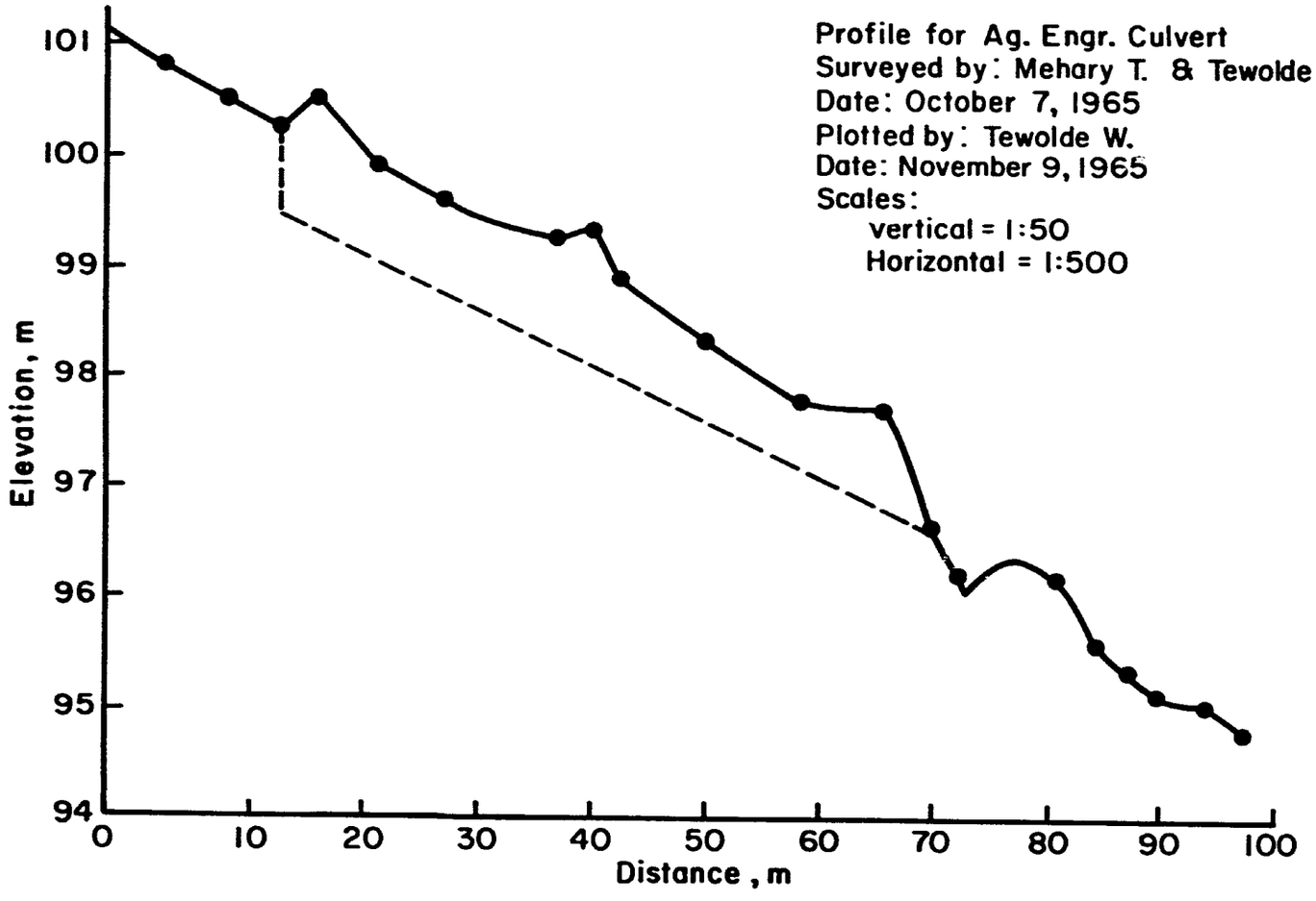

Figure 4. Cross section plot for a profile leveling exercise.

Appendix 26

TOPOGRAPHIC MAPPING USING GRID METHOD AND LEVEL[1]

Methodology Series Number Nine

Wayne Clyma and Alan C. Early[2]

Maps are essential to the best farm planning. In addition, maps are frequently the basis for engineering design of farm layouts and soil and water conservation structures and facilities. Pakistan is in dire need of maps of a scale (1:5000 or less) adequate for farm planning and engineering design. No matter where you will be employed, you will not likely find an adequate map to assist you in properly applying your engineering knowledge.

Topographic Maps

A map which shows horizontal distances, horizontal angles, and elevations is called a topographic map. The addition of elevation to a map results in the map showing topography or relief of the land surface. The contour map is the simplest method of showing elevation on an otherwise two dimensional sheet of paper. A contour is an imaginary line of constant elevation on the surface of the earth. The shore line of a lake is a contour frequently seen in nature as the water line is a line of constant elevation. A contour line is a line connecting points on the map which represent points on the surface of the ground having the same elevation. The elevation of the contour line is usually indicated by numbers on the contour line.

The following characteristics of contour lines are useful guides in drawing and interpreting maps:

1. Evenly spaced contours show a uniform slope.

2. The distance between contours indicates the steepness of the slope. Wide spacing denotes flat slopes; close spacing, steep slopes.

3. Contours which increase in elevation represent hills. Those which decrease in elevation portray valleys.

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[1]Adapted from "Agricultural Surveying for Soil and Water Conservation", by Wayne Clyma, Oklahoma State University, USAID Contract in Ethiopia, 1966.

[2]Agricultural Engineers, Colorado State University Water Management Research Project in Pakistan.

Contour elevations are shown at breaks in the contour to avoid confusion.

4. Irregular contours signify rough, rugged country.

5. Contour lines tend to parallel each other on uniform slopes.

6. Contours never meet except on a vertical surface such as a wall or cliff. They cannot cross except in the unusual case of an overhanging shelf. Knife-edge conditions are seldom found in natural formations.

7. Valleys are usually characterized by V-shaped contours, and ridges by U-shaped contours.

8. The V's formed by contours crossing a stream point upstream.

9. The U's made by contours crossing a ridge line point down the ridge.

10. All contour lines must close upon themselves either within or without the borders of the map.

Methods of Mapping

There are three methods of making topographic maps for agricultural engineering surveying. They are:

1. Grid Method

2. Angle and Stadia Method

3. Plane Table and Alidade Method (telescope alidade with stadia hairs)

The particular method used depends upon several factors. These are:

1. The use of the map.

2. The type of equipment available.

3. The kind of personnel available.

4. The topography of the land to be mapped.

5. The size of the area to be mapped.

The above three methods will be used for mapping in a laboratory exercise. Each will be discussed in detail in this

manual and the advantages and disadvantages of the particular method will be listed.

Another method of mapping in use that has potential agricultural application is aerial photography. The aerial photograph furnishes details of topography unavailable in other methods of mapping. In addition, by the use of stereoscopes, contours can be added to the aerial photograph with a minimum of field surveying for horizontal and vertical control. Aerial photographic mapping however is beyond the scope of this course.

The Grid Method

The grid method of topographic mapping has several advantages. It can be done with a farm level and steel tape, equipment which are readily available. It lends itself to topographic mapping of individual fields and farms where the ground surface is relatively flat. The amount of effort spent in the field doing the survey is about equal to the effort spent in the office preparing the map. The running of contour lines across very flat ground is difficult. Therefore, the taking of elevations at regularly spaced intervals should result in a better topographic map. The grid method is the most widely used method of surveying for land leveling since the relocation of each point is simple. This relocation of each point is essential to checking elevations as the leveling progresses.

Procedure for the Grid Method of Mapping

Where possible, the area to be mapped should have two sides that intersect at right angles (90°) with each other. This is particularly applicable to the uniform layout of the kila-bundi pattern of Pakistan. If this is not possible, then the diagonals and all four sides of the field need to be measured, or if the fields are irregular in shape a plane table survey of field boundaries is necessary before location of the grid points is possible. Two sides of the field can then be staked at regular intervals for the grid and the surveying done in the same manner as for two sides that intersect at 90 degrees.

After a preliminary survey of the area to be mapped, two sides are selected to establish the grid. Each side is then staked with tall stakes at regular intervals. The length of the interval depends upon the use of the map. General topographic maps are frequently staked at 25 or 30 meter intervals. Maps for land leveling design and computations are usually staked at 10 to 15 meter intervals.

One side of the area is then numbered at each stake location from 0 to the end of the stakes, Figure 7-1. The other

side is lettered at each stake location from A to the end of the stakes, Figure 7-1. The stakes used at each grid point should be a minimum of 1 meter high and 2 meters is preferred.

After the two sides have been staked, then two additional sides are staked. The stakes start at 1 and continue to the end of the lettered points. The other row starts at B and continues to the end of the numbered stakes. The rodman can then locate himself at any grid point by sighting along the four stakes that form the two lines that intersect at his particular grid point.

After 4 rows of stakes have been established at the grid points, then the elevation of each grid point is established by profile leveling. Each grid point is designated by the appropriate letter and number as shown in the sample notes in Figure 1. The survey is closed by returning to the BM after the elevation of each grid point has been determined. It is important that the arrangement of the grid be shown in the notes on the right side of the page. This will assure that the map is properly oriented when it is prepared in the office.

For watercourse survey purposes staking is not necessary. General watercourse surveys require the use of a one acre grid. For this purpose the approximate location of the center of an acre can be obtained visually or by pacing, but without taping or staking the location. The portable pucca turning point is merely used at this location to give a representative elevation for that acre. Surveying begins and ends at a bench-mark determined in initial bench mark survey of the water-course area.

For the detailed survey of sample farmers' fields, a more intensive data collection scheme is required. Four elevation determinations per irrigation unit (bunded unit) are required for this research purpose. Each acre will generally have 2 to 10 of these smallest irrigation units or bunded units. The intensity thus increases to 8 to 40 shots on a per acre basis, depending on the number of bunded units per acre.

Map Preparation

The topographic map is prepared from the field notes. A map prepared from the field notes shown in Figure 1 is shown in Figure 2. For relatively flat areas, a contour interval of 0.25 meters should be used. For a more rolling topography 0.50 meter or 1.00 meter intervals can be used. For water-course mapping a contour interval of 0.25 feet is required for general use. For land leveling design, a grid spacing of 50 feet is desirable on small leveling jobs and 100 feet is acceptable on large scale leveling jobs in Pakistan. The re-quired precision of leveling is ±0.05 foot (0.10 maximum

TOPOGRAPHIC LEVELING

No.	BS	HI	FS	Elev.
BM_1	1.20	101.20		100.00
A_0			2.21	98.99
A_1			2.47	98.73
A_2			2.11	99.09
A_3			1.38	99.82
B_3			1.44	99.76
B_2			1.86	99.34
B_1			2.08	99.14
B_0			2.21	98.99
C_0			2.09	99.11
C_1			2.00	99.20
C_2			1.65	99.55
C_3			1.25	99.95
C_4			0.53	100.67
D_4			0.53	100.67
D_3			1.06	100.14
D_2			1.27	99.93
D_1			1.77	99.43
D_0			1.85	99.35
E_0			1.44	99.76
E_1			1.04	100.16
E_2			0.90	100.30
E_3			0.60	100.60
E_4			0.26	100.94
TP_1	2.51	102.42	1.29	99.91
B_4			1.14	101.28
A_4			0.70	101.72
BM_1			2.44	99.98
BS = 3.71		FS =	3.73	100.00
Error of closure = FS - BS				
= 3.73 - 3.71				
= 0.02 0.02 Check				

Cloudy, windy Tewolde W.
August 19, 1965 Hailu S.

BM_1 - A point x, marked on the pole stand on the pole next to the bridge on the road to the Horticulture area about 4 meters from the road and 52 meters from the south west end of the bridge.

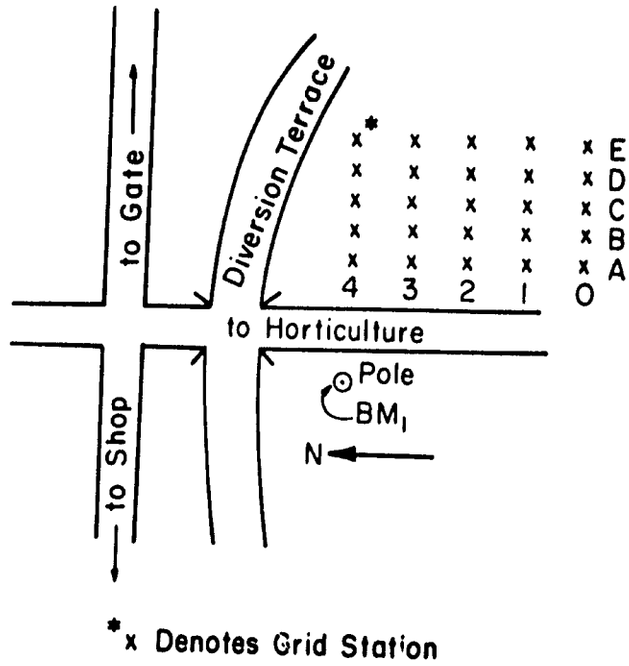
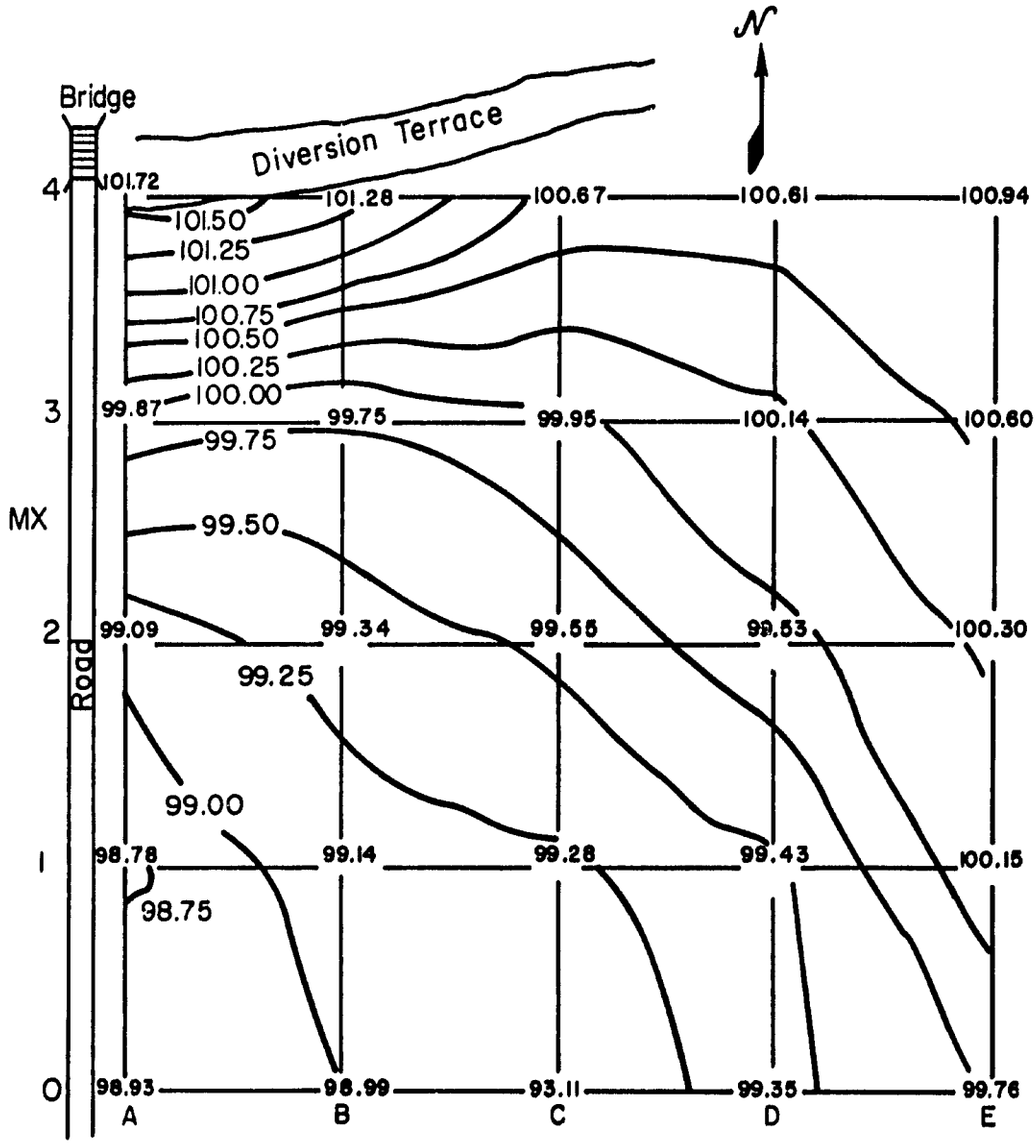


Figure 1. Field notes for topographic map using grid method of mapping.



TOPOGRAPHIC MAP
College Farm
Surveyed by Tewelderbrhan W.M. & Hailu S.
Date: August 19, 1965
Scale: 1:750
Plotted: by Hailu S.
Date: August 23, 1965

Figure 2. Topographic map from field notes in Figure 1.

difference across the irrigated unit). Thus if topographic maps are to be used for land leveling design work the contour interval should be a maximum of 0.05 feet, with 0.25 foot the preferred interval.

Note that certain information is included on the topographic map. A title, location of the mapped area, survey personnel, date of the survey, scale, person preparing the map, date of map preparation, legend, north arrow, and important natural and man-made topographic features should always be included on the map.

Maps are frequently prepared with one contour more heavily accentuated than the others. Notice in Figure 2 that the even meter contours, 99.00, 100.00, and 101.00, are more heavily accentuated. This is done to provide better contrast between the general relief and the detailed topography of the area.

The contours are entered on the map by placing a triangular scale or ruler between grid points of known elevation. The point of an even numbered contour is proportioned between the two known points, a procedure which assumes a uniform topography or slope in the vicinity.

Appendix 27

WELLS FOR SKIMMING FRESH WATER FROM AQUIFERS WITH SALINE WATERS AT GREATER DEPTHS[1]

D.B. McWhorter and W.D. Kemper[2]

ABSTRACT

As part of the water management research effort at Colorado State University, investigations into the design and operation of skimming wells have been conducted. Skimming well is the name given to a well especially designed for the purpose of exploiting the fresh water overlying more saline water in much of the Indus plain. The methods of research and some of the more practical results are described and discussed. Some preliminary results of field experiments are presented.

INTRODUCTION

Exploitation of ground water resources for agricultural, municipal and industrial uses is severely hampered in many regions of the world by the encroachment of saline water in response to fresh water withdrawals. Examples of salt water encroachment are most numerous in coastal aquifers, but a closely related problem sometimes occurs in inland aquifers as well. An important example of the latter case exists in the India-Pakistan subcontinent in the Indus River Basin where a highly valuable supply of relatively fresh ground water overlies an extensive body of more saline water in a deep alluvial aquifer. For example, in the Punjab and Bahawalpur areas of Pakistan, it is estimated that a shallow zone of relatively fresh water (less than 1000 ppm TDS) exists beneath 90 percent of the 28 million acres of irrigated lands (1). The thickness of the fresh water zone varies from 50 ft. to more than 500 feet.

The authors are not aware of the origin of the idea of "skimming" the fresh water zone through the use of wells designed especially for that purpose. The idea became known in Pakistan at least as early as the 1960's. Wang (7) reports on theoretical investigations into the performance

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[1]Presented at CENTO Panel Meeting on the Optimum Use of Water in Agriculture, Nuclear Institute for Agriculture and Biology, P.O. Box 128, Jhang Road, Lyallpur, March 3-5, 1975.

[2]Assistant Professor, Agricultural Engineering, Colorado State University, Fort Collins, Colorado and Chief of Party, Colorado State University Water Management Contract, Islamabad, Pakistan.

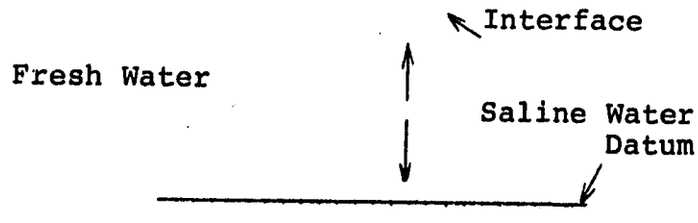
of skimming wells in 1965, and Schmorak and Mercado (5) conducted field investigations of the distribution of fresh and saline water beneath coastal collectors in 1969. Ahmad (1) discusses alternative methods for exploiting the fresh water zone in Pakistan in 1972. Various investigations into the design and operation of skimming wells have been in progress at Colorado State University since 1971.

The purpose of this paper is to report, in summary form, upon the Colorado State University skimming well research program. This research is a portion of a much broader water management research program being carried on in Pakistan and at the University. The first section is a brief review of some basic principles of flow in aquifers which contain both fresh and saline water. The remainder is a summary of the research that began with laboratory models and has progressed to field tests initiated in February, 1975.

INTERACTION OF FRESH AND SALINE GROUND WATER

The complexity of the phenomenon of flow of fresh water underlain by brine has led investigators to make numerous idealizations in attempts to reduce the mathematical description of the phenomenon to a tractable form. A very common practice is to regard the fresh water and brine as immiscible liquids with an abrupt interface between them. The pressure distribution on the interface is taken as being continuous so that the principles of continuum mechanics apply. More realistically, the aquifer can be regarded as containing a single non-homogeneous liquid, the density of which varies in space and time according to the distribution of total dissolved solids. This latter approach, while more rigorous, is much more complicated because the equations governing liquid flow and the distribution of salt are coupled and must be solved simultaneously. In any case, the interface idealization results in many useful insights and is, therefore, discussed below.

An interface between a fresh and saline zone is shown below:



The hydraulic head in the fresh and saline zones are given in equations 1 and 2 respectively:

$$H_f = P/\gamma_f + Z \tag{1}$$

$$H_s = P/\gamma_s + Z \tag{2}$$

where H is hydraulic head, P is pressure, γ is specific weight, and Z is the elevation above datum to the point in question. The elevation Z^i of the interface is given by

$$Z^i = \frac{\gamma s}{\Delta\gamma} H_s{}^i - \frac{\gamma f}{\Delta\gamma} H_f{}^i \tag{3}$$

where the superscript i denotes "on the interface" and $\Delta\gamma = \gamma_s - \gamma_f$. Equation 3, derived by solving (1) and (2) for pressure and equating at the interface, states that if the hydraulic heads in both the fresh and salt water zones are known at the interface, then the elevation of the interface can be computed. Unfortunately, determination of $H_s{}^i$ and $H_f{}^i$ as functions of space and time remains a formidable task.

The slope of the interface can be computed by differentiating equation 3 with respect to a coordinate ℓ, oriented tangent to the interface. Thus,

$$\frac{\gamma Z^i}{\gamma \ell} = \frac{\gamma s}{\Delta\gamma} \frac{\gamma H_s{}^i}{\gamma \ell} - \frac{\gamma f}{\Delta\gamma} \frac{\gamma H_f{}^i}{\gamma \ell} \tag{4}$$

Since the velocity in the fresh water and the velocity in the salt water at the interface are proportional to $\gamma H_f{}^i/\gamma\ell$ and $\gamma H_s{}^i/\gamma\ell$, respectively equation 4 predicts that the slope of the interface depends upon these velocities. Furthermore, the velocity in the fresh water and salt water zones at the interface may be distinctly different in magnitude and direction. In other words, there can exist a discontinuity in velocity in the ground water aquifer within the framework of this analysis. This is an important point, because it follows that there can exist situations in which the salt water zone is static (i.e. H_s = constant everywhere), even with flow in the fresh water zone. These situations are of particular importance in the context of this paper, because the implication is that fresh water can be withdrawn from atop a static and stable body of saline water, leaving the undesirable water largely undisturbed.

It remains to investigate the orientation of the interface for cases in which the salt water is static. However, Equation 4 reduces to:

$$\frac{\gamma Z^i}{\gamma \ell} = - \frac{\gamma f}{\Delta\gamma} \frac{\gamma H_f{}^i}{\gamma \ell} \tag{5}$$

for static salt water, which shows that the slope of the interface is upward in the direction of decreasing hydraulic head. In other words, the interface slopes upward in the direction of flow. Furthermore, the slope of the interface is very large compared to $\gamma H_f{}^i/\gamma\ell$ because $\Delta\gamma$ is a small number. A simple integration of equation 5 over γ yields:

$$\Delta Z^i = \frac{-\gamma f}{\Delta\gamma} \Delta H_f{}^i \tag{6}$$

where the ΔZ^i is a change in interface elevation and $\Delta H_f{}^i$ is a change in hydraulic head on the interface. Equation 6 is of the same form as the famous Ghyben-Herzburg equation, but there is an important difference. The Ghyben-Herzburg equation is obtained from equation 6 only if $\Delta H_f{}^i$ is identical to a change in water table elevation, a condition that does not exist except in the trivial case of a horizontal interface with no flow. $\Delta H_f{}^i$ may be approximated by a change in water table elevation, provided the flow remains approximately horizontal.

The foregoing theory has led to the conclusion that it is possible to withdraw water from the fresh water zone above a static and stable interface which will slope upward very rapidly in the direction of flow. The conditions under which this may be accomplished have not been elucidated, however. Note that the left hand side of equation 5 is the sine of the angle θ which the interface forms with the horizontal. Thus, equation 5 may be rewritten as:

$$\frac{\gamma H_f{}^i}{\gamma\ell} = -\frac{\Delta\gamma}{\gamma} \operatorname{Sin}\theta \tag{7}$$

Equation 7 is not satisfied except for:

$$\left|\frac{\gamma H_f{}^i}{\gamma\ell}\right| \leq \frac{\Delta\gamma}{\gamma f} \tag{8}$$

where $|\gamma H_f{}^i/\gamma\ell|$ is the absolute value of the gradient of hydraulic head. Relation 8 follows from the fact that $\sin\theta$ has a maximum value of unity. Thus, equation 8 becomes the condition that must be satisfied in order to withdraw water from the fresh water zone above a static salt water zone. Unfortunately, relation 8 is highly restrictive because it requires that the gradient causing flow in the fresh water zone be very small. This, of course, means small discharge rates.

The treatment of the phenomenon as flow of a single nonhomogeneous liquid is much more complex and will not be dealt with in detail here. This treatment leads to one conclusion that is an important contrast to that derived from the interface approach, however. The treatment of the ground

water as a single non-homogeneous liquid requires that there be no discontinuities in velocity anywhere within the boundaries of the flow field. Any such discontinuity would be in violation of the principles of continuum mechanics. From a practical standpoint, this conclusion means that it is not possible to withdraw fresh water from atop a completely static saline zone. In other words, pumping from the fresh water zone results in a velocity distribution in the saline zone not simply an upconing of the saline zone toward the pumping site. The fact that the salt water is more dense than the overlying fresh water tends to reduce the upward velocity in the saline zone, however, and the saline zone will be, relatively, more stagnant than the fresh water zone. Thus, the interface treatment is not a completely unrealistic approach.

LABORATORY INVESTIGATIONS

Wang (7) published a theoretical paper concerning skimming well design for Pakistan in 1965. Colorado State University undertook a laboratory investigation with the intent to compare the Wang theory with experimental results. This work is reported in detail by Sahni (4). Sahni used 2.5 mm diameter glass beads in a 15 degree radial flow model. The radial dimension of the model was 4 feet with vertical walls 2 feet high. The scale of the model required that two liquids with a large density difference be used (note from equation 6 that the interface elevation is inversely proportional to the difference in density). A petroleum core-test liquid with a density of 0.75 gm/cm^3 and a viscosity of 1.4 centi-poise was used to simulate the fresh water. The heavier saline water was simulated by ordinary tap water. A coloring solution was added to the tap water so that the interface was clearly visible through the plexiglass walls of the model. A reservoir containing both the core-test liquid and water provided a constant head in both fluids at the wide end of the pie shaped model.

A partially penetrating well was simulated by inserting a cylindrical screen into the glass beads at the point of the model. The core-test liquid was pumped from inside the screen at a constant rate until the drawdown in the simulated well and the upconing of the water stabilized. The discharge rate and the elevations of the simulated water table and of the upconed interface were measured. The experiment was repeated with successively higher pumping rates until the condition given in relation 8 was not satisfied. The largest pumping rate at which relation 8 was satisfied was designated as the "critical discharge". Pumping rates greater than the critical value produced an unstable interface which was apparent as a nearly vertical spout of the underlying water into the simulated well.

The laboratory work verified the theoretical concepts outlined previously in this paper, concerning the interface behaviour. It was concluded that the simplified analysis of Wang (7), based on the Ghyben-Herzberg equation was inadequate. Thus, mathematical studies of the flow problem were initiated. It should be pointed out here, that the two fluids used in the experiment were immiscible and, therefore, the concepts of an interface and a discontinuity of velocity apply to a high degree of approximation.

MATHEMATICAL INVESTIGATIONS

Sahni (4) developed a mathematical model based on the interface concept. His model applied only to a homogeneous and isotropic aquifer, however. Chandler and McWhorter (3) constructed a more general model, capable of handling cases in which the permeability in the vertical direction differs from that in the horizontal direction. The results of this latter model are discussed here.

Chandler and McWhorter (3) developed a solution to the steady flow equation:

$$\frac{K_r}{r}\frac{\gamma}{\gamma r}\left(r\frac{\gamma H}{\gamma r}\right) + K_z\frac{\gamma^2 H_2}{\gamma Z^2} = 0 \qquad (9)$$

where

H = hydraulic head (L)
K_r = permeability in the horizontal direction (L/T)
K_z = permeability in the vertical direction (L/T)
r = radial coordinate measured from the well axis (L)
Z = vertical coordinate measured positive upward from the original interface elevation (L)

the boundary conditions are shown schematically in Figure 1.

Optimum Well Penetration

The maximum critical discharge that can be obtained without violating condition 8 depends upon the fraction of the fresh water layer penetrated by the well. It is desirable to determine the degree of penetration which permits the maximum critical pumping rate. The critical discharge is shown as a function of well peretration in Figure 2 for an isotropic aquifer and for three anisotropic aquifers. The results are presented in dimensionless form for convenience and maximum generality. The definitions of the dimensionless critical discharge and well penetration are:

$$\hat{Q}_c = \frac{\gamma f Q_c}{\Delta\gamma H_e^2 K_r} \qquad (10)$$

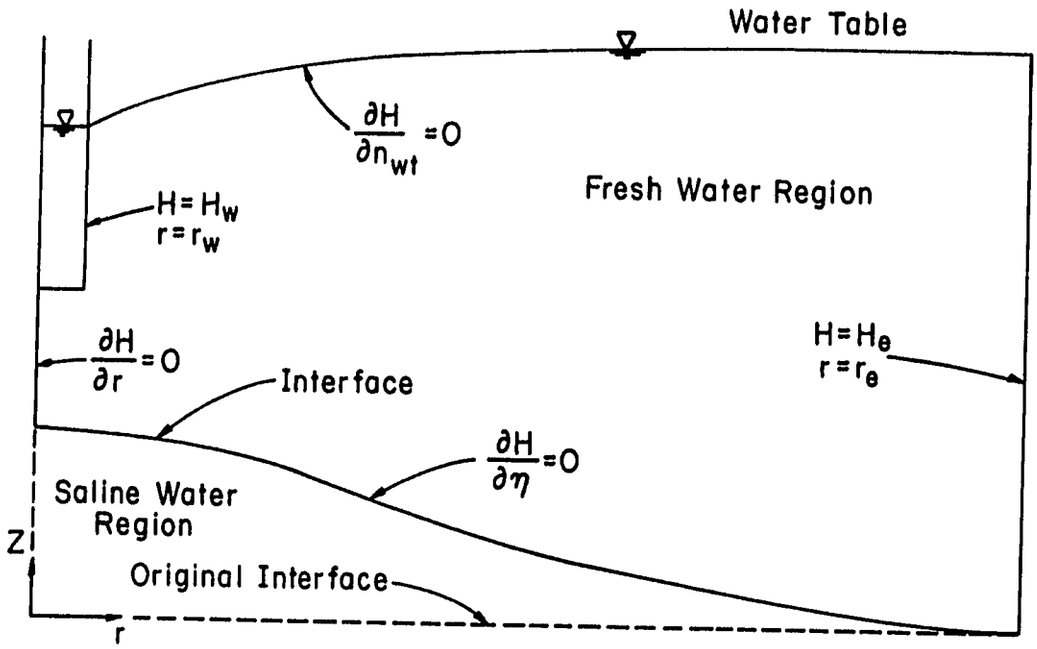


Figure 1. Schematic of interface upconing toward a pumping well.

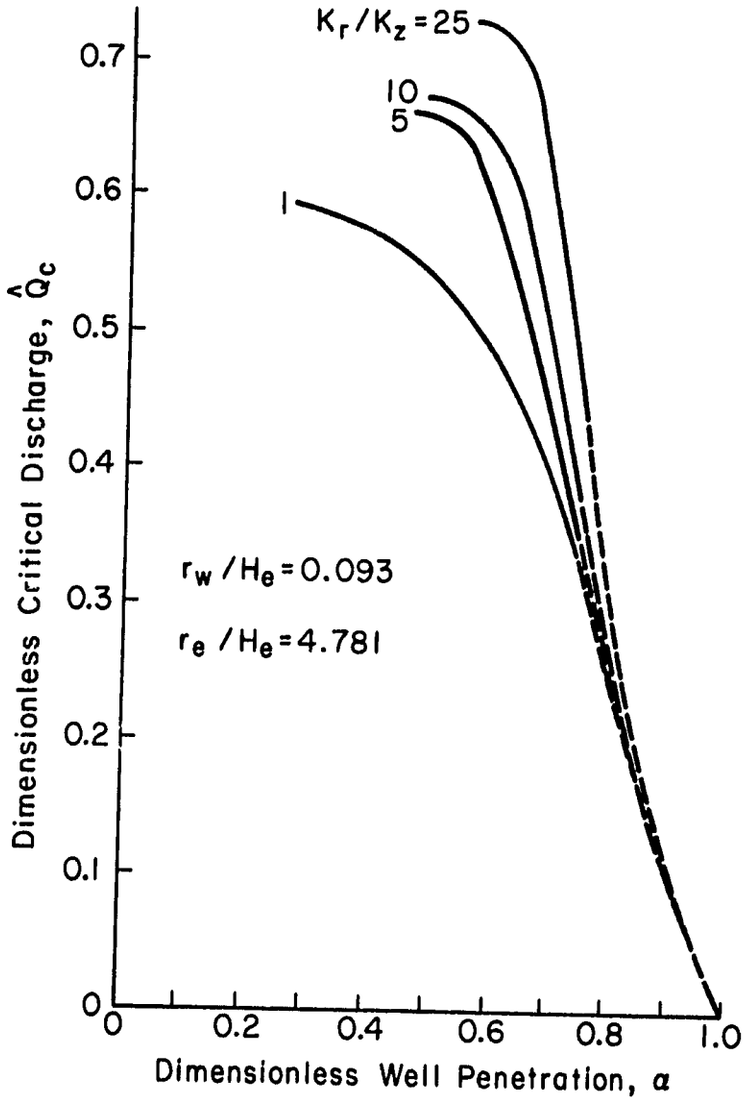


Figure 2. The effect of permeability ratio and well penetration on critical discharge.

and

$$\gamma = dw/H_e \tag{11}$$

respectively, where Q_c is the critical well discharge, d_w is the depth of the well below the undisturbed water table, H_e is the undisturbed fresh water thickness and other symbols are as previously defined.

The critical discharge is low, for all cases, when the well penetration is to a point near the undisturbed interface because the interface must rise only a short distance to reach the critical elevation. The end points of the curves in Figure 2 show that the optimum penetration increases with increasing ratios of horizontal to vertical permeability. The major practical conclusion is that, the well penetration should be only about 30 percent of the fresh water thickness for isotropic aquifers and no more than 60 percent in aquifers with a vertical permeability much lower than the horizontal permeability.

Critical Discharge

The relationship between well discharge and interface elevation immediately beneath the well was also investigated. The results are shown in Figure 3. The dimensionless interface elevation is defined as:

$$\hat{z}^i = \frac{\gamma f}{\Delta\gamma} \frac{z^i}{H_e} \tag{12}$$

The end points of the curves in Figure 3 represent the critical discharge and interface elevation. Of practical interest is the observation that the discharge is greater for the anisotropic than for the isotropic aquifer with the same interface elevation. Furthermore, the critical discharge is greater for the anisotropic cases than for the isotropic case.

DESIGN AND OPERATING CRITERIA

An example computation will serve to show the manner in which the foregoing results may be used to make decisions concerning the desired well depth and discharge. Suppose, from a field investigation, or from published data, that the following information is obtained.

H_e = fresh water thickness = 84 ft.

$K_r = 3.0 \times 10^{-3}$ ft/sec

$K_z = 3.0 \times 10^{-4}$ ft/sec

$\Delta\gamma \approx 0.02$ gm/cm^3

$\gamma_f \approx 1.0$ gm/cm^3

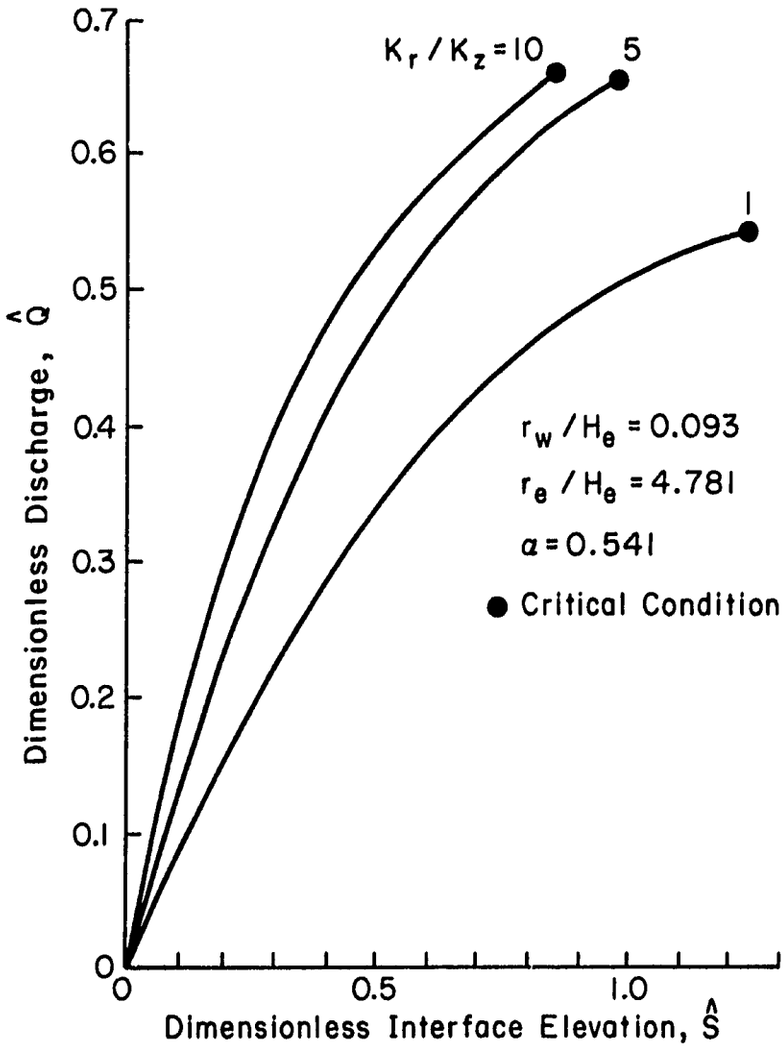


Figure 3. The relationship between discharge and interface elevation.

From these data, the permeability ratio is determined to be 10. From Figure 2, using the appropriate curve, the optimum well penetration is found to be about 50 percent, and the dimensionless critical discharge is 0.68. Thus, from equations 10 and 11:

$$\frac{\gamma f}{\Delta\gamma} \frac{Qc}{H_e^2 K_r} = 0.68$$

$$\frac{dw}{H_e} = 0.5$$

The optimum well depth, below the water table, becomes:

$$dw = 0.5\ (84) = 42 \text{ ft.}$$

and the critical discharge:

$$Q_c = (0,68)\ \frac{(0.02)}{1}\ (84)^2 (3.0\text{x}10^{-3})$$
$$\approx 0.30 \text{ cusecs}$$

It is observed that the critical discharge is very low, compared to the discharges normally experienced in Pakistan. All of the studies conducted at Colorado State University, as well as those by Wang (7) and others indicate that low well discharges are required to help prevent the upconing intrusion of the saline water into the well.

The above theory and computations do not permit one to predict the degradation of water quality that would result from pumping the well at a discharge greater than the critical value. Shariatmader and McWhorter (6) treated the problem as one of flow of a single non-homogeneous liquid which enabled them to predict the dissolved solids concentration as a function of time and flow rate. Their prediction of the salt concentration in the well discharge is shown in Figure 4 as a function of time for a particular case, in which, the initial salt content increased gradually from 1000 ppm to 8000 ppm. Even with a gradual increase of salinity with depth, the low discharge resulted in significantly lower salt content in the discharge. The difference in salt content between low and high discharges is even more marked for cases in which the initial distribution of salinity exhibits a more abrupt change. These results, again, point toward low-discharge wells.

FIELD TESTS

The question might well be asked, "How does the foregoing theory and computations relate to what really happens in the field?" Schmorak and Mercado (5) found the interface (defined by the location of the arithmetic average concentration)

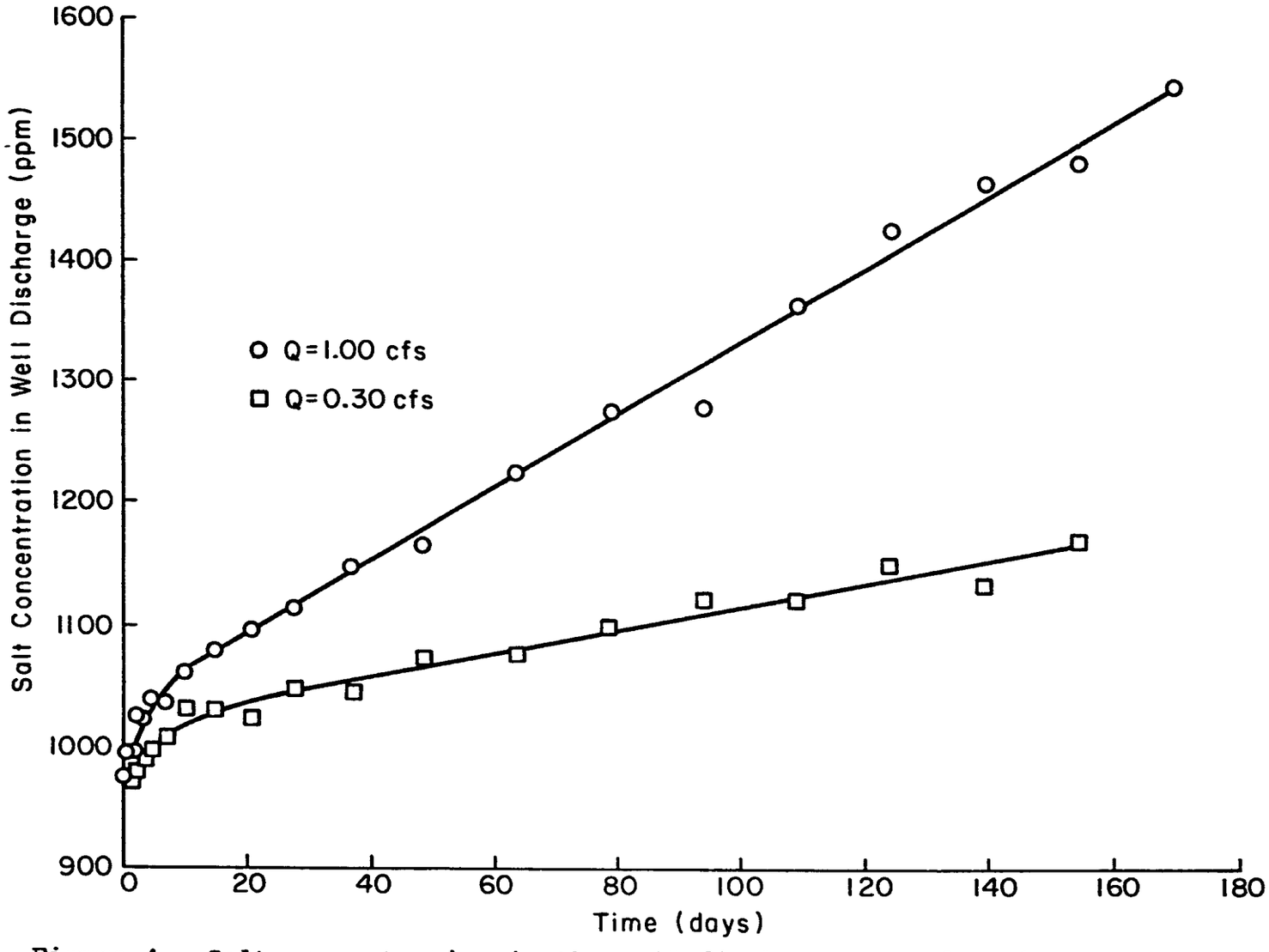


Figure 4. Salt concentration in the well discharge as a function of time.

behaved substantially as predicted from the equations of Bear and Dagan (2). These equations were based on the same concepts as discussed previously in this paper. The conditions, under which their equation apply, are not of practical interest in Pakistan, however. Nevertheless, their reported success lends credence to the work reported herein.

A small tubewell, located on the Phularwan Research Farm (a part of the Mona Reclamation area), was constructed to a depth of 105 ft, during 1974. The discharge from this well contained 2300 ppm dissolved solids with an SAR of about 14. Use of water from this well had been discontinued for about two months becuase of the high salinity. An investigation disclosed the salinity profile presented in Table 1.

Table 1. Salinity Profile in Mona Well on Phularwan Farm

Depth ft.	Elec. Cond. MMOHS/CM
13-23	2.10
23-33	1.96
33-43	1.75
43-53	1.47
53-63	1.30
63-73	1.20
73-83	1.20
83-93	1.96
93-103	3.75

These data indicate a relatively fresh water zone (≈ 800 ppm) above a more saline zone (greater than 2500 ppm) with a transition zone located below about 90 feet. Water from a nearby hand pump indicated that the relatively high conductivities measured in the first 40 feet of the well casing resulted from more saline water pumped from below during the last period of pump operation. Since, the top 30 feet of the well was cased with blind pipe, water in this section would come to equilibrium with the natural ground water salt content very slowly.

Based on the above observations, it was recommended that the tubewell be modified by blocking off the bottom 45 feet with sand and a concrete plug. This was accomplished, leaving the well with blank casing from the surface to about 30 feet and well strainer from 30 to 60 feet. A flange with a small orifice was inserted in the discharge pipe which decreased the pumping rate to 0.3 cusecs from the original 0.9

cusecs. These modifications are believed to have resulted in the marked improvement in the pumped water as indicated in Table 2.

Table 2. Salinity in Discharge - Mona Well on Phularwan Farm

Time of Pumping	TDS (ppm)	SAR	Pumping Rate (cusecs)
Prior to modification	2300	14	0.9
Following modification			
1 min. of pumping	830	3.6	0.3
20 min. of pumping	850	3.6	0.3
160 min. of pumping	770	3.3	0.3
One month later			
4 hours of pumping	830		0.3

The above results are encouraging because they seem to indicate the effectiveness of skimming wells. A much more thorough test is required, however, and we are in the process of conducting a field experiment. The location of the field test is the Phularwan Farm where two pumped wells and 16 observations wells have been constructed. The layout of the wells is shown in Figure 5. One of the wells is a large diameter dug well and the second is a normal tubewell in all respects except the depth. The depth was determined according to the skimming well theory presented in this paper.

The initial distribution of dissolved solids, as indicated by electrical conductivity, is shown in Figure 6. These data were collected from the eight observation wells located near the tubewell, by dropping an electrical conductivity probe into the wells on a water proof conducting cable. The conductivity is determined from a resistance bridge on the surface.

Pumping has not been initiated at the time of this writing. Our plans are to pump the wells in a series of successively increasing pumping rates, while monitoring the distribution of salinity in the observation wells. The discharge rate and the salt content of the discharge will also be monitored. These observations will be used to verify or, if necessary, modify our theoretical calculations. A substantial portion of the data should be available by mid-summer.

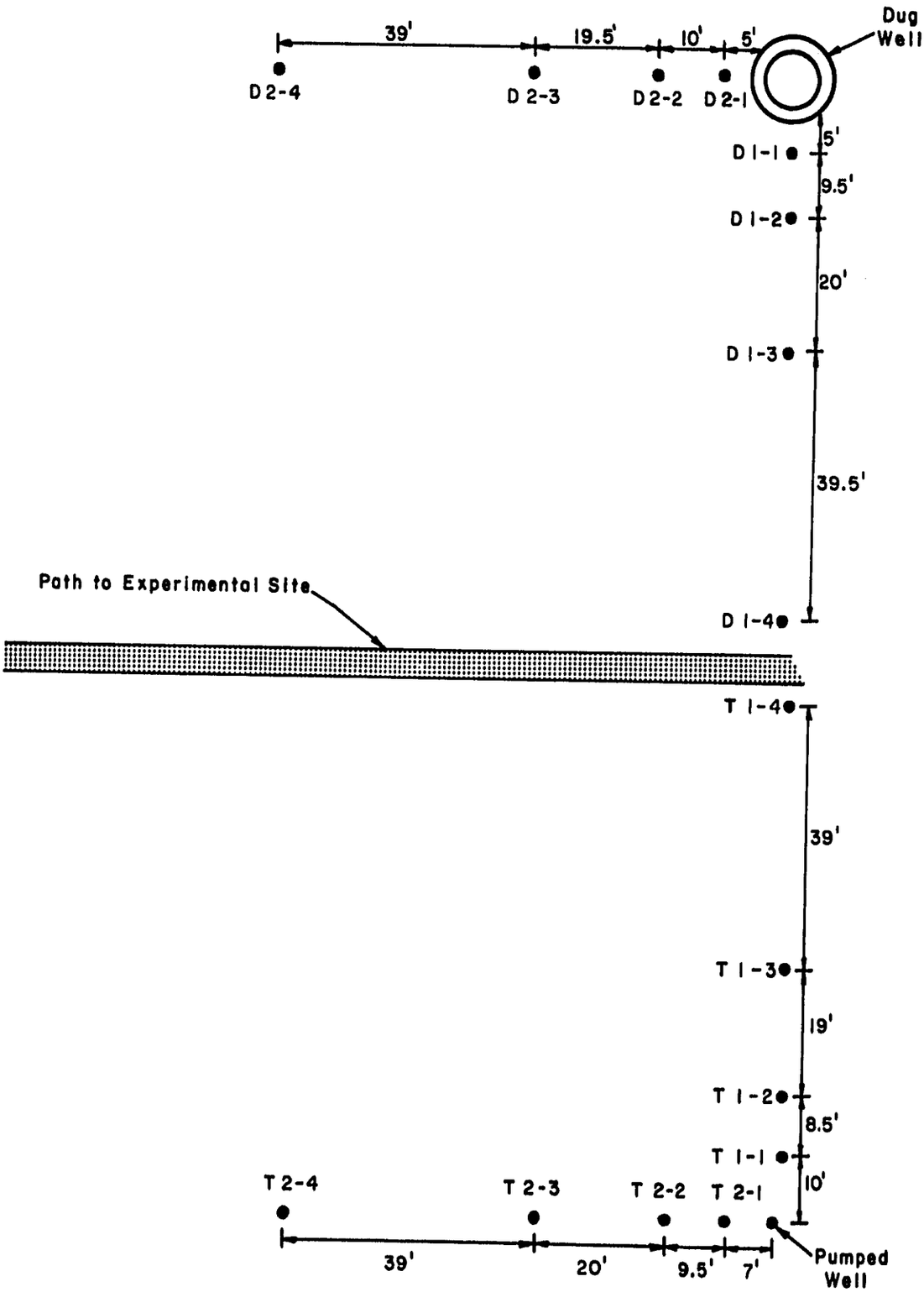


Figure 5. Layout of skimming well site.

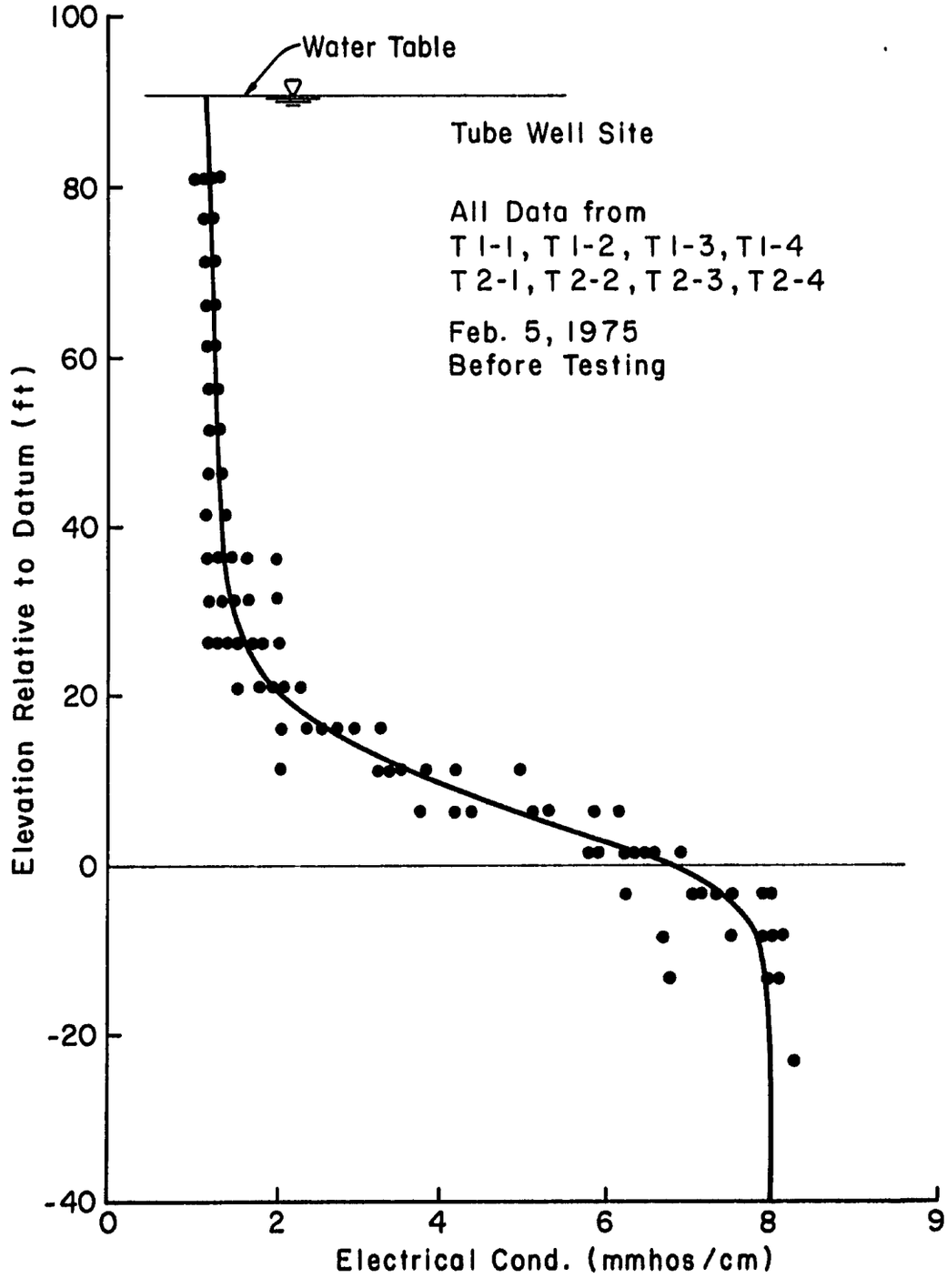


Figure 6. Salinity profile at skimming well test site.

References Cited

1. Ahmad, N., 1972. A few suggestions to conserve flood run-off and to recover fresh water from saline water zones of the Indus Plains. Proceedings of the W. Pakistan Engineering Congress, Vol. 53, pp. 133-190.

2. Bear, J. and Daga, G. 1968. Solving the problem of local interface upconing in a coastal aquifer by the method of small perturbations. Journal of Hydraulic Research, V. 1, pp. 15-44.

3. Chandler, R.L. and McWhorter, D.B. 1975. Interface upconing beneath a pumping well. Ground Water, July - August issue.

4. Sahni, B.M., 1972. Salt water coning beneath fresh water wells. Water Management Tech. Rep. No. 18, Colorado State University, Fort Collins, Colorado.

5. Schmorak, S. and Mercado, A. 1969. Upconing of the fresh sea water interface below pumping wells, field study. Water Resources Research, V. 5, No. 6, pp. 1290-1311.

6. Shariatmader, M. and McWhorter, D.B. 1975. Transient Flow of Non-homogeneous Fluids to Wells. Water Resources Research (In press).

7. Wang, F.C. 1965. Approximate theory for skimming well formulation in the Indus Plain of West Pakistan. Journal of Geophysical Research, V. 70, No. 20, pp 5055-5063.

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Appreciation is expressed for the cooperation of personnel of the Mona Reclamation Project in the experimental phases of this project. In particular Chaudhry Abdul Hamid, Executive Engineer, supervised the modification of the old well which improved the quality of its water, Moh'd Abdul Qayyum supervised analysis of the quality of the water and Mian Moh'd Ashraf, Project Director, has given encouragement and guidance to this project from its beginning.

Mr. Michael Viola of CARE Pakistan has halped organize the experimental portion of this project in Pakistan with USAID funding.

Republic Engineering has served as general consultants and Builders Associates have installed the experimental wells. Their expertise in drilling, construction and analysis has been of great help in locating an ideal site for testing and providing the physical facility necessary for precision tests.

APPENDIX 28

WATER SUPPLY FOR IRRIGATION ON ANDROS ISLAND, BAHAMAS

by

David B. McWhorter

Fresh-water supplies in continental coastal areas and on islands often exist above a body of saline water. In some instances, fresh water is found above saline water in inland aquifers as well. An important case in point is the great alluvial aquifer in the Indus River Basin in Pakistan. The author of this report has been conducting research into methods by which the fresh-water layer in Pakistan can be exploited for irrigation. A portion of the experience gained there is transferable to problems with coastal and island aquifers. Therefore, the author was asked to spend a week on Andros Island, Bahamas where the Bahamas Agricultural Research, Training, and Development Project is located. Since the purpose of the trip was to exchange experiences and knowledge, hopefully with benefits accruing to both the author and project personnel, both the Western Institute for Science and Technology and the Water Management Research Project at Colorado State University contributed financially. This document, therefore, is a report of activities to both sponsoring institutions. As such, material is included which may be considered irrelevant by one group in the light of their knowledge base but, simultaneously, considered informative by the other.

General Characteristics of Andros Island

Andros is the largest island in the Bahamas with an area of about 2200 square miles. The island is composed of carbonate sediments (limestone) that were probably formed during the Pliestocene (i.e., the Ice Age). Solution of the limestone by rain and sea waters have produced a classical karst topography, which is quite flat in overview, but contains numerous sink holes and solution channels on a smaller scale.

Precipitation on Andros, in the vicinity of the project area, is 45-50 inches annually. A dry season exists from about November to May or June, during which very little rain is received. During the winter months, daily high temperatures are in the seventies and lows range downward toward 50°F. The potential for year-around cropping exists, with irrigation in the dry season. There is essentially zero surface-water runoff from the island. Infiltration capacity is high and sufficient to accomodate very intense rainfalls. Approximately 33 inches of the annual precipitation are evaporated and

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[1]Agricultural Engineer, CSU.

transpired back to the atmosphere in the natural condition. The remaining 12 inches recharge the groundwater reservoir.

Fresh ground water is stored in a large, floating body of fresh water, separated from the underlying saline water by a sharp transition from fresh to saline water. The elevations of the water table above the mean sea level range from less than one foot to more than two feet in the interior of the island. The corresponding thicknesses of the fresh-water body are 35 to more than 80 feet. In the Bahamas Agricultural Research, Training and Development Project (BARTAD) area, the interface between the fresh and saline waters ranges from 40 to 50 feet below land surface and the water table is some 4 feet below the ground.

Over the years, a dynamic equilibrium has been established in which the 12 inches of annual groundwater recharge are discharged to the sea on the boundaries of the island. This water is being wasted in the sense that no significant portion is being used for domestic, municipal, industrial, or agricultural purpose. On the other hand, it is the seaward gradient (or flow) of the fresh water that is responsible for excluding sea water from the portion of the aquifer now occupied by fresh water. Total consumptive use of the 12 inches of excess water would result in complete elimination of the fresh groundwater reservoir that now exists. Even a partial consumptive use of the excess will result in a reduction of fresh groundwater storage and the establishment of a new dynamic equilibrium. A more detailed discussion of these aspects are presented subsequently.

The groundwater aquifer, being composed of a highly solution channeled limestone, is very, very permeable. Specific capacities of wells, no more than 35 feet deep, range upward of 2,000 gpm per ft of drawdown. The wells are drilled either by reverse rotary or percussion and are left uncased except for a short surface casing. In the BARTAD Project area, the typical well is 35 feet in depth and is pumped for periods up to one hour at approximately 500 gpm. Pump tests on wells less than 22 feet in depth have a low specific capacity relative to the same well when deepened beyond 22 feet. Apparently, a significant increase in permeability exists below the 22 foot level. Drillers report a hard layer at about 22 feet which is believed to be an erosional unconformity produced during one of the periods of glaciation in the Pliestocene when sea level was reduced. Subsequent rise of sea level deposited additional carbonate sediments on the old erosional surface and zone of soil development. Recrystallization has resulted in a more dense, crusty layer, at the unconformity.

Other stratagraphic horizons are known to exist in the limestone aquifer. These observations, together with well documented effects of barometric fluctuations, point toward a partially confined aquifer. The storage coefficient or

specific yield is generally regarded as being about 20-30 percent, nevertheless. Tidal fluctuations, extremely high transmissibities, and solution-channel permeability make it very difficult to establish aquifer properties by normal aquifer test procedures. A cone of drawdown, in the usual sense at least, is not observed, and the equilibrium drawdown associated with any particular pumping rate is established almost immediately in the pumped well.

Objectives of Report

After a site inspection, discussions with Mr. Bill Elliot (Agricultural Engineer) and a study of some data and background material, it became possible to formulate two relatively specific objectives to which this report is addressed. The first objective identified was to comment on the advisability of pumping the irrigation wells, with a depth of 35 feet, at a rate of 500 gpm. This pumping procedure has not, apparently, caused significant upconing of saline water. The second objective is to comment on the over-all water-management picture for the project and to suggest a monitoring scheme from which the behavior of the system can be deduced.

The Water Budget

A great deal can often be learned about groundwater supply by formulating a water budget. In the simplest form, the water budget is nothing more than an accounting of all water that enters and leaves the system and the corresponding changes in storage. On the assumption that annual volumes are of interest, the gross water budget can be written:

$$\text{Inflow} - \text{Outflow} = \text{Change in Storage},$$

where it is understood that annual volumes of inflow, outflow and storage are being considered.

Inflow to the groundwater system on Andros results entirely from precipitation under natural conditions. Outflows include evaporation, transpiration, seepage to the sea, and small withdrawals for domestic and agricultural purposes. At the present time, evapotranspiration by natural vegetation and seepage to the sea completely dominate the small quantities used by the limited population. It may safely be assumed that a dynamic equilibrium now exists in which inflow equals outflow on an annual basis. This means, of course, there is no change in storage. By this method, it has been estimated that the seepage to the sea on Andros is about 12 inches, and evapotranspiration (ET) is about 33 inches annually.

Groundwater recharge has developed a number of lenses containing fresh water that float on the underlying sea water. Because the density of the fresh water is only slightly less

than sea water, the greater part of the fresh water body is below sea level, in much the same way as the large fraction of an iceberg exists below the water surface. The volume of fresh water contained in a lens depends upon the distance from the lens to the point of discharge to the sea, the permeability of the aquifer, and the rate of recharge. Other things being equal, the thickness of the lens is reduced when the rate of recharge is reduced.

Development of an irrigated agriculture on Andros will most certainly disturb the natural dynamic equilibrium. For the purposes of this very preliminary investigation, it can be assumed that the potential evapotranspiration of agricultural crops on Andros is approximately 50 inches annually (year around cropping assumed). A potential ET of 50 inches is 71 percent of the pan evaporation measured at the BARTAD Project by Mr. William Elliot. Before clearing, cropping, and irrigating, the natural ET was about 33 inches. Thus, the development of agriculture will increase ET by about 17 inches on the developed land area. Water for the increased ET demand must, necessarily, come from the groundwater. Not only will 12 inches of recharge (that presently exists) be used but an additional net withdrawal of 5 inches must be made.

It is clear that, should the developed land eventually include all the land above the lens, the water stored in the lens would be depleted and there would no longer be an adequate water supply. On the other hand, developing only a fraction of the land surface above the lens insures that the remaining portion will continue to contribute 12 inches of water to the groundwater reservoir, annually. Lateral inflow from the undeveloped lands to the aquifer beneath the developed lands can provide the required water. Provided that the volume of recharge beneath the undeveloped land is greater than the withdrawal from the agricultural land, a new dynamic equilibrium will eventually be established, and the water supply will last indefinitely.

Unfortunately, simply insuring that a new dynamic equilibrium be established is not sufficient. This is true because the thickness of the fresh-water lens depends upon the rate of recharge. The thickness of the lens, under the new dynamic equilibrium, must be sufficient to accomodate wells that can be pumped at a satisfactory rate with adequate water quality. A satisfactory pumping rate and adequate water quality are two important factors that must be considered in the determination of safe yield from the aquifer.

Safe Yield

The current procedure in the BARTAD Project is to dig wells on an approximate 200 foot square grid, resulting in a well on every acre, approximately. A portable pump and sprinkler irrigation system is moved from well to well as required

to provide irrigation water. Apparently, it has been determined that digging a well on every acre is less expensive than using a small number of supply wells with an extensive distribution system. Technical considerations also favor a large number of wells, each of which produce small total volumes, rather than a centralized system in which large volumes are removed from a limited number of wells. This is true because of the tendency of the salt-fresh water interface to upcone beneath the pumped wells. Upconing is minimized by extracting small volumes from many points versus extracting the same total volume from a few wells.

Mr. Elliot's experience on the project area indicates that wells capable of producing 500 gpm are required to operate the irrigation system satisfactorily. He has found that wells penetrating below a depth of approximately 22 feet have a significantly higher specific capacity than those that are less than 22 feet deep. As a practical matter, it is apparent that wells should be at least 27 feet deep, and possibly somewhat deeper. Rough estimates of potential evapotranspiration indicate that each well will be required to pump 500 gpm for about 1 hour at each irrigation. Thus, the total volume of water removed at each irrigation is about 4000 ft^3.

The extent of interface upconing in response to the above withdrawals can be estimated by assuming that the entire volume of fresh water is displaced by the upconed interface. The elevation z of the interface above its original position (before pumping) is assumed to be described by the equation

$$z = - c \ \ell n \ r/r_e \quad ,$$

where c is a constant that must be determined, r is the radial coordinate measured from the well center, and r_e is maximum radius of influence of the well. The total volume of fresh water displaced by the upconing is

$$v = - 2\pi c \ s_y \int_{r_w}^{r_e} r \ \ell n \ r/r_e \ dr$$

or

$$v = -\pi c \ s_y \{r_w^2 \ \ell n \ r_e/r_w + r_w^2/2 - r_e^2/2\} \quad ,$$

where r_w is the well radius, and s_y is the effective porosity of the aquifer.

Assuming that r_e=100 feet , r_w=1 foot , s_y=0.2 , and v=4,000 ft^3 , the constant c is computed to be 1.28 feet. The maximum elevation of the cone beneath the well becomes

$$z_{max} = 1.28 \ \ell n \ 100 \simeq 6 \text{ feet} \quad .$$

This calculation indicates that very little salt-water entrain-

ment is to be expected in a well from which 4,000 ft^3 of water are withdrawn, provided the bottom of the well is at least 6 feet above the undisturbed interface. Successive one hour pumping periods at 4 or 5 day intervals are likely to keep the interface from falling back to its undisturbed position after each pumping period, however. Thus, a gradual increase in salinity in the pump discharge is likely to be observed during the irrigation season. Such an increase has, in fact, been observed in wells terminating as much as 10 feet above the original interface in the BARTAD Project.

The upconing of the interface beneath the pumping wells is a local transient perturbation, superimposed on the regional rise of the interface caused by a reduction of groundwater recharge. Thus, the regional interface elevation, under the conditions of the new dynamic equilibrium, should be maintained at least 8-10 feet below the bottom of the wells. If the minimum practical depth of the wells is 27 feet, then the minimum regional interface depth should be maintained at 35 feet. This depth is approximately 30 feet below mean sea level. Even at this elevation, some increase in pumped water salinity should be anticipated.

The maximum safe interface elevation of 30 feet below mean sea level, determined above, is now used to compute the maximum safe increase in consumptive water use that can be tolerated. As mentioned previously, the maximum safe yield is a function of the fraction of the total land overlying a fresh-water lens that is developed. The maximum safe yield from a small developed land area is much higher than from a large development because there is a greater lateral flow of groundwater in the former case. Lateral inflow to the aquifer beneath the developed property is undoubtedly multi-dimensional. Lateral inflow can be expected to be approximately radial in the case of a small developed area over a lens whose width and length are approximately equal. If the lens is in the form of long narrow trough, the lateral inflow to the developed area may be more nearly confined to directions normal to the long axis of the lens.

Equations for the maximum safe increase in consumptive use as a function of the ratio of developed area to the total land area over a lens are derived in the Appendix to this report. Both radial and one-dimensional lateral flow were considered. The results of numerical computations are shown in Figure 1. The vertical axis represents the maximum safe <u>increase</u> in annual consumptive use over and above the 33 inches presently being used by native vegetation. The horizontal axis is the ratio of developed area A_i to the total area above the lens A_t.

The relationship between the maximum safe increase in consumptive use and the fraction of the total area that is developed for the BARTAD area should be between the two curves shown in Figure 1. Note that the effect of geometry on safe

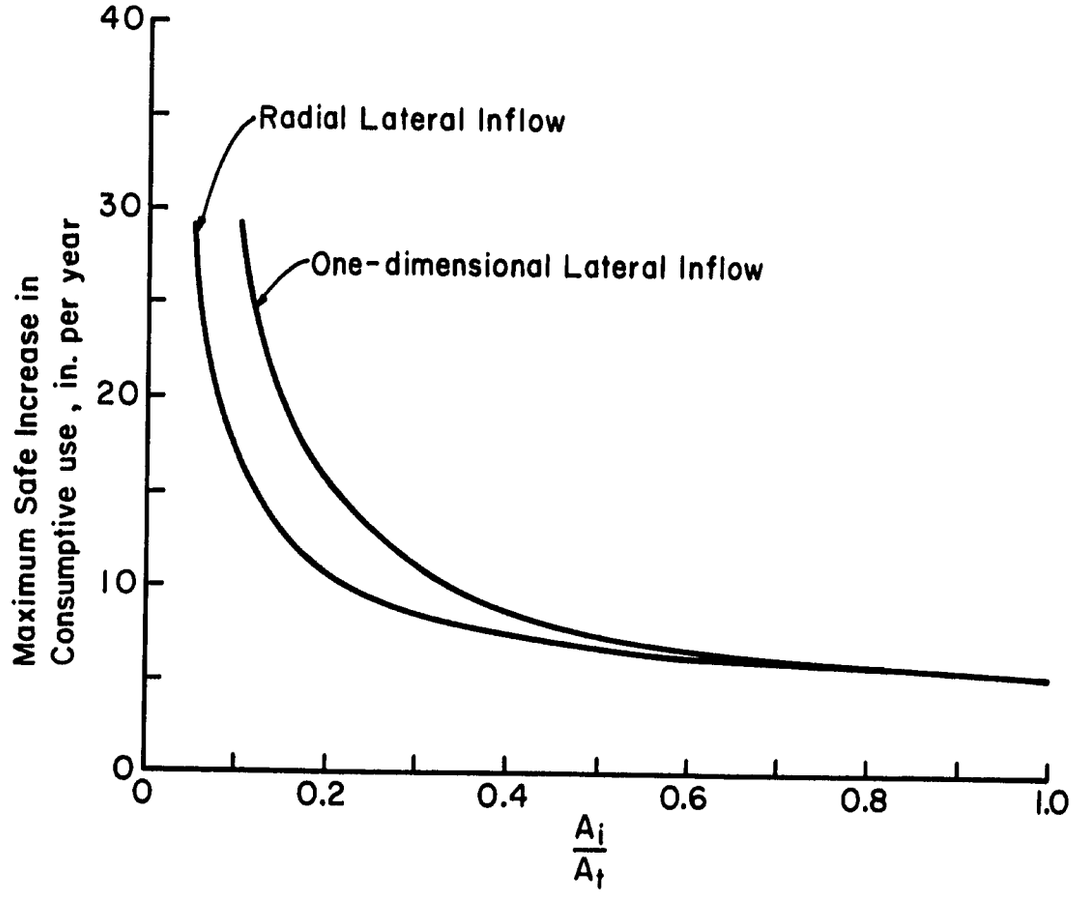

40
30
20
10
0
Maximum Safe Increase in
Consumptive use , in. per year
Radial Lateral Inflow
One-dimensional Lateral Inflow
0
0.2
0.4
0.6
0.8
1.0
$\frac{A_i}{A_t}$

Figure 1.

yield becomes negligible when about 50 percent of the area above the lens is developed. Figure 1 can be used in two ways. If a certain fraction of the land area above a lens is to be developed into an irrigated agriculture, Figure 1 can be used to determine the range of safe consumptive use in addition to the consumptive use under undisturbed conditions. Crop selection and cropping intensity can then be adjusted so as not to exceed the established limits of consumptive use. On the other hand, a knowledge of the ET requirements of planned crops permits one to use Figure 1 to estimate the maximum land area that should be developed.

Potential evapotranspiration by crops in the BARTAD Project is likely to be on the order of 50 inches, annually. Consumptive use under natural conditions is estimated to be 33 inches. This means that development of agriculture will increase the consumptive use by 17 inches. Figure 1 indicates that 17 inches of increased consumptive use can be safely tolerated on only 10-18 percent of the total land area overlying the lens. It may also be concluded that an increased consumptive use of 17 inches on the current BARTAD area (for which A_i/A_t is less than 0.10) is not likely to result in water supply problems. Should the cropped area approach 10 percent of the total land area above the lens, the water supply must be regarded as marginal, however.

The experience of Dr. Richard Cant with the Ministry of Works, Common Wealth of the Bahamas, has led him to believe that the maximum safe yield from a lens is between 18 and 19 percent of the incident rainfall. In the case of the BARTAD Project area this limit amounts to about 9 inches of increased consumptive use, over and above the consumptive use under undisturbed conditions. In other terms, the safe increase in water use is 75 percent of the total groundwater recharge in the lens. As a final check on all of the above computations, the increased water use indicated in Figure 1 was computed as a percent of the 12 inches of groundwater recharge that is believed to occur over the entire lens under natural conditions. These computations are explained in the Appendix and shown graphically in Figure 2. It is clear that the safe increases in consumptive use shown in Figure 1 result in total withdrawal volumes well below Dr. Cant's upper limit. The reason for this resides in the fact that Dr. Cant's limit is for shallow wells, pumped at very low rates, while the limits estimated herein are for deeper wells pumped at much higher rates.

Other Factors

The above computations should be viewed as preliminary quidelines, only. In point of fact, they are based more on theory than on actual data and observations on Andros Island. A number of factors should be kept in mind when considering the foregoing analysis. First, the rather high use rates indicated in Figure 1 for small A_i/A_t are possible only if

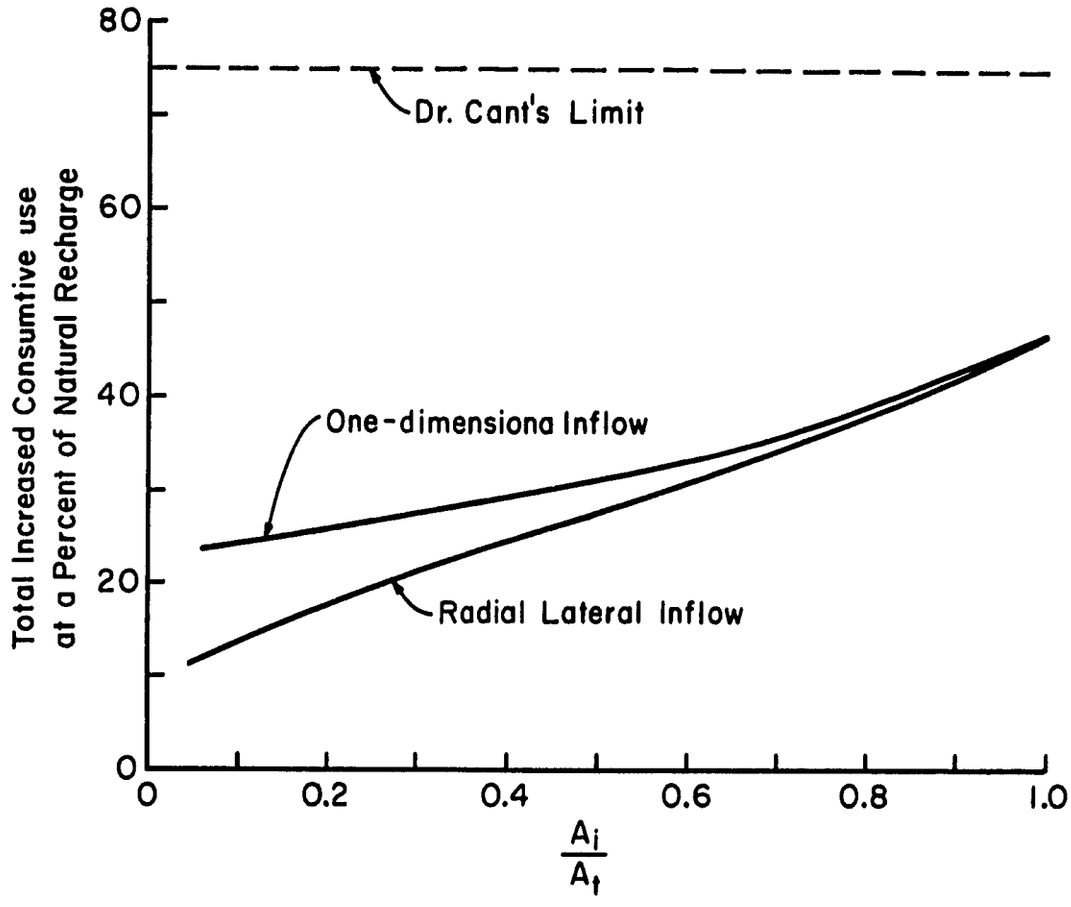

80
60
40
20
0
Total Increased Consumtive use
at a Percent of Natural Recharge
Dr. Cant's Limit
One-dimensiona Inflow
Radial Lateral Inflow
0
0.2
0.4
0.6
0.8
1.0
$\frac{A_i}{A_t}$

Figure 2.

lateral inflow actually occurs as assumed. It is quite possible for areas of low permeability to restrict the lateral movement and cause the estimated safe yields to be overly optimistic. No safety factor has been included to account for such an event.

No consideration of drought has been included. A prolonged drought, during which withdrawals proceed as estimated, could result in salinization of a substantial portion of the aquifer. Finally, and possibly most importantly, the upconing computations do not include the unknown effect of dispersion caused by repeated raising and lowering of the interface in response to pumping, or the lag that exists between the time at which a well is pumped and the time at which the pumped volume is replenished by lateral inflow.

The above qualifying remarks are made here, not only as a reminder of the assumptions underlying the analysis, but also to indicate the critical importance of hydrologic monitoring. It is only through the collection of appropriate data in the field that the actual system behavior can be deduced with confidence. The BARTAD Project affords an excellent opportunity to collect the information required for the prudent development of a larger scale irrigated agriculture on Andros.

Evapotranspiration by crops play the central role in determining the demand for groundwater. No attempt was made in this work to compute the potential ET from meterological, cropping pattern, and cropping intensity data. The figure used herein, (50 inches annually) is reasonable but a much better estimate could easily be computed from available information. In as much as the water supply for a large development appear marginal at best, it is believed important to refine the estimate of ET. Ideally, the actual ET should be measured. Given the unique conditions of the profile between the surface and the water table, it would require a major effort to make meaningful ET measurements, however.

Crop growth is well known to be affected by irrigation water quality in many cases. There exists the definite possibility of pumping water of low quality. Taking into account the type of crops and soil properties, it is possible to estimate the tolerance of the crops to a variety of constituents in the irrigation water. By this procedure, a safe limit on salinity in the pumped water could be set. The entire water resource should be evaluated in terms of this limit on water quality because it establishes a safe groundwater yield that may be higher or lower than that established from hydraulic considerations alone. For example, pumping water for irrigation can result in continuous concentration of dissolved solids in the groundwater. This is true because the dissolved solids in the pumped water remain in the soil after the water has been evaporated or transpired. The residual dissolved solids are subsequently flushed back into the groundwater.

Unless there exists a net subsurface outflow of groundwater, sufficient to remove the residual dissolved solids, the groundwater can become unuseable after a period of years. This is not only an academic possibility; rather it is a very real one, particularly when the initial groundwater contains significant concentrations of dissolved solids.

Conclusions and Suggestions

1. The fresh-water resources on Andros Island occur in lenses above saline water. The very existence of the lenses depends upon the maintenance of a net groundwater recharge into the lenses.

2. Providing groundwater to supply the potential evapotranspiration of crops will result in a net groundwater depletion beneath the developed BARTAD Project lands. Calculations indicate that lateral inflow from the undeveloped lands adjacent to the project is sufficient to replenish the supply, however.

3. Using data available for the lens beneath the BARTAD Project, it is estimated that the maximum land area above the lens that can be developed for agriculture without endangering the water supply is between 10 and 18 percent of the total area above the lens. Consideration of droughts, reduced lateral inflow, and the concentration of dissolved solids by repeated use of the groundwater were not considered. The above determination is sensitive to the value of ET used. Annual ET on cropped land was assumed to be 50 inches.

4. Fresh-salt water interface upconing beneath the pumping wells is estimated to be about 6 feet in response to a total withdrawal of 4,000 ft^3. A four or five day interval between pumping periods is probably not sufficient for complete recession of the upconed salt water. As a result, salinity in the pumped water is likely to increase throughout the pumping season. It is expected that lateral inflow and recharge during the wet season will be sufficient to depress the local upconing beneath the wells, and pumped water quality will return to approximately the initial level before the next irrigation season. This is critical and should be monitored closely.

5. The current practice of making small withdrawals from many wells tends to minimize interface upconing and the continued use of this practice is encouraged.

6. Aside from the local upconing, a general rise in the interface can be expected. This rise in the interface is a necessary consequence of disturbing the

natural inflow-outflow balance. The rise will be very gradual and probably not perceptible except as a long term trend. This is true because the increased water use is provided by both lateral inflow and a change in storage reflected by the rising interface. A new dynamic equilibrium will eventually be established and the interface will cease to rise.

7. Maximum water quality will be obtained by minimizing the volumes pumped and minimizing the well depth insofar as practical. It is suggested that pumping tests be conducted at 2.5 foot intervals from the 20 foot depth until an acceptable capacity is realized. Wells should not be drilled any deeper than absolutely necessary to provide the required capacity. Intake of the suction lines should be as near the water surface in the well as practical.

8. The salinity in pumped water should be determined on each well each time it is pumped. To insure that the determinations have a common base for comparison, the discharge should be sampled just before the pump is shut off. From 5 to 10 representative wells near the center of the well field should be pumped and sampled at least once about the middle of the wet season to provide an indication of the recovery of water quality. It is also important that samples of the discharge not be missed at the initial pumping of each well at the beginning of the irrigation season. Knowledge of the increase in salinity during the pumping season, coupled with water quality recovery data during the dry season, will ultimately determine the pumping rates and withdrawals that can be tolerated.

9. Monthly monitoring of the water table and interface elevations in the monitoring wells is suggested. If time constraints limit the number of wells that can be monitored, at least one interior and exterior well should be included. The current practice of recording water table fluctuations with a recorder should be continued. Determination of the salinity distribution in the interior monitor well on a monthly basis is suggested.

10. The current practice of recording pumped volumes and the day on which each well is pumped should definitely be continued. These data are critical to the interpretation of groundwater behavior. The same can be said for the weather data presently being taken.

11. It is suggested that a refined estimate of the potential evapotranspiration from a "typical" farm unit be made. The data are available from which this estimate can be made. The author of this report was

not able to make this computation because of time limitations, but believes it to be an important consideration in the water supply picture for Andros.

12. A theoretical consideration of the effect on upconing of the lag between the time a well is pumped and the time at which recession is complete should be made. The data collected under recommendation 8 above will eventually establish the effect for the BARTAD Project area, but a method by which this information can be extrapolated to larger developments is essential. This is true because the time lag will become increasingly large as the area of development is increased. Again, this author was not able to make this study in the short time available.

13. It is recommended that an attempt be made to determine the tolerable limit of water quality. This can probably be accomplished with sufficient accuracy by extrapolating current knowledge. A reasonably complete analysis of the chemical make up of the fresh, brackish, and saline groundwater would be required. With information on the tolerable limit of water quality and refined estimates of ET, the entire water resource should be re-evaluated.

It will be noted that much of the monitoring program suggested above is already being conducted by Mr. Elliot at the project site. The monitoring program is repeated herein because it is believed to be of critical importance in establishing the water supply which appears, at the present, to be a significant constraint on the development of irrigated agriculture on Andros.

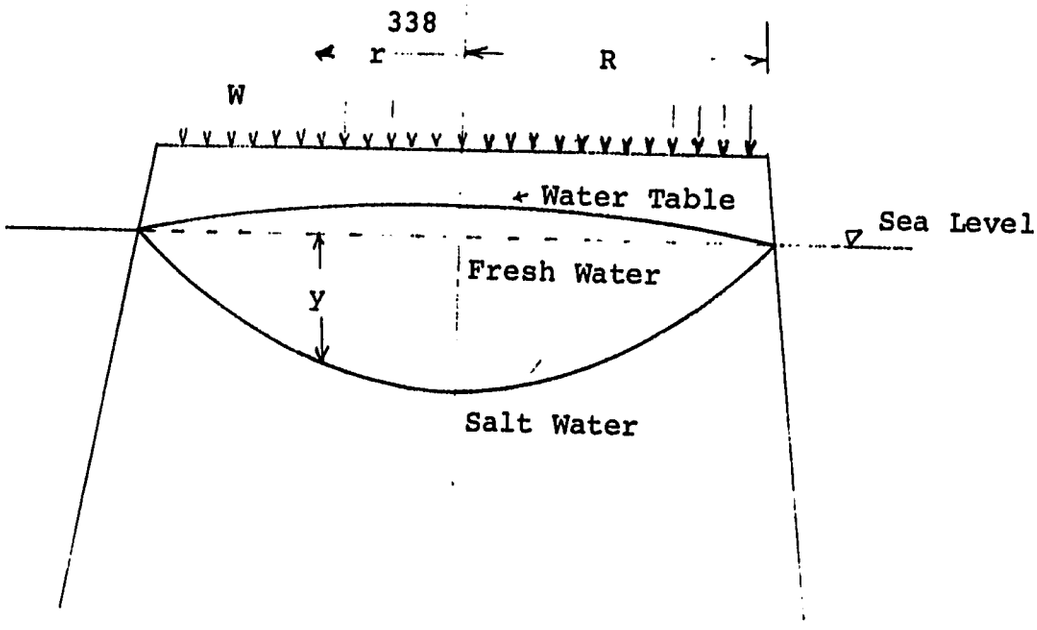
Appendix: Derivation of Equations for Safe Yield

A cross-section through an idealized circular island on which a uniform recharge rate W exists is shown below. The depth below sea level to the interface is given by the well known equation

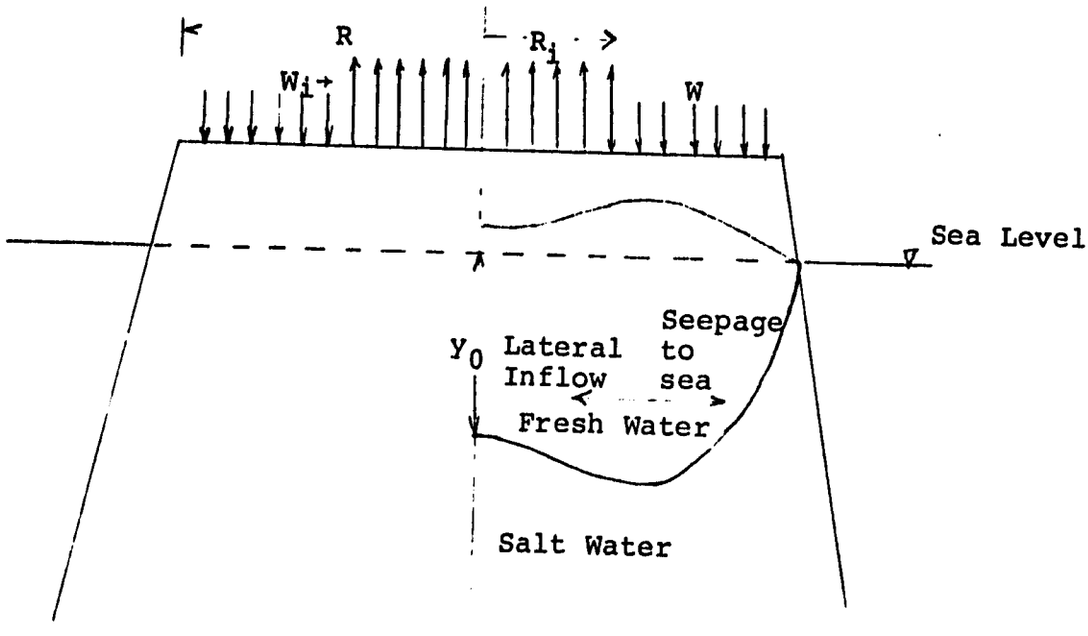
$$y = \left\{ \frac{W}{0.0512K} (R^2 - r^2) \right\}^{\frac{1}{2}} \qquad (1)$$

where y is the depth to the interface below sea level, W is the recharge rate, K is the hydraulic conductivity of the aquifer, R is the radius of the island, and r is the radius to the point where the depth is y.

Groundwater withdrawals that are consumptively used can be regarded as reductions in the recharge W. If the recharge rate is reduced to W_i on an area near the center of the lens, the interface will shift to a new equilibrium position as shown below. It should be noted that W_i may be zero or negative



as well as positive.



The equation for the shape of the interface in this case is not available in the literature and is, therefore, derived herein. Since the system is in dynamic equilibrium, the discharge rate Q through the surface of a vertical cylinder of radius r less than R_i is

$$Q = \pi r^2 W_i \tag{2}$$

and this must be equal to the discharge computed from Darcy's law. Thus,

$$r^2 W_i = - K\ 2\ r(y_1+y)\ \frac{dy_1}{dr} \quad , \tag{3}$$

where y_1 is the elevation of the water table above sea level and y is the elevation of the interface below sea level. The Ghyben-Herzberg relation states that

$$y \simeq \frac{\rho}{\Delta\rho}\ y_1 \simeq 40\ y_1 \tag{4}$$

so equation 3 may be written

$$\pi W_i r^2 = - \pi(0.0512)K\ ry\ \frac{dy}{dr} \quad . \tag{5}$$

Integration of equation 5 between the center of the irrigated area (i.e., r=0) where y is equal to y_0 and the boundary of the irrigated area where $r=R_i$ and $y=y_1$, yields

$$y_0^{\ 2} = \frac{W_i R_i^{\ 2}}{0.0512K} + y_1^{\ 2} \quad . \tag{6}$$

The next step is to calculate $y_1^{\ 2}$. This is accomplished by analyzing the flow for r greater than R_i, where the discharge through the surface of a vertical cylinder of radius r is

$$Q = W_i \pi R_i^{\ 2} + W\pi(r^2 - R_i^{\ 2}) \quad . \tag{7}$$

This flow must also be given by Darcy's law. Thus,

$$W_i \pi R_i^{\ 2} + W\pi(r^2 - R_i^{\ 2}) = -0.0512\pi K\ ry\ \frac{dy}{dr} \quad . \tag{8}$$

Integration of equation 8 from $r=R_i$ where $y=y_1$ to $r=R$ where $y=0$ yields

$$y_1^{\ 2} = \frac{1}{0.0512K}\ \{W(R^2 - R_i^{\ 2}) + 2(W_i - W)R_i^{\ 2}\ \ell n\ R/R_i\} \quad . \tag{9}$$

Putting equation 9 into equation 6 yields

$$y_0^{\ 2} = \frac{R^2}{0.0512K}\ \{(W_i - W)R_i^{\ 2} + WR^2 + 2(W_i - W)R_i^{\ 2}\ \ell n\ R/R_i\} \tag{10}$$

or after some rearrangement:

$$y_0^{\ 2} = \frac{R^2}{0.0512K}\ \{W + (W_i - W)(R_i/R)^2[1 - \ell n(R_i/R)^2]\} \tag{11}$$

Equation 11 is an expression for the depth to the interface at the center of the lens when the recharge rate on an area extending to R_i is reduced to W_i. Notice that if R_i is zero, equations 11 and 1 are consistent with each other. Also notice that the ratio $(R_i/R)^2$ is the ratio of the

irrigated area to A_i to the total area A_t above the lens. Thus,

$$y_0^2 = \frac{R^2}{0.0512K} \{W + (W_i - W) \frac{A_i}{A_t} [1 - \ln \frac{A_i}{A_t}]\} \quad . \tag{12}$$

When $A_i = 0$ before development,

$$y_0^2 = \frac{R^2 W}{0.0512K} \quad . \tag{13}$$

In the BARTAD Project, the depth below sea level of the lens is about 41 feet, and W is about 12 inches per year. Using these values in equation 13 gives

$$\frac{R^2}{0.0512K} = 140 \quad ,$$

so that equation 12 becomes

$$y_0^2 = 140\{12 + (W_i - 12) \frac{A_i}{A_t} [1 - \ln \frac{A_i}{A_t}]\} \quad , \tag{14}$$

in which y_0 is in feet, and W_i is in inches per year.

As discussed in the text, it was determined that W_i should be maintained so that y_0 never becomes less than 30 feet below sea level. Solving for W_i and putting $y_0 = 30$ gives

$$W_i = \frac{6.43 + 12\{ \frac{A_i}{A_t} (1 - \ln \frac{A_i}{A_t}) - 1\}}{\frac{A_i}{A_t} [1 - \ln \frac{A_i}{A_t}]} \quad . \tag{15}$$

Finally, the safe increased consumptive use, over and above that being used before irrigation, is

$$\text{Safe Increased Use} = W - W_i \quad .$$

The final expression becomes

$$\text{Safe Increased Use} = \frac{5.67}{\frac{A_i}{A_t} \{1 - \ln \frac{A_i}{A_t}\}} \quad . \tag{16}$$

Rarely, if ever, will a fresh water lens be circular as assumed above. In order to establish the effect of geometry on the safe increased use, an analysis was made for the case in which flow is one-dimensional. This situation is approximated in the field by a lens whose geometry is that of a long trough. Using procedures similar to those presented above,

the equation for safe increased use is

$$\text{Safe Increased Use} = W - \frac{\dfrac{0.0512Ky_0^{\,2}}{L^2} - W\left(1 - \dfrac{A_i}{A_t}\right)^2}{\dfrac{A_i}{A_t}\left(2 - \dfrac{A_i}{A_t}\right)} \tag{17}$$

for the general case. For the conditions at the BARTAD Project, equation 17 is

$$\text{Safe Increased Use} = 12 - \frac{6.43 - 12\left(1 - \dfrac{A_i}{A_t}\right)^2}{\dfrac{A_i}{A_t}\left(2 - \dfrac{A_i}{A_t}\right)} \quad . \tag{18}$$

Safe increased use for lenses of irregular geometry should be between the two extremes analyzed here.

Safe Increased Use as a Percent of Recharge

The total volume of increased use V is the product of the increased uses computed from equation 16 or 18 and the irrigated area A_i . The total volume of recharge under natural conditions is A_tW . Thus, the total increased consumptive use as a percent of natural recharge is

$$100\ (\text{Safe Increased Use})\ \frac{A_i}{A_t}$$

APPENDIX 29

FIELD TESTS OF SKIMMING WELLS

by

McWhorter[1], Kemper[2], Jehangir[3], and Trout[1]

Research into fresh-saline ground-water hydraulics was initiated in 1971 as a part of the broader water management research effort. The objective was to ultimately develop design and operating criteria for irrigation wells constructed at locations where a layer of "fresh" water was underlain by unuseable "saline" ground water. The research progressed by 1974 to the point where field testing was the logical next step. Summaries of the research conducted through 1974 have been reported previously and this report is devoted to the research in 1975.

The essential aspects of a field testing plan developed by D. B. McWhorter were implemented during 1975. Construction of a shallow tube well and a large diameter dug well was completed in February on the Phularwan Farm, a part of the MONA Reclamation. This location was selected because the vertical distribution of salinity closely matched that used in mathematical and laboratory models. The salinity profile, as indicated by specific conductance, featured an upper region in which the salt concentration was nearly uniform and a lower zone in which the concentration was nearly uniform but at a much larger value than in the upper zone. The transition between the upper fresh water zone and the lower brackish zone occurred over a distance of about 20 feet. The fresh-water zone was taken as 80 feet thick and the depth of the wells determined from this number in accordance with previous research.

In addition to the two shallow pumping wells, 16 observation wells were constructed (8 at each pumped well). The wells were approximately 120 feet deep and penetrated well into the brackish water. The purpose of the observation wells was to monitor the expected upconing of the brackish water in response to pumping. Orifice plates were installed on the pump discharge lines so that the well discharge could be monitored.

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D. B. McWhorter spent the month of February in Pakistan to help initiate the testing program. A problem with the observation well network was experienced during the first pumping period. Because the pumped wells penetrate only a short distance into the aquifer, the distribution of hydraulic head in the vicinity of the well is such that equi-head surfaces have an oblong or bulb shape. The gradient of head has a pronounced vertical upward component, therefore. In comparison to the aquifer, the resistance to vertical flow in the observation wells is practically zero. The result is that the observation wells act as a short-circuiting conduit, permitting brackish water to flow upward in the well bore causing salinity measurements in the observation wells to be meaningless.

The observation wells were subsequently modified by suspending several small diameter plastic tubes in the well bore; each tube terminating at intervals of about 10 feet. The observation wells were then backfilled with aquifer material so that the resistance to flow is approximately that of the aquifer. Samples are withdrawn from the tubes and analyzed for salinity.

The production capacity on neither the dug well nor the tube well was as high as anticipated. The water level in the tube well dropped from 8 to 16 feet below the static water level during a 13 day pumping period at a discharge of 65 gallons per minute. The water level finally fell below the suction pipe inlet. The large drawdown experienced in the pumped tube well, when compared with a much, much smaller drawdown in the aquifer at a distance of 10 feet, indicates very high well losses. The well losses may be the result of well screen and gravel pack plugging by particle migration, although this cannot be determined directly. If funds are available, another tube well will be constructed to a depth of 50 feet below the static water level in an attempt to produce a greater upconing of the interface. To increase the capacity of the dug well, the concrete bottom is being removed and a filter pack about 3 feet thick is being placed over the sand. This will permit water to enter through the bottom of the well where previously only lateral inflow was realized.

Effect of Pumping on Salinity Profiles

Figures 1, 2, 3, and 4 show the salinity profiles immediately prior to pumping on the 16th of August and on August 27th at the observation wells which were 10, 19, 38, and 77 feet, respectively, from the shallow tube well which was being pumped. This well is constructed with a PVC well screen, 6 inches in diameter, extending from 12 feet to 36 feet below the soil surface. The screen contains 100 slots per foot; each slot with dimensions of 0.05 inch by 2.5 inches.

These curves show a slight rise in the saline-fresh water interface as the pumping took place. The rise averaged about

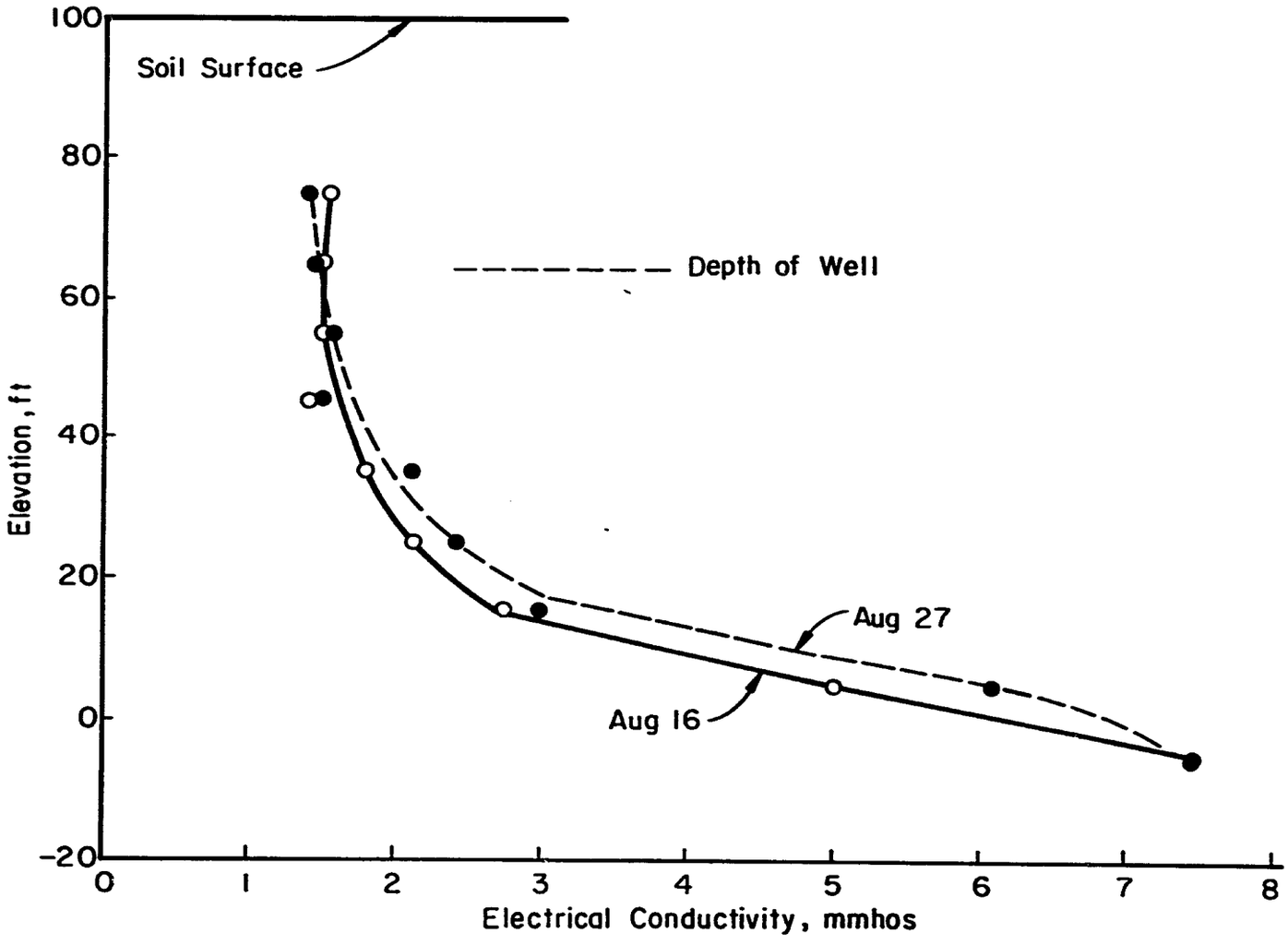

Figure 1. Salinity Profile at Skimming Well Site (at 10' from the well).

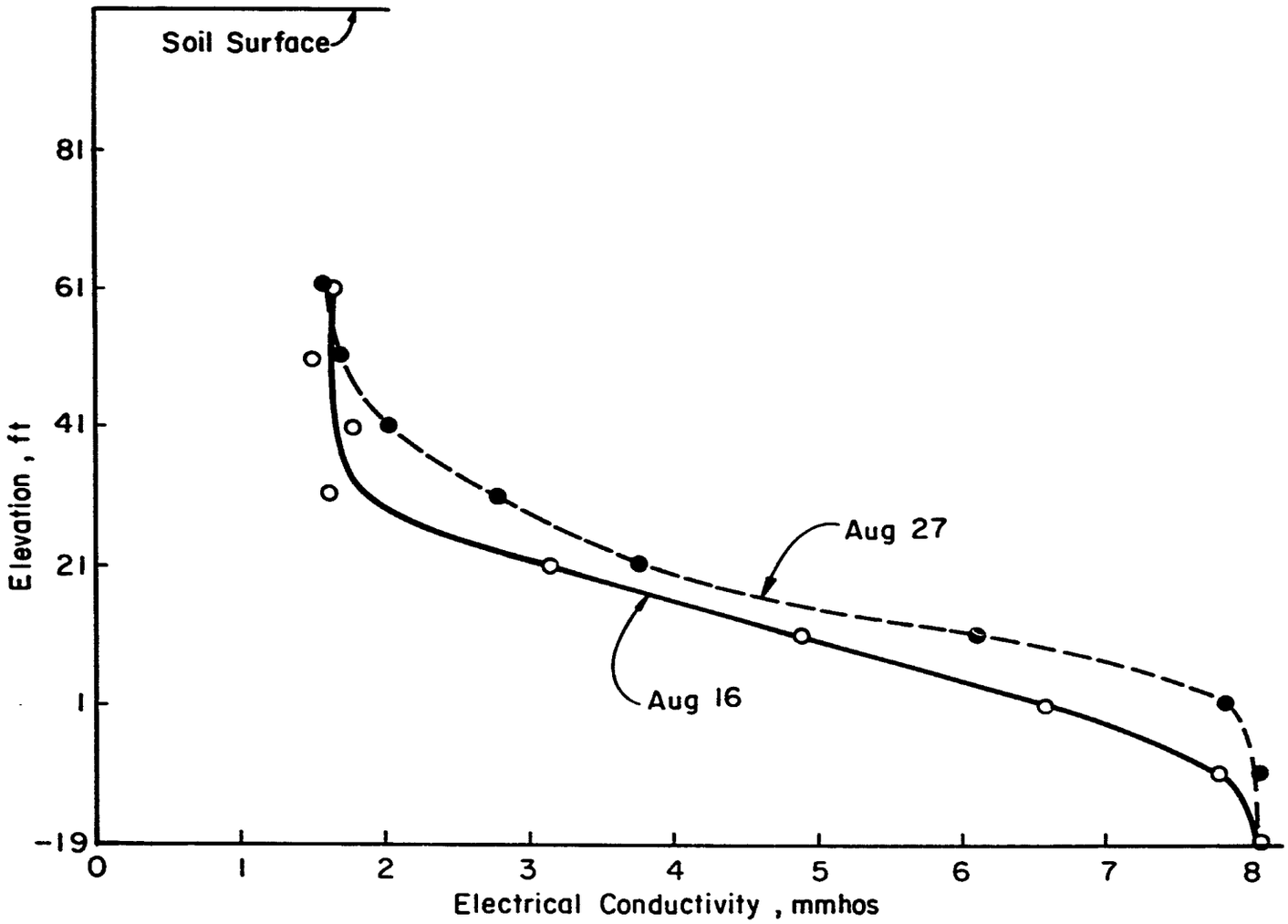

Figure 2. Salinity Profile at Skimming Well Site (at 19' from the well).

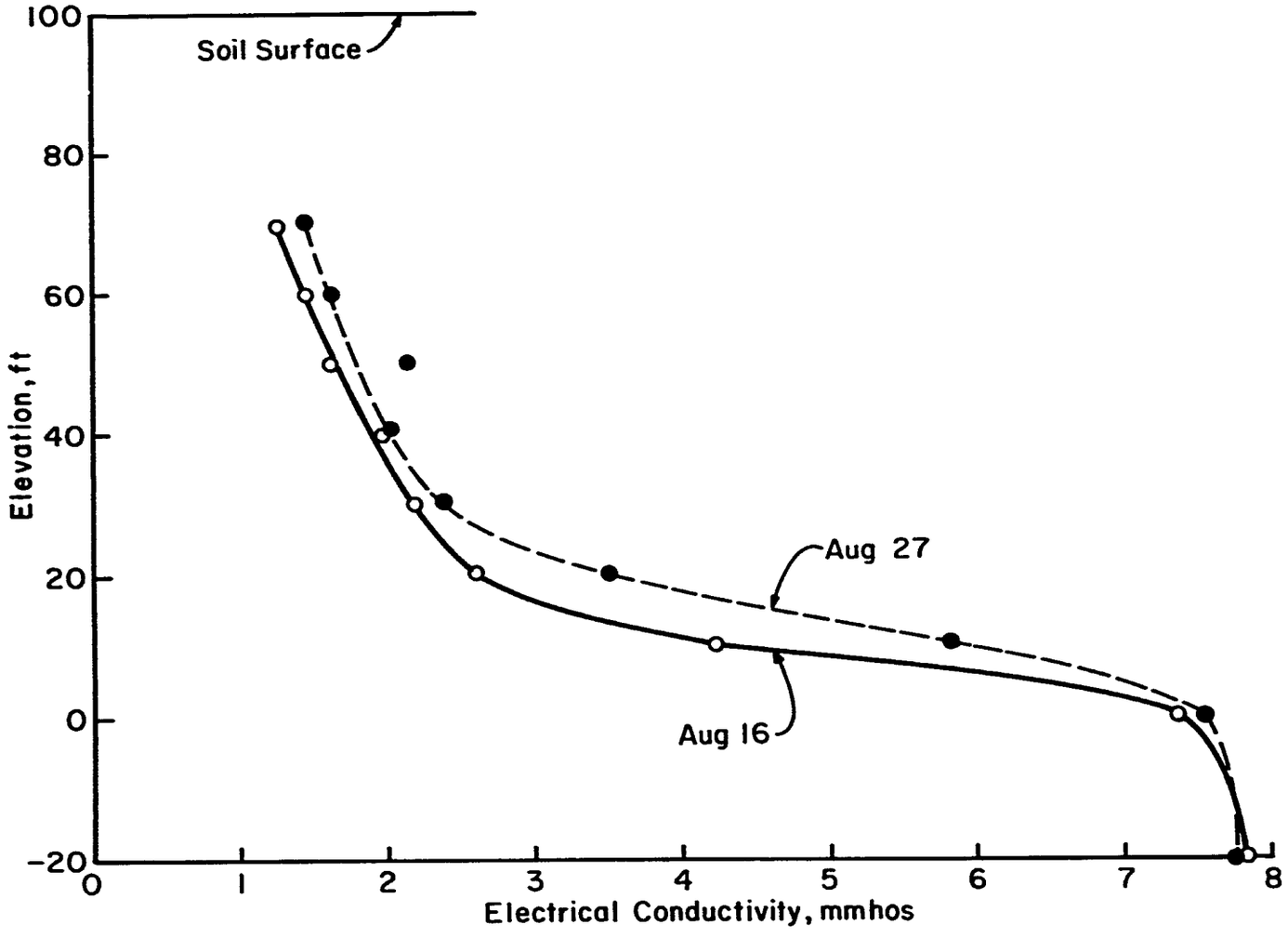

Figure 3. Salinity Profile at Skimming Well Site (at 39' from the well).

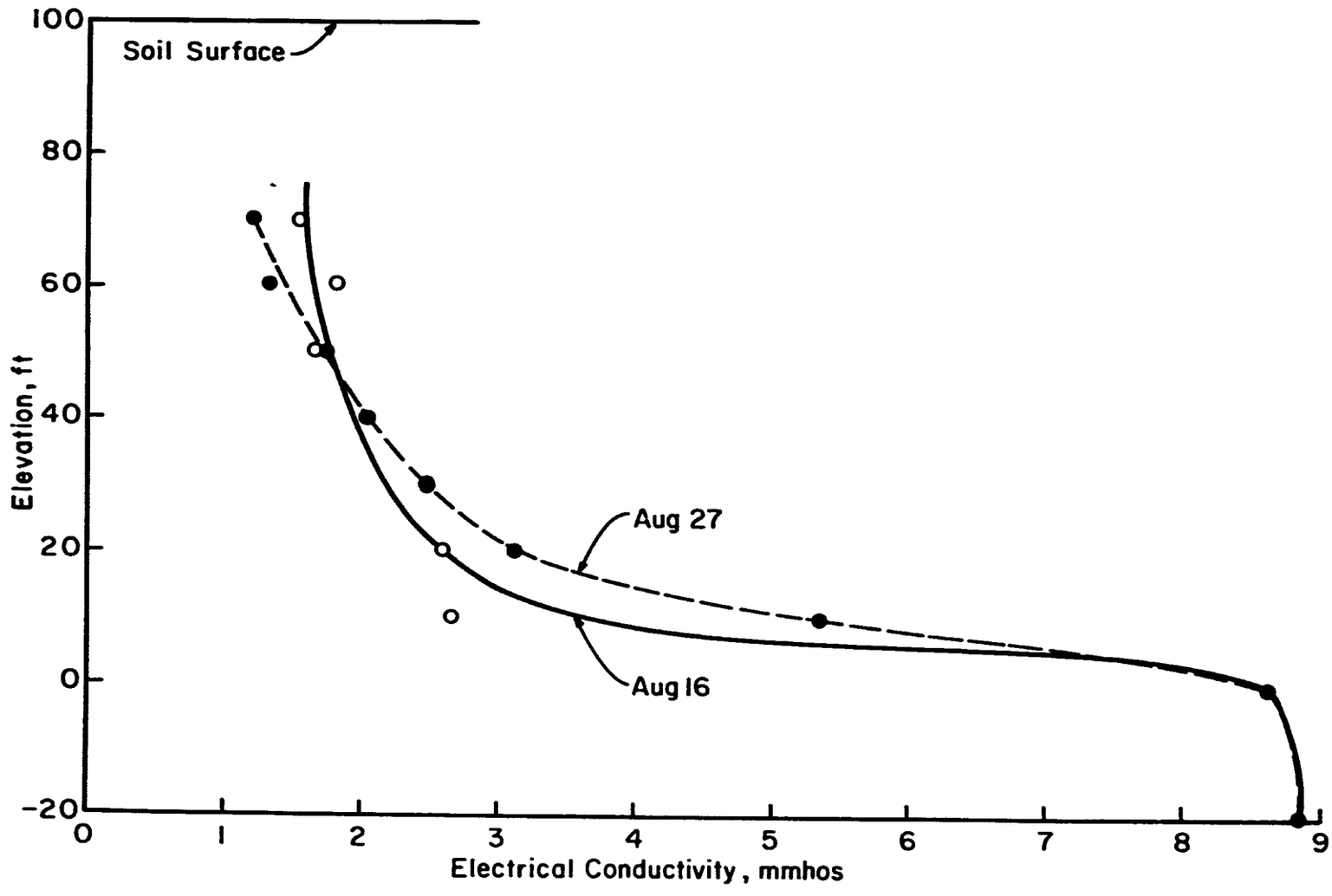

Figure 4. Salinity Profile at Skimming Well Site (at 77' from the well).

3 feet at the observation site 77 feet from the well, 5 feet at the site 39 feet from the well, 7 feet at the site 19 feet from the well, but was only about 4 feet at the site 8 feet from the well. According to theory, the rise should be greatest at the observation site nearest the well and the only explanation we have for this anomally is the existence of inhomogeneities in the aquifer or malfunctioning of the sampling system. Ignoring the data point at the observation well nearest the pumped well and plotting the data on semi-log paper provides an estimate of the volume of fresh water displaced by the rise in the interface. This procedure yields a displaced volume of approximately 1.2×10^5 feet^3 within an effective radius of influence of 260 feet. The actual volume of fresh water pumped is 1.4×10^5 feet^3. This calculation indicates that the upconed interface accounts for a large percentage of the pumped volume and that a great deal more pumping is required to cause a more significant rise in the interface.

Practical Applications

A small tubewell, located on the Phularwan Research Farm (a part of the MONA Reclamation area), was constructed to a depth of 105 feet, during 1974. The discharge from this well contained 2300 ppm dissolved solids with an SAR of about 14. Use of water from this well had been discontinued for about two months because of the high salinity. An investigation disclosed the salinity profile presented in Table 1.

Table 1. Salinity Profile in Mona Well on Phularwan Farm

Depth ft.	Elec. Cond. mmohs/cm
13-23	2.10
23-33	1.96
33-43	1.75
43-53	1.47
53-63	1.30
63-73	1.20
73-83	1.20
83-93	1.96
93-103	3.75

These data indicate a relatively fresh water zone (800 ppm) above a more saline zone (greater than 2500 ppm) with a transition zone located below about 90 feet. Water from a nearby hand pump indicated that the relatively high conductivities measured in the first 40 feet of the well casing resulted from more saline water pumped from below during the last period of pump operation. Since the top 30 feet of the well was cased with blind pipe, water in this section would come to equilibrium with the natural ground water salt content very slowly and this is probably the reason for the somewhat higher salt content.

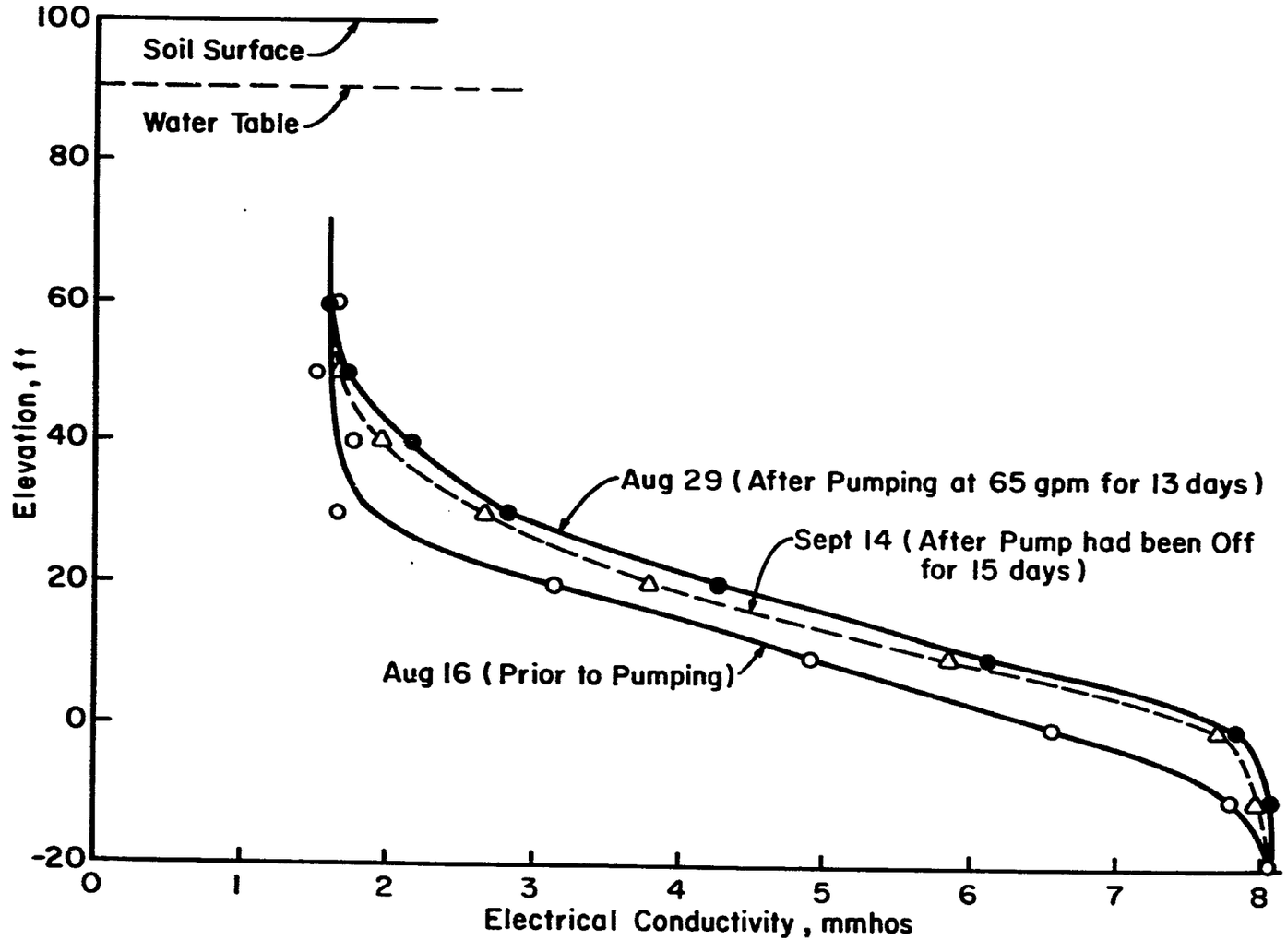

Figure 5. Observation Well at T1-2 (which is 18' from the shallow tubewell).

Based on the above observations, it was recommended that the tube well be modified by blocking off the bottom 45 feet with sand and a concrete plug. This was accomplished, leaving the well with blank casing from the surface to about 30 feet and well strainer from 30 to 60 feet. A flange with a small orifice was inserted in the discharge pipe which decreased the pumping rate to 0.4 cusecs from the original 0.9 cusecs. These modifications resulted in the marked improvement in the pumped water as indicated in Table 2.

Table 2. Salinity in Discharge - Mona Well on Phularwan Farm

Time of Pumping	Total Salts (ppm)	Sodium Adsorption Ratio	Pumping Rate (cusecs)
Prior to modification	2300	14	0.9
Following modification			
1 min. of pumping	830	3.6	0.4
20 min. of pumping	850	3.6	0.4
160 min. of pumping	770	3.3	0.4
One month later			
4 hours of pumping	830		0.4

The water from this well is now used regularly for irrigation on the research station.

On the basis of the successful modification of this tube well the new Assistant General Manager for Planning in WAPDA has requested that we determine the salinity profile in the twelve wells that have been closed down in the MONA project area because the pumped water was too saline or sodic. Based on these salinity profiles we will decide whether these wells can be modified to yield substantial quantities of water with satisfactory quality. Since wells of this type now cost nearly $30,000 each to construct (and bring in the electric power) their rehabilitation is a worthwhile project.

Similar requests have been received from farmers to help them rehabilitate saline wells, and we are doing this as we can work it into our schedule - and as the farmers will agree to take water samples for us. Our experience with the observation wells, prior to their modification, indicated that the salinity profile in the wells returned, within about one week, to that which is representative of the salinity in the aquifer. This is an important observation because it tells us that measurements in the screened section of a pumped well within one week after shut-down should be representative of the salinity distribution in the aquifer adjacent to the well. This fact permits us to make recommendation concerning rehabilitation without a great deal of costly test boring and monitoring.

Appendix 30

THE INFLUENCE OF PUDDLING, WATER LEVEL, AND STRAW RETURN ON SOIL PHYSICAL PROPERTIES, PADDY RICE YIELDS, AND YIELD OF A FOLLOWING UPLAND CROP

S.A. Bowers and Tran Ba Su[1]

September, 1974

Objective

In a paddy rice-upland crop multiple cropping system, to determine the influence of puddling, water level, and straw return on the soil physical properties and crop yield and to determine alternate techniques if any of the above practices are detrimental to the system.

Introduction

With exception of the floating rice areas, paddy rice is the predominate Delta crop. Paddy rice culture includes both soil puddling, to diminish water losses through deep percolation and reduce power requirements in soil preparation, and maintenance of flooded conditions to control weed growth.

Some detrimental effects are associated with these practices. First, puddling impairs growth and yield of upland crops by restricting drainage, aeration, impeding root penetration and development, etc. Maintaining flooded conditions, particularly in the dry season, may increase evaporation and the cost of pumping.

Where herbicides are available for weed control, these practices might possibly be eliminated. Results from a 1974 project experiment showed little paddy rice yield reduction on granulated, nonflooded (but high moisture content) soils. Possibly, the labor of puddling and additional pumping costs might not be compensated by the slight yield increases. Similarly, if the system includes upland crops, we must determine if soil puddling adversely influences yield of succeeding upland crops.

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[1]Project Advisor, Mekong Delta Soils Project, University of Cantho, Cantho, Vietnam and Research Assistant, Mekong Delta Soils Project.

Experimental Procedure

The field experimentation consisted of two sequential, related experiments on the same plots. Both experiments were randomized complete block design.

Experiment 1 included the following treatments:

P_o - granulated soil (not puddled)

P_1 - puddled soil

F_o - soil not flooded

F_1 - soil flooded

The above treatments in factorial combination resulted in four individual treatments. With six replications there were 24 plots each 4m x 5m.

The granulated treatment (P_o) resulted from hoeing the soil three times and allowing it to dry prior to planting. The puddled treatment was applied by working the soil with rakes, while flooded, until the plots were level and all aggregates apparently dispersed.

The flooded treatment consisted of a 5cm depth of water maintained by daily additions. The soil moisture content of the nonflooded treatment was maintained near saturation by water addition when necessary.

Plots were direct seeded with IR-22 on September 14. Row and plant spacing was 25cm x 25cm, respectively. All plots were given a single basal fertilizer application of 60-60-45; the fertilizer applied was 20-20-15 ammophosko.

Because of the late rainy season, plots could not be harvested until January 3, 1975. Following harvest and drying of plots, samples were taken from each plot for bulk density determination and aggregate size distribution. In addition, using a newly designed double ring infiltrometer, infiltration curves were established for each plot.

Experiment 2 resulted from applying two additional treatments to the plots of experiment 1. The experiment intent was to determine how previous cultural techniques would influence yield of an upland crop in a paddy rice-upland crop multiple cropping system. The experimental treatments were as follows:

P_o - granulated soil (previous rice crop)

P_1 - puddled soil (previous rice crop)

F_o - soil not flooded (previous rice crop)

F_1 - soil flooded (previous rice crop)

S_o - no rice straw incorporated

S_1 - rice straw incorporated (2mt/ha)

These straw treatments resulted in three replications of eight treatments each. The straw, which was for structural improvement, was incorporated by roto-tilling. All plots were roto-tilled at the same time. Following, 50 kgN/ha were broadcast on each plot and irrigated by light sprinkling. All plots were planted to green beans two weeks after straw incorporation.

Results and Discussion

Table 1 shows paddy rice yields from experiment 1. Table 2 shows the analysis of variance (2^2 factorial) of the yield data. The results fail to detect any significant differences due to treatment. The experiment coefficient of variation was 15.1 percent. This value, although not excessive, does approach the upper limit of acceptability.

Accepting the results as valid, the experiment suggests that where weed growth is controlled by other methods (hand picking in this experiment), the practices of puddling and flooding this particular soil do not significantly increase paddy rice yields. This finding is similar to that reported in a 1974 project drum experiment. Here, using the same soil type, puddling and flooding cause significant but small increases in paddy rice yield.

The average yields due only to puddling (P_1) and non-puddling (P_o) were respectively 4.58 and 4.34 mt/ha. Thus, in this experiment, puddling increased yields 0.24 mt/ha, or 5.53 percent. Similarly, the yield due to flooding (F_1) and nonflooding (F_o) only were respectively 4.72 and 4.20 mt/ha. Here flooding increased yields 0.52 mt/ha or 12.4 percent. Statistically, both increases must be considered insignificant and due to naturally occurring variation.

At evacuation time, plot soil samples had not been analyzed for bulk density and aggregate size distribution. Infiltration trials were run on each plot. These trials were run after drying had occurred on the surface, but before initiation of the severe surface cracking shown in Figures 17-18 (Appendix 1).

There was no discernable difference in infiltration as related to treatment. It appears that variability within

TABLE 1. Paddy rice yields in mt/ha.

TREAT.	REPLICATIONS						AV.
	I	II	III	IV	V	VI	
P_oF_o	4.42	4.22	4.40	3.36	3.63	4.03	4.06
P_oF_1	5.95	3.16	4.59	4.78	4.34	4.96	4.63
P_1F_o	6.20	3.69	4.39	4.84	3.73	3.25	4.35
P_1F_1	4.77	5.14	5.22	4.17	5.06	4.55	4.82

TABLE 2. 2^2 factorial analysis of variance for paddy rice yields.

Source of Variation	df	Sum of Squares	Mean Square	F
Replications	5	4.4821	0.8964	1.9797ns
Treatments	3	2.0003	0.6667	1.4724ns
Puddled	1	0.3504	0.3504	0.7739ns
Flooded	1	1.6328	1.6328	3.6060ns
PxF	1	0.0171	0.0171	0.0378ns
Error	15	6.7917	0.4528	

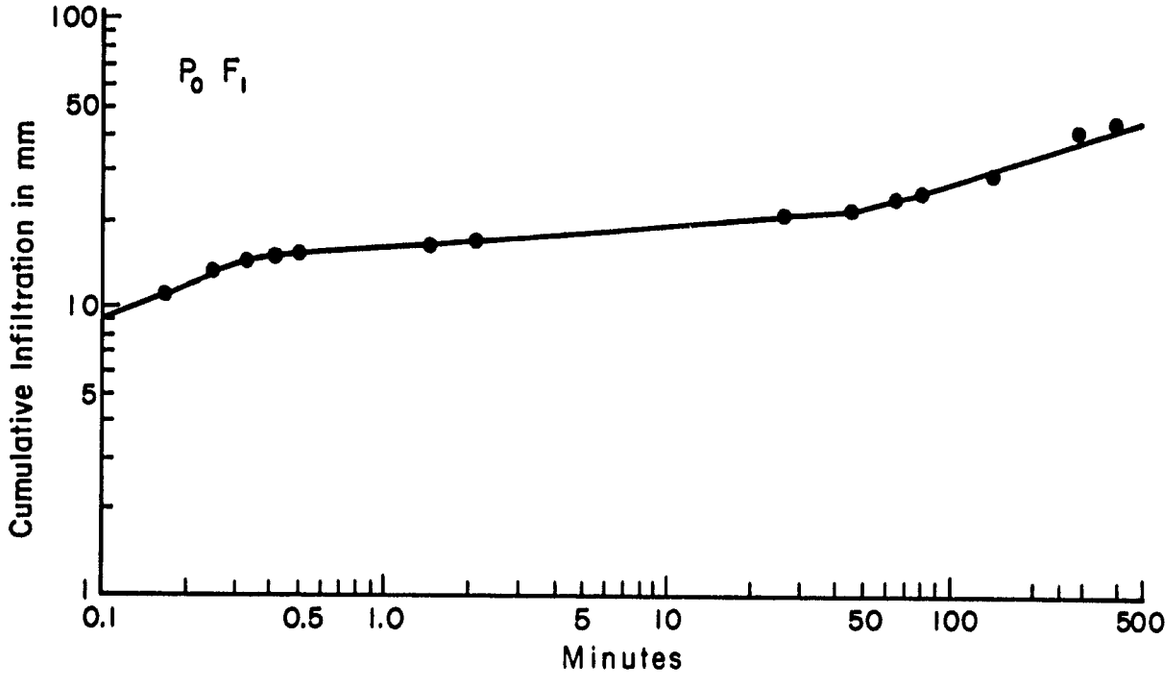

Figure 1. Infiltration curve on a granulated-flooded soil. The curve shows three different infiltration rates; the last, starting at 45 minutes, may be related to subsoil cracking.

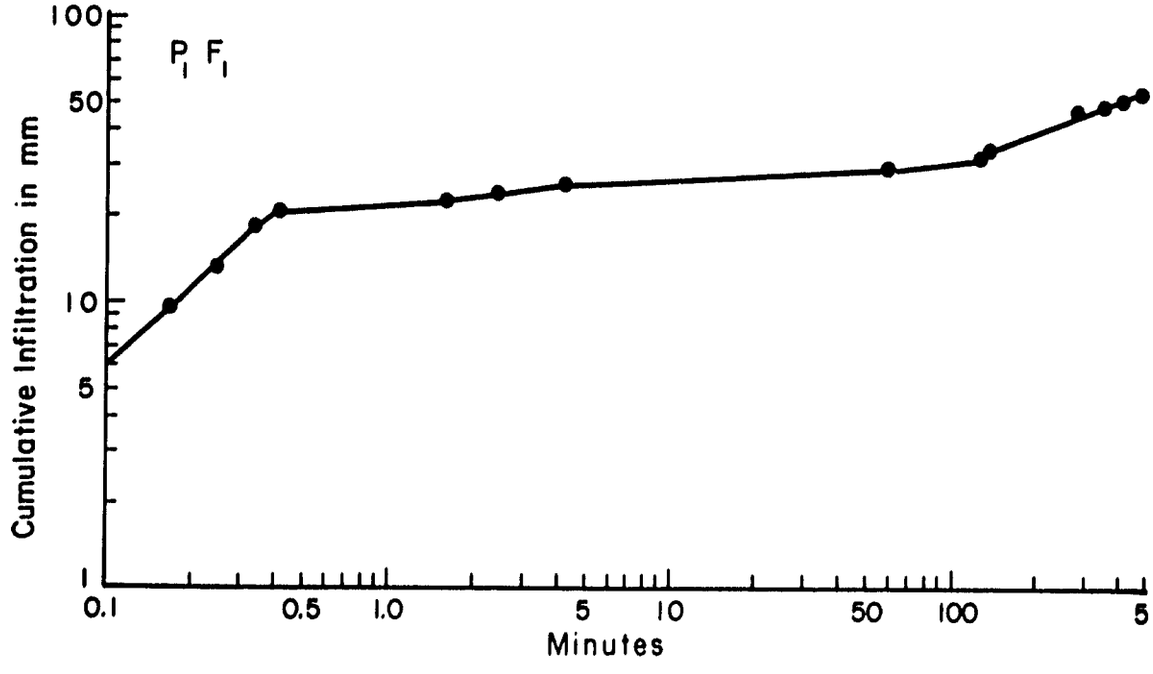

Figure 2. Infiltration curve on a puddled-flooded soil. This curve also displays three different infiltration rates.

treatments must have been greater than variability between treatments. Figures 1 and 2 are infiltration curves on puddled and nonpuddled plots. Most curves showed a noticeable increase in infiltration rate at the end of the run. This possibly could be correlated to subsurface cracks as shown in Figures 19-20 (Appendix 1).

No conclusion can be made concerning experiment 2 since the project was terminated prior to data collection.

Conclusions

This experiment failed to detect any significant differences in paddy rice yield due to puddling and flooding. This suggests these practices could be eliminated on this particular soil where weed control is possible by other means.

The effect of puddling, flooding, and straw return on the complete paddy rice-upland crop multiple cropping system could not be determined due to the premature termination of the project.

Appendix 31

WET SEASON CORN VARIETY TRIAL

S.A. Bowers and Tran Ba Su[1]

October 1, 1974

Objective

To determine which corn varieties are most productive in the Delta during the wet season.

Introduction

Flooding and excessive rainfall presently prohibit production of most upland crops in the wet season. With the establishment of water control, wet season production of upland crops may be feasible in many areas.

The human demand for corn, a favorite food among Vietnamese, has prevented its use as a feed grain. Swine production, which greatly increased during the war years, depended primarily on imported feeds. Increasing corn production would not only help the country towards self-sufficiency and conservation of foreign exchange, but also to help stimulate and sustain animal production within the country.

As part of the project's assignment to develop multiple cropping systems, corn must be evaluated as a systems component. Thus, the project investigated corn as a possible wet season crop.

Experimental Procedure

Corn seed was provided by the Rockefeller research organization in Bangkok. Eighteen varieties, believed potentially adaptable to Delta wet season conditions, were selected. In addition, a local Vietnamese variety was included as a check. The 19 varieties are listed in Table 1.

These varieties were planted on beds 0.2m high, 1.5m wide, and 6m long. Three rows were planted on each bed, row spacing was 0.6m. Plant spacing within the row was 0.15m and later thinned to 0.3 meter. One variety was planted on each bed. Prior to planting, ammophosko fertilizer at a 80-80-60 rate was worked into each bed.

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[1]Project Advisor, Mekong Delta Soils Project, University of Cantho, Cantho, Vietnam and Research Assistant, Mekong Delta Soils Project.

The statistical design was a randomized complete block with four replications totaling 76 plots.

Data was kept on emergence, plant heights, insect and disease damage, yield, rainfall, date of flowering, and maturity. Only emergence, rainfall, and yield data was retrieved.

Results and Discussion

Table 1 shows the emergence counts on two separate days, October 16 and October 22, 1975, for each variety and each replication. Also shown is the average emergences, and the average percent change in emergence using the October 16, 1975 counts as a base.

Table 2 shows the rainfall from October 10, 1974 until December 25, 1975. On October 12, 1974 69mm (2.72") of rainfall flooded some portions of the plots; the excess water was pumped out within a few hours. The soil remained saturated for several days. On October 16, 1974 emergence counts were taken on all plots (Table 1). Emergence, although continuing, was much less than the 120 seeds planted. The lower emergence was possibly influenced by excessive soil moisture. The better stands were observed on the higher plot sections.

On October 17, 1975, 103.5mm (4.07") flooded most of the plots; pumping was not possible until approximately 36 hours later. Emergence counts on October 22, 1975 (Table 1) showed indeed that prolonged excessive moisture influenced emergence and stand. Most plots showed a decrease in the number of plants; a few plots did show an increase indicating the emergence had not ceased. On the average, only the Local Check showed an increase in number of plants; all other varieties showed a decrease.

Because other factors (difference in viability) may have influenced emergence, an analysis of variance was not determined for emergence counts. Based only on the average percent emergence change (%ΔE-Table 1) from October 16, 1975 until October 22, 1975, Local Check, Phil DMR 2, Cuprico Flint Comp DMR, Bogor Comp 2, and Thai Comp DMR must be judged as varieties most able to withstand prolonged excessive moisture.

Table 3 shows the yields in mt/ha for each variety in each replication. Because of poor stands, yields were calculated on the basis of any available 1/2 row. This yield data was judged unsuitable for an analysis of variance. A comparison is made on the basis of average yield with the realization that these figures serve only as a relative indicator of varietal yielding potential. The better yielding varieties were Synthetic 99, EH 3407, Syn P_{200}x Kesan, Mardi Comp2, and Local Check.

Varieties	REPLICATIONS I		II		III		IV		AVERAGE EMERG			RANK
	10/16	10/22	10/16	10/22	10/16	10/22	10/16	10/22	10/16	10/22	%ΔE	%ΔE
UPCA VAR.1	85	81	62	55	43	40	45	38	58.8	53.5	-9.0	12
PHIL.DMR 2	66	64	82	82	93	90	44	42	71.2	69.5	-2.4	2
PHIL DMR 3	82	83	58	46	82	75	57	54	69.8	64.5	-7.6	10
EH 3407	19	22	41	37	33	32	89	78	45.5	42.3	-7.0	9
THAI COMP. 1 DMR	46	44	68	68	65	51	61	65	60.0	57.0	-5.0	5
CUPRICO FLINT COMP. DMR	35	36	13	13	65	61	11	10	31.0	30	-3.3	3
LOCAL CHECK	27	47	87	62	58	67	51	51	55.8	56.8	+1.8	1
GUATEMALA PB5	7	6	41	40	70	60	38	32	39.0	34.5	-11.5	17
GENJAH KRETEK	4	4	14	11	13	13	63	56	23.5	21.0	-10.6	15
P.C. 1501	13	12	65	60	41	36	29	28	37.0	34.0	-8.1	11
SYN. P_{200} X KISAN	28	29	31	29	74	64	87	75	55.0	49.3	-10.4	14
HUNIS COMP.	34	31	20	20	69	66	77	69	50.0	46.5	-7.0	8
PHIL.DMR 6	38	35	71	63	45	42	42	33	49.0	43.3	-11.6	18
BOGOR COMP 2	23	38	101	82	72	70	58	54	63.5	61.0	-3.9	4
PHIL DMR 4	12	30	42	40	89	68	77	68	55.0	51.5	-6.4	7
SYN. 99	55	62	88	65	95	94	97	70	83.8	72.8	-10.8	16
MARDI COMP.C_2	2	8	50	42	79	66	61	57	48.0	43.3	-9.8	13
PHIL DMR 1	39	55	79	58	48	42	50	48	54.0	50.8	-5.9	6
PHIL. DMR 5	60	56	44	53	104	63	51	53	64.8	56.3	-13.1	19

Table 1. Emergence count of corn varieties on two different dates; average emergence, change in emergence, etc.

Table 2. Rainfall in mm from October 10 - December 25, 1974.

Date	mm	Date	mm
10/10/74	13.8	11/7/74	15.7
10/12/74	69.0	11/13/74	72.5
10/17/74	103.5	11/14/74	44.5
10/18/74	2.9	11/17/74	15.7
10/19/74	33.0	11/20/74	2.7
10/21/74	3.0	11/11/74	11.7
10/27/74	83.0	11/24/74	3.5
11/1/74	21.8	12/16/74	10.2
11/2/74	16.0	12/25/74	27.0
11/3/74	17.2	TOTAL	566.7

Table 3. Corn yield in MT/ha. Based on 1/2 row.

Variety	REPLICATIONS				AVERAGE
	I	II	III	IV	
UPCA VAR.1	11.47	13.00	3.38	3.00	7.71
PHIL DMR 2	8.10	5.61	5.01	6.00	6.18
PHIL DMR 3	9.88	6.55	7.31	6.75	7.62
EH 3407	12.00	11.33	6.95	9.33	9.90
THAI COMP. 1 DMR	7.80	9.17	9.94	6.05	8.24
CUPRICO FLINT COMP.DMR	11.33	11.62	7.94	4.66	8.88
LOCAL CHECK	9.44	11.44	6.50	8.56	8.98
GUATEMALA PB5	6.80	7.24	7.44	8.05	7.38
GENJAH KRETEK	1.73	9.33	10.44	5.16	6.66
P.C. 1501	4.16	10.11	8.04	8.94	7.81
SYN. P_{200} X KISAN	8.62	8.61	9.12	10.90	9.31
HUNIS COMP	5.85	8.18	6.50	4.94	6.36
PHIL DMR 6	3.81	9.02	1.11	4.42	4.59
BOGOR COMP 2	8.22	9.11	11.33	2.71	7.84
PHIL DMR 4	7.33	9.61	6.92	4.23	7.02
SYNTHETIC 99	6.22	11.48	8.24	15.35	10.32
MARDI COMP.C_2	2.34	6.83	9.61	6.86	8.99
PHIL DMR 1	7.38	9.94	7.42	8.72	8.36
PHIL DMR 5	9.52	8.40	9.05	6.82	8.44

Conclusion

The present data is insufficient to make any rigorous conclusions in selecting varieties for wet season production. However, based only on indications of their apparent abilities to withstand prolonged excessive soil moisture, and their apparent relative yielding capacities, the Local Check, Cuprico Flint Comp DMR, EH 3407, Phil DMR 1 and Synthetic 99 are varieties which deserve further testing.

Appendix 32

IRRIGATION PRACTICES FOR TRADITIONAL AND PRECISION LEVELED FIELDS IN PAKISTAN[1]

Arshad Ali, Wayne Clyma and Mohammad Ashraf[2]

Programs for the optimum use of water in agriculture require a knowledge of the irrigation practices of farmers in Pakistan. Understanding farmer's practices together with a quantitative determination of how he uses his water forms the basis by which the problems in irrigated agriculture in Pakistan can be defined. Understanding is the basis on which recommendations for assisting farmers in the optimum use of their water should be made.

Irrigation practices for several different areas in Pakistan have been studied. The effects of these practices on the quantitative use of water will be presented. A brief review of the improvements in farm water management provided by precision leveled fields will also be presented.

IRRIGATION PRACTICES

A quantitative approach to farm water management is necessary to evaluate irrigation practices on any field. Before irrigation practices can result in effective use of water, the researcher and the farmer must become aware of the quantitative implications of the amount of water he applies to a field and the amount of water that is available in the soil. The two aspects of quantitative water management which will be emphasized in this discussion are:

1. The amount of irrigation water applied must be measured.

2. The soil moisture status must be measured or computed.

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[1]Paper prepared for presentation at the CENTO Panel Meeting on the Optimum Use of Water in Agriculture, March 3-5, 1975. This research was supported in part by USAID Contract AID/ta-c-1100 Water Management Research in Arid and Sub-humid Lands of the Less Developed Countries.

[2]Assistant Professor and Chairman, Department of Irrigation and Drainage, Faculty of Agricultural Engineering, University of Agriculture, Lyallpur; Agricultural Engineer, Colorado State University, Water Management Research Contract, Islamabad, and Project Director, Mona Reclamation Experimental Project, Water and Power Development Authority, Bhalwal, respectively.

Without measuring the amount of water that is applied to a particular bunded area or field, the amount of water applied, according to approximately 700 observations of individual fields, can range from less than one inch to in excess of thirteen inches. The soil moisture deficiency at the time of irrigation, based on estimates of approximately 300 observations, can range from zero to six inches (in.) in the top four feet of soil. In a number of instances, the amount of water that can be stored is near the minimum while the amount of water applied was near the maximum. Among researchers and eventually among farmers a quantitative approach to farm water management is essential for proper use of irrigation water.

Since present preliminary data suggest that the amount of water applied and the soil moisture status at the time of irrigation is substantially different in supplemented water supply areas as compared to unsupplemented water supply areas, the water management practices in these two areas will be discussed separately. First, however, brief reviews of the factors affecting the amount of water applied during an irrigation and the soil moisture status at the time of an irrigation will be presented.

Amount of Water Applied

Probably the most universal irrigation practice in Pakistan is that researchers and farmers apply water to a field until all of the field is covered with water including any high spots. The amount of water applied under this circumstance is assumed to be either three inches or four inches depending upon the depth of water present on the field at the time the water application is stopped.

The amount of time required to apply a given amount of water (three acre inches per acre for example) to a given area depends only upon the rate (discharge in cusec for example) at which it is applied. The amount applied in covering a given area depends upon the discharge, surface topography (levelness and slope), infiltration rate, size of field, field geometry 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. The assumption of researchers and farmers that the amount of water applied in covering any given area is constant is responsible for much of the ineffective use of water in Pakistan.

A more detailed discussion of how the factors affecting the amount of water applied is given by Clyma, Ali and Ashraf (1975a). The principal conclusion is that these factors interact to result in the range in amounts of water

applied of one to thirteen inches. The amount of water applied may be anywhere within this range but the result is accidental without some form of water measurement.

Soil Moisture Status

The amount of water applied during a given irrigation should be primarily a function of the amount of water that can be stored in the soil. Water may also be applied to a field to permit tillage, to provide water for germination, for temperature control and to reduce surface or soil salinity. However, the primary reason for application of irrigation water is to replenish the soil moisture. Thus, if the soil moisture deficiency is one inch, then only one inch of irrigation water should be applied. If the soil moisture deficiency is six inches, then commonly six inches of irrigation water should be applied.

Experience may suggest that the minimum amount of water that can be applied to a field to effectively irrigate all the field is two inches and thus it would be ineffective use of irrigation water to attempt to apply only one inch. In addition, in some soils to attempt to apply six inches in one irrigation would result in excessive overtopping of bunds or may result in inundation times, because of low infiltration rates, that would kill any crops growing on the field. These conditions suggest that practical considerations may again alter the amount of water that is actually applied to the field but the principal objective of an irrigation is to replenish the soil moisture deficiency.

Factors which affect the soil moisture deficiency at the time of irrigation are: soil texture, crop stage of growth, length of time between irrigations, climatic factors which affect evapotranspiration, depth of ground water, and the amount of water applied at the previous irrigation. These factors also interact such that one may negate the principal effect of the other. For example, climatic factors during April, May and June result in a large amount of potential evapotranspiration. However, if the crop was just planted during this period then the actual water use will be a small fraction of the potential so that the soil moisture deficiency at the time of an irrigation may also only be a small fraction of what is normally expected.

The practice of farmers in the United States and also observed here in Pakistan, is that they tend to apply too much water too frequently during the early and late stages of growth of the crop and too little water during the peak consumptive use periods. The result is that wastage of water occurs early and late during the season because of over-irrigation and excessive moisture stresses result during the period of peak consumptive use resulting in substantial

reductions in yield. The effects of amount of water applied and soil moisture deficiency on farmer irrigation practices on supplemented and unsupplemented watercourses will now be discussed.

Supplemented Water Supply Areas

Amount of water applied during an irrigation has been measured on farmers' fields for Mona (a SCARP Area), for private tubewell supplemented areas near Shadab, Mian Channu, and Multan. Measurements have also been made for a number of unsupplemented watercourses in Lyallpur District.

Mona

Table 1 presents the results on amounts of water applied given by Clyma, Arshad and Ashraf (1975a) for the Mona area on SCARP watercourses. Table 2 presents additional data for the SCARP area. The median amount of water applied in the two different sets of data are different. The median amount of water applied from Table 1 is 4 to 5 inches and in Table 2 is 2 to 3 inches. The data in Table 2 were collected during a period of watercourse construction when the use of the tubewell was restricted. Water was supplied to the farmers at a reduced rate and in by-pass channels with resulting excessive watercourse losses. This has resulted in a reduced supply of water throughout the period the data were collected.

Another factor has contributed to the large number of small amounts of water applied. For a period of approximately one month in November of 1974 an enumeration of fields that were partially irrigated was made. The fields that were partially irrigated represented 20 percent of the total sample and all application amounts were less than 2 inches. The partial irrigations accounted for 60 percent of the total application amounts that were less than 2 inches. The conclusion is that the data in Table 2 represents a considerable number of fields that are partially irrigated.

Shadab

Irrigation practices on a watercourse in the Shadab area have been observed since October 1974. This is a private tubewell supplemented watercourse but one additional feature of the supply is that much of the area commanded by the mogha is above the full supply water level in the watercourse and jalars must be used to lift the water. Unusual amounts of water is lost from the watercourse (Clyma, Ali, and Ashraf, 1975a) with the result that the supply rate at the field is very low. The results of the limited number of observations are presented in Table 3. The median application amount for canal water only is between 2 and 3 inches and for tubewell

Table 1. Application Amounts Applied During an Irrigation from November 1972 to November, 1973 for Mona (from Clyma, Ali and Ashraf, 1975a).

Depth of Application (in.)	Number of Observations	Percent of Total	Total Accumulated
0 ≤ 1	0	0	0
1 ≤ 2	2	4	4
2 ≤ 3	3	6	10
3 ≤ 4	10	19	29
4 ≤ 5	11	21	50
5 ≤ 6	8	15	65
6 ≤ 7	4	8	73
7 ≤ 8	7	13	86
8 ≤ 9	1	2	88
9 ≤ 10	4	8	96
≥ 10	2	4	100
Totals	52	100	

Table 2. Application Amounts Applied During an Irrigation from November, 1973 to January, 1975 for Mona

Depth of Application (in.)	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	100.00
Totals	393	100.00	

Table 3. Application Amounts Applied During an Irrigation for Both Canal and Tubewell Water in the Shadab Area.

Depth of Application (in.)		Number of Evaluations	Percent of Total	Total Accumulated
		All Observations		
1 ≤ 2.0		11	28.0	28.0
2 ≤ 3.0		12	30.0	58.0
3 ≤ 4.0		10	25.0	83.0
4 ≤ 5.0		7	17.0	100.0
	Totals	40	100.0	
		Canal Water Only		
1 ≤ 2.0		10	37.0	37.0
2 ≤ 3.0		11	40.0	77.0
3 ≤ 4.0		4	15.0	92.0
4 ≤ 5.0		2	8.0	100.0
	Totals	27	100.0	
		Tubewell Water Only		
1 ≤ 2.0		1	8.0	8.0
2 ≤ 3.0		1	8.0	16.0
3 ≤ 4.0		6	46.0	62.0
4 ≤ 5.0		5	38.0	100.0
	Totals	13	100.0	

water is between 3 and 4 inches. Such a difference is surprising for such a limited number of observations, but is at least partially explained by the fact that a servant both operated the tubewell and irrigated the field resulting in excessive application of water.

Mian Channu

Observations of farmer irrigation practices were conducted for the rabi 1973-74 on several farms near Mian Channu.[1] A number of observations were on different farms and others are for subsequent irrigations during the growing season for wheat. Again, the median amount of water applied when using canal water was between 2 and 3 inches while the median amount applied using tubewell or tubewell plus canal water was between 3 and 4 inches (Table 4). Furthermore, the percent of the total applications in excess of 5 inches was 24 percent while none of the applications using canal water only exceeded 5 inches.

Multan District

An evaluation of the amounts of water applied on a watercourse in Multan District during the latter part of June, 1974 was conducted when farmers were given rauni irrigations for cotton. In 94 percent of the instances for tubewell water and 74 percent for canal water (Table 5) the water was for rauni. This caused the higher percentage of applications greater than 5 inches for the canal water as well as contributed to the higher median applications for the tubewell water. Many of the higher application amounts were on 0.5 to 1.0 acre fields with a relatively low flow during the time of irrigation. Median application amounts (Table 5) for canal water only were between 3 and 4 inches and for tubewell water only was between 4 and 5 inches.

Unsupplemented Water Supply Areas

A large area in Lyallpur District is not a part of any SCARP, and because of relatively saline ground water there are very few private tubewells. In these areas the water supply is inadequate and as would be expected, irrigation practices differ as compared to supplemented water supply areas. Table 6 presents the results of some 200 observations of irrigation applications for canal water only and tubewell plus canal water. The median application amount for tubewell

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[1] Results from "Effects of Precision Land Leveling on Farm Management and Irrigation Practices in Pakistan" by P.G.M. van der Boom and T.L.M.H. Gerards. Unpublished report of Agricultural University of Wageningen, the Netherlands. Agricultural Extension and Farmers Training Center, and Colorado State University.

Table 4. Application Amounts for Canal Water and Private Tubewell Supplemented Watercourses in the Mian Channu Area.

Depth of Application (in.)	Number of Observations	Percent of Total	Total Accumulated
	All Observations		
1 ≤ 2	3	10	10
2 ≤ 3	9	28	38
3 ≤ 4	7	22	60
4 ≤ 5	9	28	88
5 ≤ 6	2	6	94
6 ≤ 7	-	-	-
7 ≤ 8	2	6	100
Totals	32	100	
	Canal Water Only		
1 ≤ 2	3	20	20
2 ≤ 3	5	33	53
3 ≤ 4	1	7	60
4 ≤ 5	6	40	100
5 ≤ 6	-	-	-
6 ≤ 7	-	-	-
7 ≤ 8	-	-	-
Totals	15	100	
	Tubewell plus Canal or Tubewell Water Only		
1 ≤ 2	-	-	-
2 ≤ 3	4	23	23
3 ≤ 4	6	35	58
4 ≤ 5	3	18	76
5 ≤ 6	2	12	88
6 ≤ 7	-	-	-
7 ≤ 8	2	12	100
Totals	17	100	

Table 5. Application Amounts for Irrigations from Canal Water Only and Tubewell Water Only for June 12-27, 1974 on a Watercourse in Multan District.

Depth of Application (in.)	Number of Observations	Percent of Total	Total Accumulated
	Canal Water Only		
1 ≤ 2	3	3	3
2 ≤ 3	18	20	23
3 ≤ 4	33	29	52
4 ≤ 5	20	19	71
5 ≤ 6	14	13	84
6 ≤ 7	8	8	92
7 ≤ 8	2	2	94
8 ≤ 9	1	1	95
9 ≤ 10	2	2	97
10 ≤ 11	2	2	99
11 ≤ 12	1	1	100
Totals	104	100	
	Tubewell Only		
3 ≤ 4	5	31	31
4 ≤ 5	6	38	69
5 ≤ 6	3	19	88
6 ≤ 7	2	12	100
Totals	16	100	

Table 6. Application Amounts From Canal Irrigations in a Non-SCARP Area of Lyallpur District.

Depth Application (in.)	Number of Observations	Percent of Total	Total Accumulated
	Canal Water Only		
0 ≤ 1	7	6	6
1 ≤ 2	33	21	27
2 ≤ 3	55	36	63
3 ≤ 4	30	19	82
4 ≤ 5	15	8	90
5 ≤ 6	8	5	95
6 ≤ 7	3	2	97
7 ≤ 8	2	2	99
8 ≤ 9	1	1	100
Totals	154	100	
	Tubewell Plus Canal Water		
1 ≤ 2	7	15	15
2 ≤ 3	15	33	48
3 ≤ 4	10	22	70
4 ≤ 5	8	18	88
5 ≤ 6	2	4	92
6 ≤ 7	2	4	96
7 ≤ 8	1	2	98
13 ≤ 14	1	2	100
Totals	46	100	

plus canal water is again higher than for canal water only. For all the observations the median application is between 2 and 3 inches for canal water only and between 3 and 4 inches for tubewell plus canal water. Almost twice as many supplemented applications exceed 4 in. as do unsupplemented applications.

In actuality, a more direct comparison can be made between supplemented and unsupplemented water supply practices. The following median application amounts for irrigations with canal water only or with tubewell water only and tubewell plus canal water are given in Table 7. The largest difference is between the SCARP area and the non-SCARP, unsupplemented area. Two to three inches is the median application for unsupplemented areas except one. In Multan district most of the observations involved rauni irrigations and the median application is higher as would be expected.

Comparison of Supplemented and Unsupplemented Areas

Irrigation practices as measured by the amount of water applied differ from unsupplemented as compared to supplemented water supply areas. A number of factors probably cause this circumstance some of which are not known and others have not been documented. One factor which has several different effects, is size of the irrigation unit or bunded area of the field.

An analysis of the size of irrigation unit for Lyallpur District, Multan District and Mona is given in Tables 8, 9 and 10 respectively. The results are:

Type of Water Supply	Median area
Unsupplemented (Lyallpur)	$0.2 \leq 0.3$
Supplemented	
Lyallpur	$0.3 \leq 0.4$
Sargodha	$0.4 \leq 0.5$
Multan	$0.4 \leq 0.5$

These results suggest that the size of the irrigation unit in supplemented water supply areas is nearly double the size in unsupplemented water supply areas. This circumstance causes the median application amount to be higher for several different reasons.

For a constant water supply rate, the amount of water applied increases as the size of the irrigation unit increases. This occurs because a longer time is required to apply a given

Table 7. Median Application Amounts for Supplemented and Unsupplemented Water Supply Areas.

Location	Median Amount of Irrigation (in.)	
	Supplemented	Unsupplemented
Mona	4 ≤ 5	
Lyallpur District	3 ≤ 4	2 ≤ 3
Shadab	3 ≤ 4	2 ≤ 3
Mian Channu	3 ≤ 4	2 ≤ 3
Multan District	4 ≤ 5	3 ≤ 4

Table 8. Size of Irrigation Unit for Non-SCARP Area of Lyallpur District.

Area Interval (acres)	Number of Observations	Percent of Total	Total Accumulated
	Canal Water Only		
0 ≤ 0.1	18	11	11
0.1 ≤ 0.2	43	27	38
0.2 ≤ 0.3	33	20	58
0.3 ≤ 0.4	9	6	6
0.4 ≤ 0.5	10	6	70
0.5 ≤ 0.6	24	15	85
0.6 ≤ 0.7	6	4	89
0.7 ≤ 0.8	1	1	90
0.8 ≤ 0.9	1	1	91
0.9 ≤ 1.0	4	3	94
> 1.0	10	6	100
Totals	159	100	
	Tubewell Plus Canal Water		
0.1 ≤ 0.2	11	24	24
0.2 ≤ 0.3	10	21	45
0.3 ≤ 0.4	3	7	52
0.4 ≤ 0.5	3	7	59
0.5 ≤ 0.6	14	30	89
0.6 ≤ 0.7	3	7	96
0.7 ≤ 0.8	1	2	98
0.8 ≤ 1.0	1	2	100
Totals	46	100	

Table 9. Size of Irrigation Unit for the SCARP Area at Mona.

Area Interval (acres)	Number of Observations	Percent of Total	Total Accumulated
0 ≤ 0.1	4	1	1
0.1 ≤ 0.2	18	5	6
0.2 ≤ 0.3	68	17	23
0.3 ≤ 0.4	41	10	33
0.4 ≤ 0.5	91	23	56
0.5 ≤ 0.6	117	30	86
0.6 ≤ 0.7	14	4	90
0.7 ≤ 0.8	10	2.5	92.5
0.8 ≤ 0.9	6	1.5	94.0
0.9 ≤ 1.00	7	2.0	96.0
> 1.00	17	4.0	100.00
Totals	393	100.00	

Table 10. Size of Irrigation Unit for a Private Tubewell Supplemented Watercourse in Multan District.

Area Interval (acres)	Number of Observations	Percent of Total	Total Accumulated
0-≤ 0.1			
0.1-≤ 0.2	1	1	1
0.2-≤ 0.3	20	15	16
0.3 ≤ 0.4	1	1	17
0.4 ≤ 0.5	60	47	64
0.5 ≤ 0.6	11	8	72
0.6 ≤ 0.7	2	1	73
0.7 ≤ 0.8	4	3	76
0.8 ≤ 0.9	1	1	77
0.9 ≤ 1.0	15	12	89
> 1.0	14	11	100
Totals	129	100	

amount of water and the longer time results in more water infiltrating the soil. Thus, to cover the field, more water will have to be applied to compensate for that already in the soil.

As the size of the irrigation unit increases the absolute difference in elevation between the lowest point and the highest point will increase. To maintain a level field, the farmer must expend more effort in leveling his field or a poorer leveled field will result.

As the distance over which leveling must be accomplished increases, more difficulty is encountered in leveling a field. Clyma, Ali and Ashraf (1975a) concluded that unleveled fields cause farmers to apply additional irrigation water to cover the high areas. Sometimes as much as twice the amount of water is applied to a field in covering the high area as would be required if the field were precisely level. These factors suggest that farmers with a short water supply reduce the size of their irrigation unit, more precisely level their fields and, as a result, apply less water during a given irrigation. To understand some of the broader implications of these practices, a quantitative discussion of these practices will now be presented.

Quantitative Water Management

To effectively evaluate irrigation practices requires not only a knowledge of the amount of water applied but also the amount of water needed in the soil (the soil moisture deficiency). The amount of water stored in the soil for a given irrigation and the seasonal pattern for a given crop are also important. The result permits a quantitative evaluation of irrigation practices and also provides a basis for suggesting improvements in farm water management.

Application Efficiency

Irrigation application efficiency, E_a, is defined as:

$$E_a = \frac{\text{water stored in the root zone}}{\text{water applied to the field}}$$

When the amount of water applied is less than the amount that can be stored in the root zone, the amount applied equals the amount stored and an application efficiency of 100 percent results. A number of the factors which affect both the amount of water stored in the root zone and the amount of water applied have been discussed in a previous section.

Application efficiencies for 64 observations in a SCARP area and 200 observations in a non-scarp with both unsupplemented and supplemented water supplies area are summarized in Tables 11 and 12. Table 11 was taken from Clyma, Ali and

Table 11. Irrigation Application Efficiencies Observed at Mona on Traditionally Farmed Fields for the Period November, 1972 to November, 1973 (from Clyma, Ali and Ashraf, 1975a).

Application Efficiency Interval (Percent)	Total for Interval	Percent of Total Observations	Total Accumulated
0 ≤ 10	13	20	20
10 ≤ 20	17	26	46
20 ≤ 30	16	25	71
30 ≤ 40	7	11	82
40 ≤ 50	2	3	85
50 ≤ 60	3	5	90
60 ≤ 70	1	2	92
70 ≤ 80			
80 ≤ 90			
90 ≤ 100	5	8	100
Total	64	100	

Table 12. Irrigation Application Efficiencies for Non-SCARP Areas of Lyallpur District for April through September, 1974.

Application Efficiency (Percent)	Number of Observations	Percent of Total	Total Accumulated
	Canal Water Only		
0 < 10	5	4	4
30 ≤ 40	4	3	7
40 ≤ 50	8	5	12
50 ≤ 60	8	5	17
60 ≤ 70	11	7	24
70 ≤ 80	14	9	33
80 ≤ 90	6	4	37
90 ≤ 100	98	63	100
Totals	200	100	
	Tubewell Plus Canal Water		
0 ≤ 10	-	-	-
30 ≤ 40	1	2	2
40 ≤ 50	-	-	-
50 ≤ 60	3	7	9
60 ≤ 70	3	7	16
70 ≤ 80	1	2	18
80 ≤ 90	4	8	26
90 ≤ 100	34	74	100
Totals	46	100	

Ashraf (1975a) and the major conclusion was that application efficiencies are low and much wastage of water occurs. In the SCARP area the median application efficiency was between 20 and 30 percent with only a limited number of underirrigations. The results suggest that improving farm water management can increase water supplies substantially and increase the effectiveness of attempts to reduce waterlogging and salinity.

The results in the unsupplemented water supply area suggest a different pattern of practice. Two-thirds of the observations (Table 12) consist of underirrigations and only 12 percent applied more than twice as much water as can be stored. The supplemented water supply had higher application efficiencies and more underirrigation. Observations of canal water only were throughout kharif. The observations for supplemented irrigations were for the first half of September only. This condition may imply effective use of water but may actually result in ineffective use of water. Further measurements during the monsoon and rabi must be obtained to determine if the seasonal and annual pattern of use results in salinity accumulations. Also the effect of underirrigation on crop stress must be evaluated for the season in order to properly evaluate water management practices to determine the needed improvements.

In unsupplemented water supply areas with a water supply rate similar to the Lyallpur District, overirrigation does not appear to be a prevalent practice. How seasonal patterns influence water management practices will now be discussed.

Seasonal Irrigation Practices

Individual applications can be in excess or deficient while the seasonal use of water can be good. A better understanding of water management practices and better procedures for improving those practices can be developed through an understanding of the seasonal pattern of use for particular crops. Seasonal irrigation practices for wheat for three types of water supply conditions will be discussed: (1) SCARP, (2) Private tubewell supplemented and (3) Unsupplemented.

SCARP Watercourses

The first two of the four irrigations for a farmer's field of wheat were measured for the rabi 72-73 season. The soil moisture deficiency was also measured at the time of irrigation. The dates for the additional irrigations were obtained from farmer interview at the end of the season. Evapotranspiration was estimated from the results of Haider, Farooqi and deMooy (1975). Amounts of water applied were estimated from measurements on other farmer's fields on the same watercourse.

The results are plotted in Figure 1 showing the amount of water applied, the amount of intervening rainfall, the evapotranspiration for the previous interval, the water in storage in a four foot root zone and assuming a water holding capacity of 2.0 inches per foot of depth for the soil, the amount of water stored from each irrigation and the amount of deep percolation or excess irrigation water applied.

The 9 inch rauni application was measured and was applied by the farmer to fill a 1.5 inch deficiency in the top foot of soil. Deep percolation was excessive especially during the first two irrigations. Excessive soil moisture deficiencies are implied at the time of the third irrigation by the results presented in Figure 1. Actually, use of a soil probe had shown free water at 3.5 feet resulting from a high water table and soil moisture was not limiting crop growth. The seasonal results from Figure 1 are:

	Inches
Total evapotranspiration	16.0
Total water applied	24.1
Rainfall	2.8
Deep percolation	16.0
Amount of water stored	10.9
Seasonal application efficiency	40 percent

Water use from the water table will decrease the amount used from the soil root zone decreasing the amount stored during the last two irrigations by an estimated 4.75 inches. The resulting seasonal application efficiency is estimated to be 25 percent.

The results do graphically illustrate the tendency to irrigate too much, too frequently early in the season and too little during the period of peak water use. Farmer practices are to apply 4 to 6 irrigations but this farmer applied fewer. Without a high water table his crop yield would have been drastically reduced. His practice may have been planned or accidental.

Private Tubewell Supplemented

Irrigation practices in the Mian Channu area were suited for a season during rabi 73-74 as previously described. A portion of the irrigations were measured and the dates of the others obtained from farmer interview. The rauni irrigation, the 5th and 10th irrigations were measured. The data show the pattern for a private tubewell supplemented area and the number of seasonal irrigations are the median for 20 farmers interviewed in the area. The principal difference in

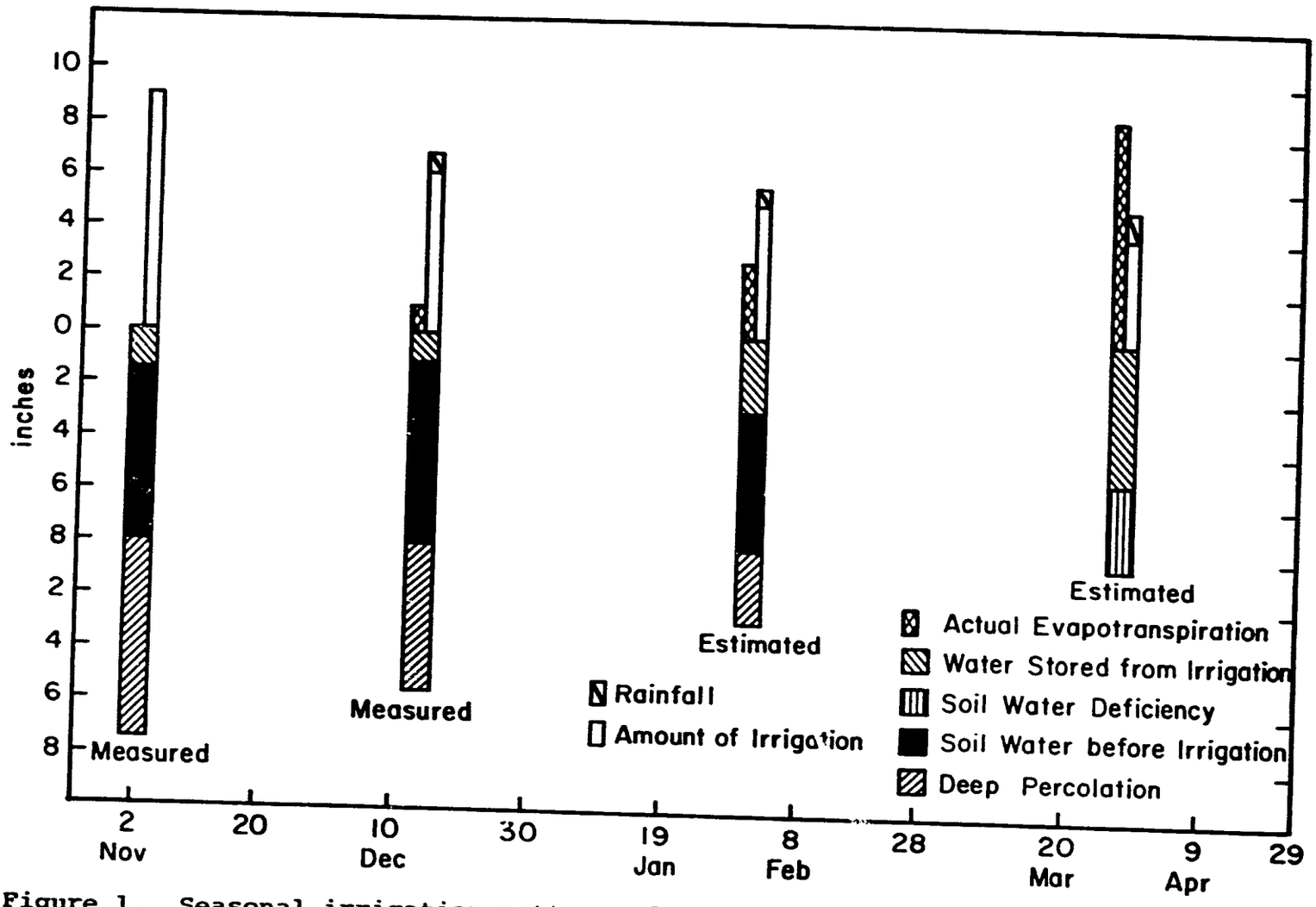

Figure 1. Seasonal irrigation pattern of a wheat field in a SCARP Area of Sargodha District during 1972-73.

this field from other fields is that it is a 35 x 800 ft. border that has been leveled. The leveling reduced the average amount of water applied per irrigation from the median amounts reported for the Mian Channu area in Table 4.

Seasonal irrigation practices for a private tubewell supplemented area shown in Figure 2 are:

	Inches
Evapotranspiration	19.7
Total water applied	32.9
Rainfall	1.8
Deep percolation	13.1
Amount of water stored	19.7
Seasonal application efficiency	55 percent

The farmer with a private tubewell has the flexibility of supply to apply weekly irrigations during the periods when he thinks the water is needed. If, however, the average application had been the median observed for supplemented watercourses or 3.5 inches, then the seasonal application efficiency would have been 40 percent. Thus, the pattern of applications and the amount of application can be more nearly adjusted to meet the crop water requirements, but as presently evaluated this farmer does a much better job of farm water management than the average farmer.

Unsupplemented Water Supply

Figure 3 represents a season pattern of irrigations based on partial seasonal data from several different fields. The initial soil water content at the time of rauni can be variable dependent upon the canal supplies for that particular year. Observations in some canal water only areas had suggested that the soil profile to four feet would be at field capacity except for the first foot. Observations at the beginning of rabi 74-75 during a water short year usually measured very dry profiles. When the profile is not full at the beginning of the season, the water in excess of evapotranspiration goes to replenish the soil water. In this instance the third irrigation had an excess of about 0.4 in. and the remaining irrigations were underirrigations. After the middle of March soil moisture deficiencies were exceeding 50 percent of the available. Longer irrigation intervals or a missed turn during this period would result in severe moisture stress and substantial yield reductions.

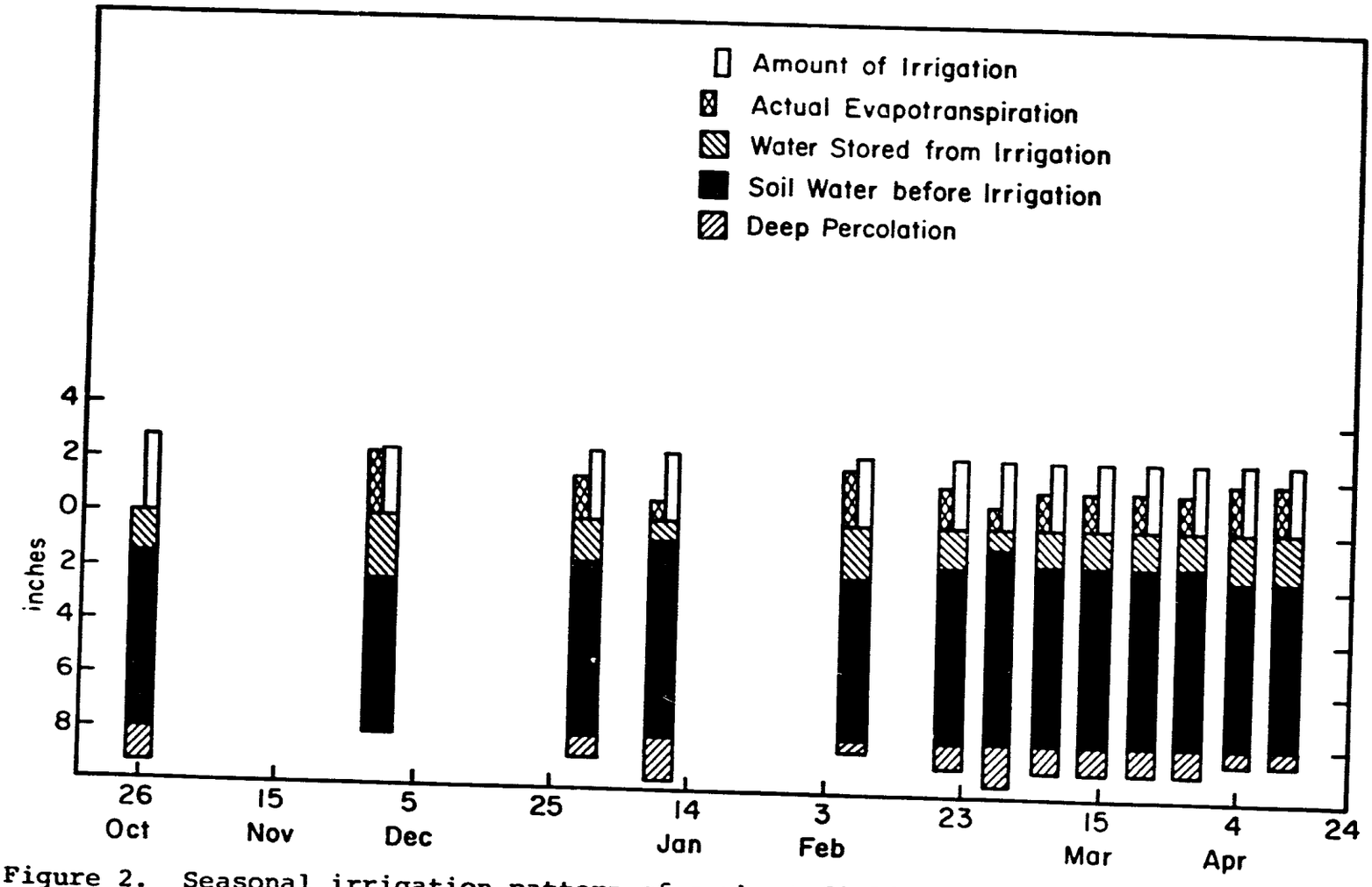

Figure 2. Seasonal irrigation pattern of a wheat field on a private tubewell supplemented farm near Mian Channu during 1973-74.

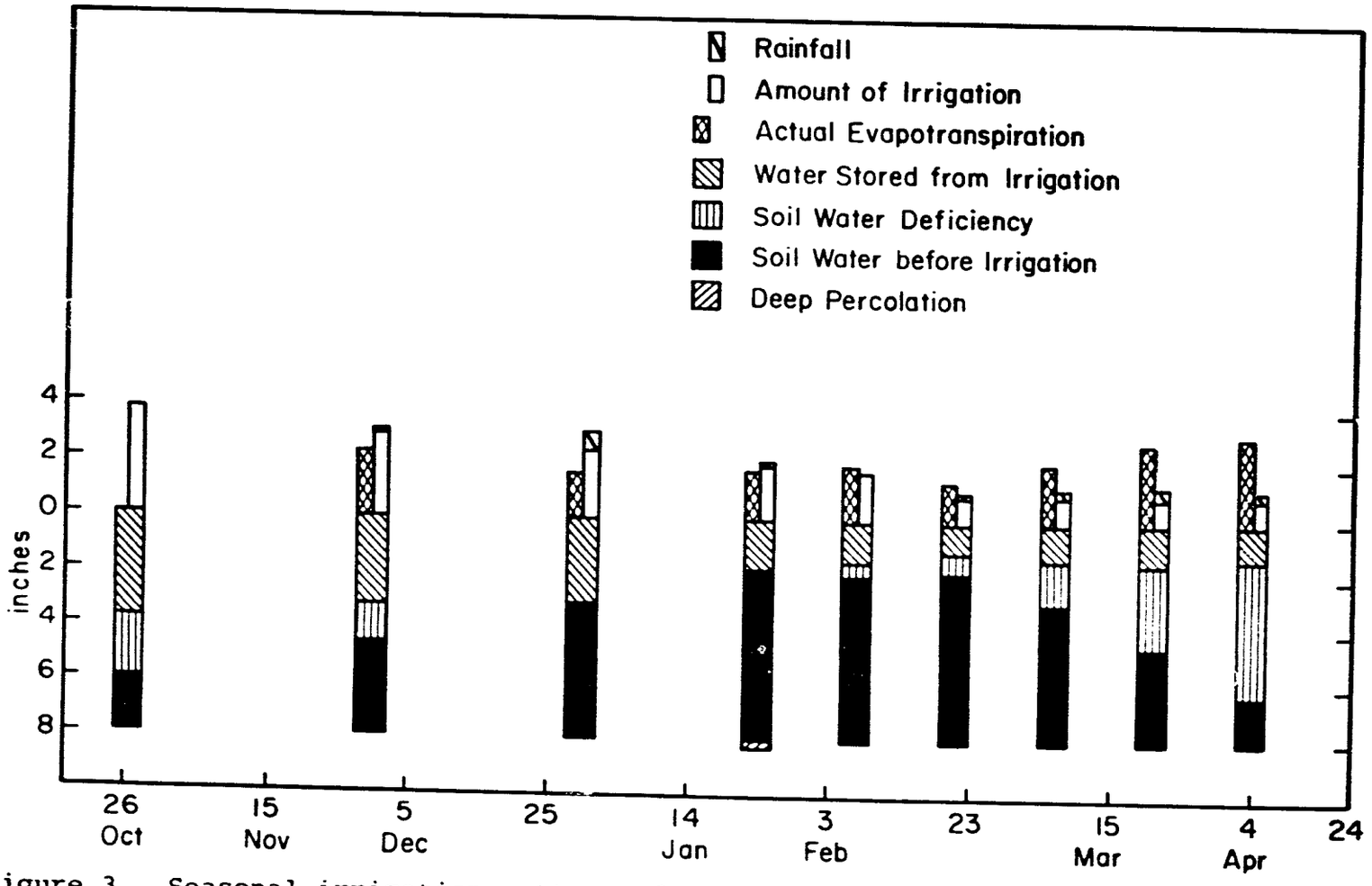

Figure 3. Seasonal irrigation pattern of a wheat field on a farm with only canal water supply near Mian Channu during 1973-74.

The results on water use for the unsupplemented area were:

	Inches
Evapotranspiration	17.40
Amount of water applied	17.0
Rainfall	1.8
Amount of water stored	16.8
Amount of deep percolation	0.4
Application efficiency	90 percent

The result implied from this seasonal pattern of water use is that excellent water management practices are being followed. Unless periodic excess applications at rauni or monsoon rainfall to provide leaching, salinity will become a problem. Also, the levels of soil moisture stress developed in March suggest yield reductions already have occurred or would if one irrigation turn is missed in this period.

Additional studies are needed of seasonal irrigation practices to better understand farmer water management practices. Understanding the seasonal pattern of water use will provide a better basis for improving farm water management practices in Pakistan.

PRECISION LAND LEVELING

Modern irrigation requires control of water for efficient use as well as maximum crop yields. Precision land leveling is a process of smoothing the land surface to a level plane without slope and with a maximum elevation variation of $\pm$ 0.05 inches. Dimick (1974) and Clyma, Ali and Ashraf (1975a), have reviewed various advantages of precision land leveling. In Pakistan the primary advantages are related to savings in water and improved yield.

Evaluations of fields after precision land leveling in Multan District, Mian Channu, Shadab and Sargodha District have resulted in measured savings in water of one-third to one-half on precision leveled fields compared to traditional fields. Uniformity of stands, uniformity of growth, reduced fertilizer leaching, and more uniform conditions for field operations all result in improved yield on precision leveled fields. Precision land leveling is expected to average near 600 rupees per acre but with many fields already nearly level, precision leveling will cost much less on these fields.[1]

Increased yields from land leveling come not only from increased yields on the acres already farmed but will result

[1]Private communication, Mr. Murray Cox and Mr. Tom Dempster.

in increased yields from the increase in cropping intensity. Since overirrigation will be reduced by precision land leveling, waterlogging and salinity will be reduced, will be more easily controlled and will cost less also.

Preliminary studies at Mona have shown 2 to 2.5 inches of water can be applied uniformly to a level border 28 x 640 ft. Reductions in watercourse length of up to 60 percent can also be achieved.

Observations of farmer irrigation practices on the precision leveled fields have shown much higher application efficiencies as compared with those on the unleveled fields. This indicates that the excessive water application on the unleveled fields, which is 2 to 4 times more than optionally needed in SCARP areas, can be minimized through precision land leveling. The importance of precision land leveling thus cannot be over emphasized. In a country like Pakistan, there is every need to utilize already short irrigation water most efficiently such that a given quantity of water can be used to grow more acreage. This is possible if fields are properly leveled.

References

Clyma, Wayne, Arshad Ali and Moh'd Ashraf, 1975a. Irrigation Practices and Application Efficiencies in Pakistan. WAPDA, Joint Contribution of Colorado State University and Directorate of Mona Reclamation Project, CMO, Publication No. 36, Bhalwal, January.

Dimick, N.A., 1972. Guide for Precision Land Forming in Pakistan. USAID/Islamabad.

Haider, G., Farooqi, M.A.R. and deMooy, C.J., 1975. Estimation of Consumptive Use of Water for Wheat Under Optimum Management Conditions. A paper presented in CENTO Panel Meeting on the optimum use of water in agriculture, March 3-5.

Clyma, Wayne, Arshad Ali and Moh'd Ashraf, 1975b. Watercourse Losses. A paper presented in the CENTO Panel Meeting on the optimum use of water in agriculture, March 3-5.

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Appendix 33

IMPROVED WATER AND LAND USE MANAGEMENT THROUGH PRECISION LAND LEVELING[1]

Arshad Ali, Wayne Clyma and Alan C. Early[2]

Abstract

Farmers in Pakistan use the level basin system of irrigation and expend considerable effort in attempting to maintain the level of their fields. Measurements of individual fields in Pakistan have shown that frequently the fields are not level and much wastage of the water results caused by excess water application and other management factors. An analysis of these factors is given from observations of the hydraulics of water application to level basins. Data from irrigation of leveled borders are presented to show the improvement in control of the amount of water application. The procedure of land use improvement through precision land leveling is described. The savings in water will improve yields on existing cultivated land, permit increasing the area under cultivation, and reduce salinity and waterlogging.

INTRODUCTION

Precision land leveling is the basic requirement of any successful surface irrigation project and would rank high in priority for any program directed at improving water management and reducing waterlogging and salinity. Though much of the agricultural land in the Indus plains has a natural topography well suited for irrigation, there is a great need for more precise land leveling to allow uniform application of irrigation water over the field, especially to prevent over irrigation, to improve the control of irrigation water and to provide for the removal of excess water (Clyma and Corey, 1974).

The farmers in Pakistan do level their fields by means of an indigenous karah without applying engineering techniques.

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[1]Paper prepared for presentation at the International Conference on Waterlogging and Salinity, Lahore, October, 1975, sponsored by the Dept. of Civil Engineering, University of Engineering & Technology. This research was supported in Part by USAID Contract AID/ta-c-1100, Water Management Research in Arid and Sub-Humid Lands of the Less Developed Countries.

[2]Chairman, Department of Irrigation and Drainage, Faculty of Agricultural Engineering, University of Agriculture, Lyallpur and Agricultural Engineers, Colorado State University, Water Management Research Contract/Pakistan, respectively.

Consequently, fields are frequently not precisely leveled. They remain sloping and/or have high and low spots resulting in considerable wastage of water due to non-uniform applications. Low places receive much more water than those at a higher elevation and high areas very little water. Thus, all the area in an undulating field does not concurrently reach wattar condition, a term describing the proper moisture content for planting a crop. By the time the low areas come to watter the high areas are too dry for optimum seed germination, and poor crop stands are the result. Reduced water applications on high spots can result in salinization and reduced crop yield. Substantial water savings and improved crop yields can be obtained if the field is leveled to permit all parts to be irrigated evenly.

In a survey of two watercourses near Lahore based on 4 elevation shots per acre, forty three percent of the acres had the maximum difference from the mean elevation greater than 0.10 foot. Ten percent of the acres had maximum difference from the mean of greater than 0.25 foot. Many of these acres were subdivided into smaller bunded areas so that this description does not present the entire picture.

Another way to present this data is as the maximum range of elevations within a given acre as follows:

Range of Elevations Per acre	No. of Acres	Cumulative Acres	Percent of total	Cumulative Percent
0.00	15	15	6	6
≤0.05	10	25	4	10
>0.05; ≤0.10	40	65	15	25
>0.10; ≤0.15	51	116	19	44
>0.15; ≤0.20	58	174	22	66
>0.20; ≤0.25	28	202	11	77
>0.25; ≤0.30	23	225	9	86
>0.30; ≤0.35	8	223	3	89
>0.35; ≤0.40	7	240	3	92
>0.40; ≤0.45	2	242	1	93
>0.45; ≤0.50	6	248	2	95
>0.50; ≤0.55	1	249	1	95
>0.55; ≤0.60	5	254	2	97
≥0.60	9	263	3	100

This latter description of the distribution of the land surface elevations indicates that only 25 percent of the area

surveyed had acres which were within the presently accepted criteria (0.10 ft. maximum difference) for level basins. Seventy five percent of the land surveyed in plots of one acre had elevation differences of greater than one tenth of a foot, and thirty four percent had elevation differences of greater than 0.20 feet.

The same two watercourse areas were divided into blocks of land rectangular to square in shape and of 6 to 10 acres in size. This is an approximation of the size that might be considered for leveling at one time by a farmer or group of farmers. The following table presents the frequency distribution of range of elevations encountered.

Range of Elevations (maximum-minimum)	Number of Blocks (6-10 acre size)
≤0.6 ft.	5
>.6; ≤0.8	10
>.8; ≤1.0	4
>1.0; ≤1.2	7
>1.2; ≤1.5	4
≥1.5	7

The range of elevations for blocks was 0.40 to 3.75 feet and the median category was 0.8 to 1.0 foot elevation difference. In 30 profiles of individual bunded areas at Mona, 30 percent of the fields differed by at least 0.2 ft. and 37 percent differed by 0.4 ft. or more. In a limited survey of fields actually leveled (Cox and Dempster, 1975) up to 200 cubic meters of soil are required to level the average field at a cost of 3. Rs. per cubic meter for a total cost of up to 600 Rs. per acre.

Assuming a uniform sloping plane and equal volumes of cut and fill, the volume and cost of leveling are as follows:

Range of Elevations (Max.-Min.)	Approx. Volume of Soil (meter^3)	Approx. Cost of Leveling (Rs. per Acre)
0.2	40	92
0.4	80	184
0.6	120	276
0.8	160	368
1.0	200	460
1.2	240	552
1.4	280	644
1.6	320	736

From this analysis, the median cost of leveling might be projected to be 368 to 460 Rupees per acre. The cost of course will be dependent upon the size of area to be leveled in one block.

The level basin method of irrigation most frequently used by the Pakistani farmer requires that the fields be precisely leveled. Otherwise water is not supplied to the crop growing on the high area causing a reduction in yield and is wasted in irrigating the high spots which can become salinized unless they are sufficiently covered with water to leach excess salts. Precision land leveling removes the high and low areas and reduces the field to a level plain with zero slope. While leveling, the land the fields may be reshaped more efficiently so that the length of the watercourse serving the fields can be greatly reduced. This has the double benefit of eliminating a wasteful watercourse and increasing the acreage of cropped land. For instance, in a block of 9 acres, at the Mona Project, seven watercourses occupied about .33 acres of land. Six watercourses were eliminated during precision land leveling, thus adding 0.3 acres to the cultivated area. One channel now serves the entire 9 acres arranged into border strips measuring 30' x 640'. With proper leveling and layout, the area is served by one watercourse instead of seven using only one-tenth the length of channel. Irrigation water can now be supplied to the field with a much higher delivery efficiency. Application depths of less than 2 inches have been accomplished.

The procedures utilized in the following case studies are those given by Criddle et al (1956) for evaluation of border irrigation systems with some modifications suggested by Merriam (1968) and Wu and Bishop (1970). Soil moisture deficiency was estimated using procedures described by Halderman (1969) by estimating texture and soil cohesion. These data are discussed in this article with an emphasis on the implications to precision land leveling.

FIELD STUDIES

Observations of farmers' irrigation practices (Clyma et al, 1975) at the Mona Reclamation Project, Bhalwal have provided preliminary data that show how precision land leveling helps farmers to improve their management of water. Measurements during irrigation of a leveled, partially leveled, and unleveled fields at farms near Main Channu have also been made to study the effect of precision land leveling on irrigation efficiency and uniformity of water application.

IRRIGATION EVALUATION

Farmer irrigation practices were evaluated from the following data which were collected before, during and after the time water was applied to the field.

1. Watercourse discharge at the field (and the amount of water applied)

2. Soil Moisture deficiency

3. Two or more longitudinal profiles of the field

4. Advance and recession times of water at marked stations in the field.

5. Infiltration during irrigation

Before the water was turned into the border, circular cylinders were located at selected stations in the border. When water reached a cylinder water was poured into the cylinder and the rate water infiltrated into the soil measured. The infiltration data from one cylinder are plotted in Figure 1. This graph is used to determine the amount of water that has entered the soil given the time that water has covered the soil, the intake opportunity time.

A nucca or field outlet was cut in the watercourse bank and water diverted to the field. This time becomes the zero time for the "advance" and "recession" curves of Figure 2. When the water moved across the surface and reached a point fifty feet down the border, the time was noted. The time the water reached additional stations became the data used to plot the "advance" curve on Figure 2.

After water is stopped from entering a border, the water infiltrates into the soil and gradually disappears from the surface. When 50 percent of the water disappears from the ground surface a distance of 25 feet either side of a station, that time becomes a point on the "recession" curve. The difference in time as read from the advance and recession curves is called the "intake opportunity time" and is the time during which water infiltrates into the soil. For example, in Figure 2 at station 100 feet, the intake opportunity time was 82 minutes and the amount applied from Figure 1 was 4.5 inches.

Ground surface elevations as determined with an engineering rod and level are shown under the advance and recession curves in Figure 2. At station 40 feet, there was a high spot approximately 0.1 feet high and several feet square. Observations of when the high spot was covered and uncovered with water were made during the irrigation. These data will be discussed in the next section with the implications for precision land leveling.

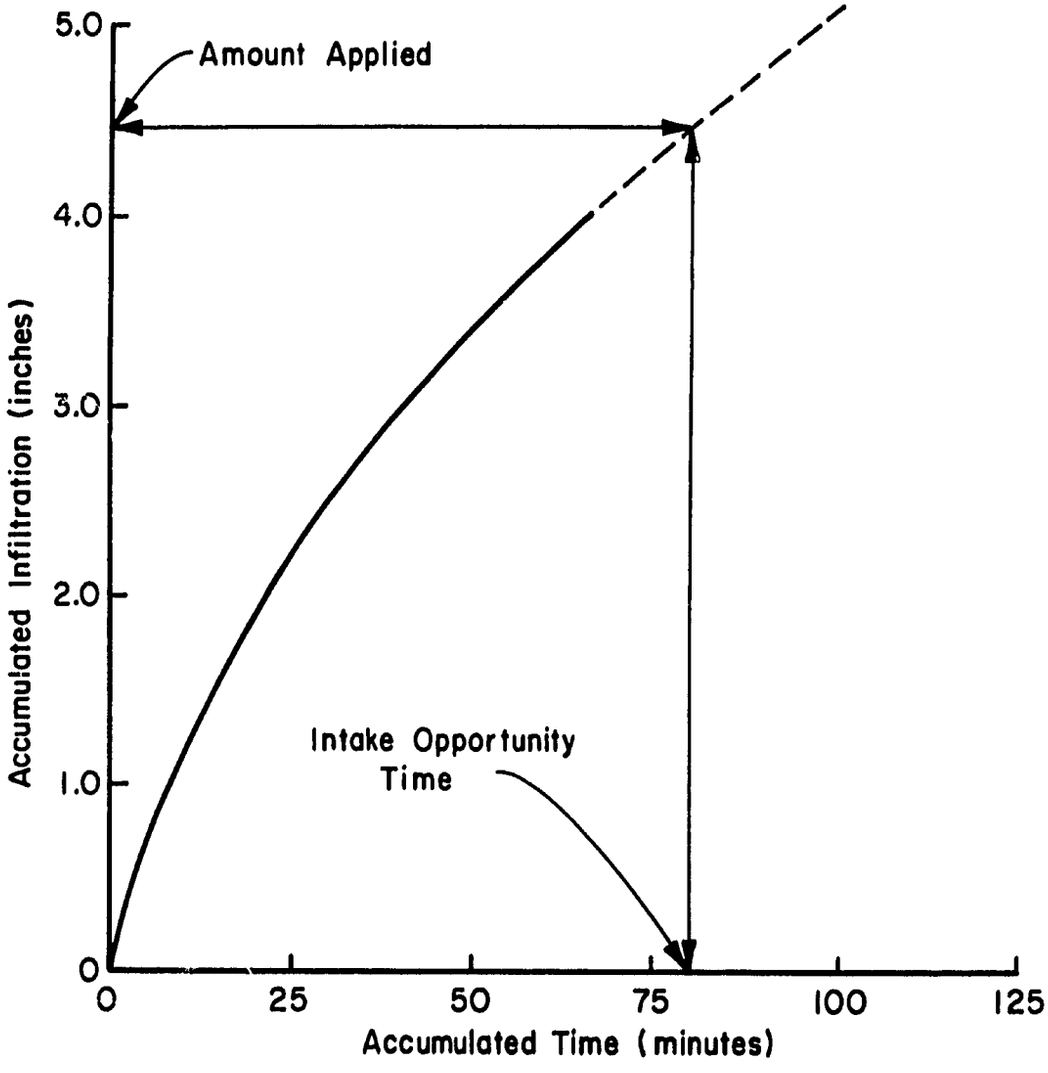

Figure 1. Average soil infiltration relationship at Mona Project Tubewell #137, January 10, 1973, for wheat crop.

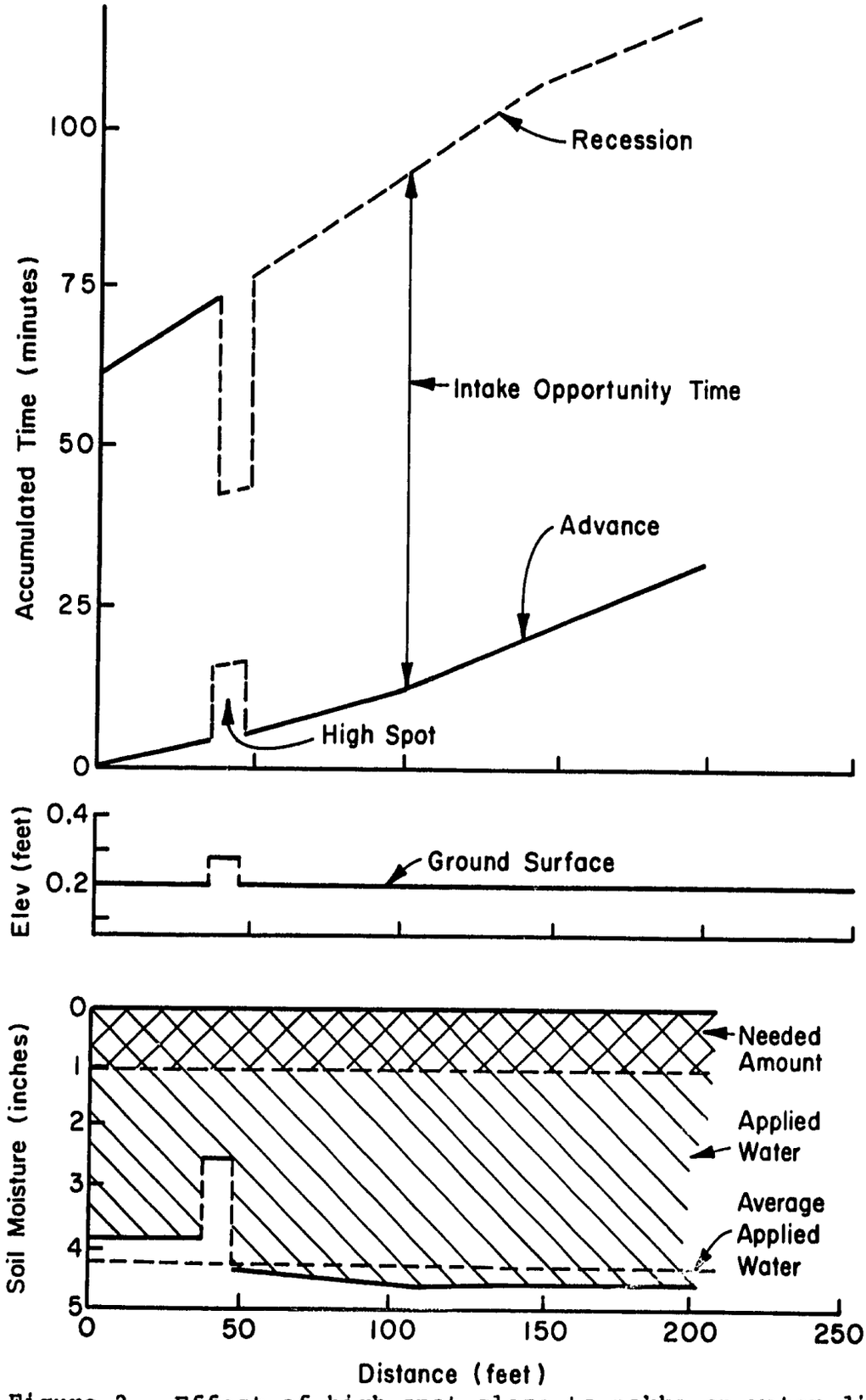

Figure 2. Effect of high spot close to nakka on water distribution at Mona Project Tubewell #137 January, 10, 1973, for wheat crop.

EFFECTS OF A HIGH SPOT

Water applied to an irrigation border advances along the ground surface at a rate dependent upon the flow rate into the basin, width of the border, slope, roughness of the surface, and infiltration rate of the water into the soil. The depth of flow is also a function of these factors. At station 40 feet, in Figure 2, after the water reached the high area an additional twelve minutes were required before the water covered the high area.

A sandy soil has a high infiltration rate which causes the depth of water on the surface at any time to be much less than the depth that was applied. A high spot in a field is not covered with water and does not infiltrate water in proportion to the difference in elevation of the high spot from the rest of the field. In this instance 1.2 inches (0.1 feet), the elevation difference, is compared to 4.2 inches, the average depth of water application. If elevation were the only factor, the difference of three inches would have been applied to the high spot, 70 percent of the depth that the rest of the field received.

The amount of water applied to the high spot as shown in Figure 2 computed by using the infiltration curve in Figure 1 was 2.4 inches. The ratio of 2.4 to 4.2 is 60 percent and represents the percentage the high spot received compared to the remainder of the field. Water covered the high spot for 28 minutes versus 75 minutes for the surrounding area (Figure 2). This is 37 percent of the time the remainder of the field was inundated.

A high spot close to the watercourse is covered more readily than a high spot of the same height but at the opposite end of the field. This is because a depth of water in the basin that will cover the high spot will occur earlier and water will cover the high spot while the remainder of the field is being irrigated as in Figure 2.

Figure 3 shows the effect of a high spot at a greater distance from the watercourse than for Figure 2. Approximately 40 minutes of additional time was required to cover the high spot after the remainder of the field had been irrigated, and approximately 1.5 as much time was required to cover the high spot as for the entire field. More than twice as much time was required to cover the high spot as compared to the area immediately around the high spot. More water than necessary must be applied to the field just to cover the high spot and even greater over-irrigation is required to result in an adequate amount of infiltration into the high spot. High spots on the more remote half of the field thus require substantial over-irrigation, as in this particular case the farmer tried to cover the high spot.

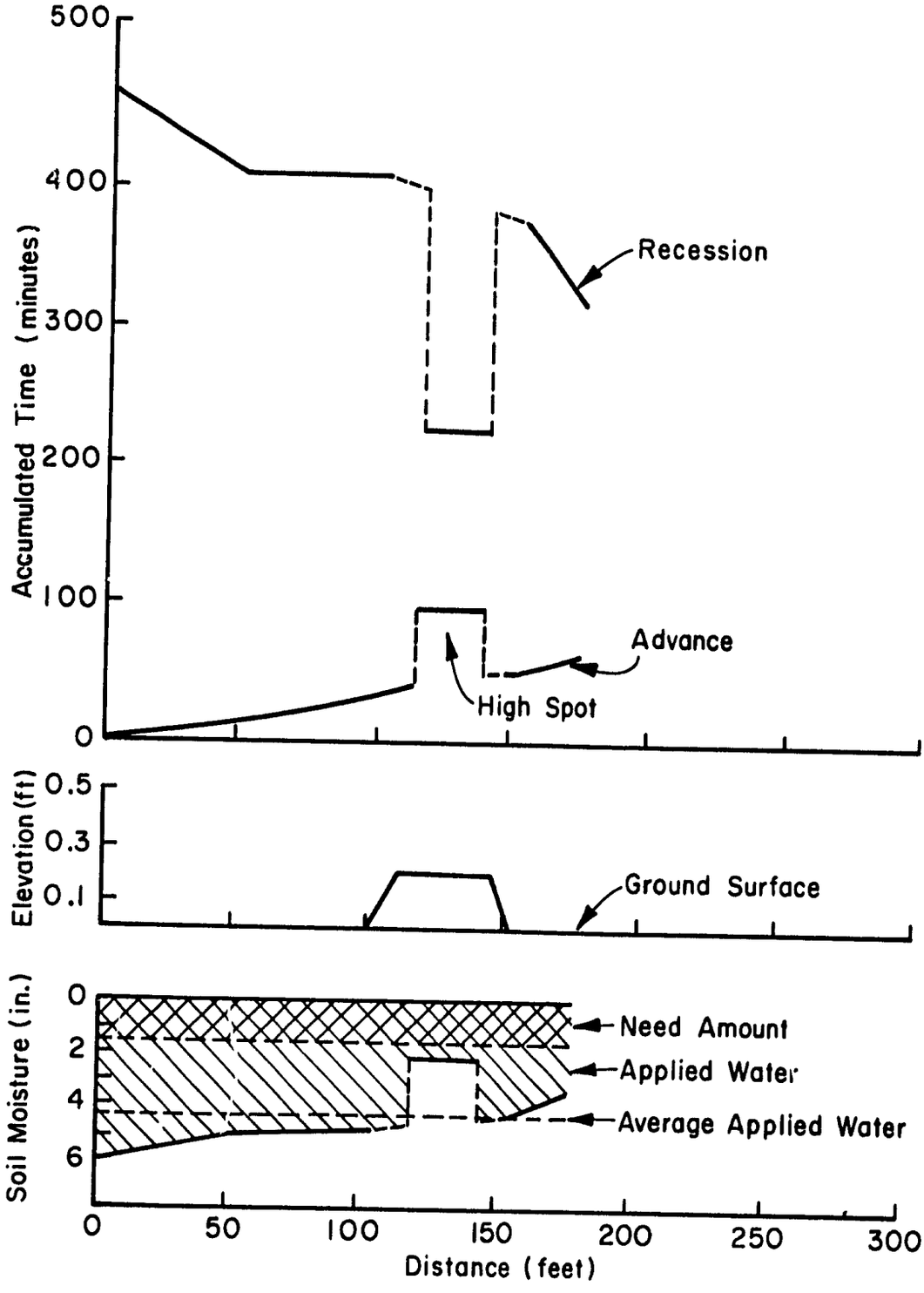

Figure 3. Effect of high spot away from nakka on water distribution at Main Channu Tubewell on September 11, 1973 for cotton crop.

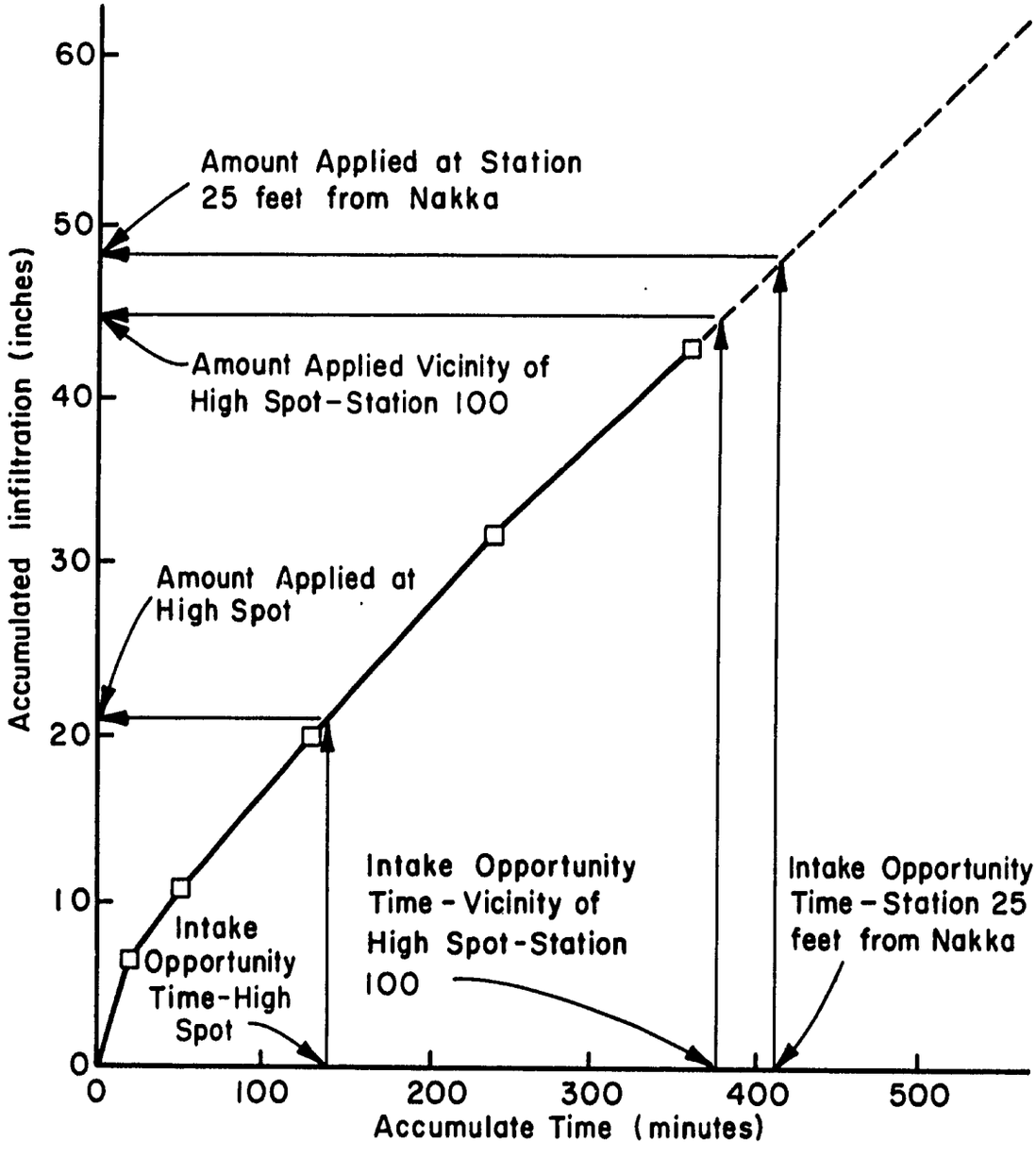

Figure 4. Average soil infiltration relationship at Mian Channu private tubewell on September 11, 1973, for a cotton crop.

In doing so he applied about 5.7 inches of water on the remainder of the field, when only 1.5 inches of water was needed in the root zone of the crop.

When the high spot is farther from the watercourse, the difference between amount of water stored in the soil assuming elevation as the primary factor and the amount of water stored assuming opportunity time as the primary factor are even greater than before. Considering the elevation alone, the 5.7 in. minus 2.4 in (0.2 ft. = 2.4 in.) gives 58 percent of the average amount stored in the field is stored in the high spot. Based on opportunity time and the infiltration curve of Figure 4, 2.1 in. or 37 percent of the average amount stored in the field is stored in the high spot. The opportunity time of the high spot is 34 percent of the opportunity time of the immediate area. The amount applied as determined from the infiltration curve is very misleading. High spots are frequently highly salinized within a month to six weeks into the growing season, frequently so much so that nothing grows on them. This salinization drastically reduces the infiltration rate of the soil in the high spot. The use of Figure 1 and Figure 4 assumes that the infiltration on the high spot is the same as the rest of the field. Because of salinization it would be expected in most instances to be somewhat less and in some instances much less.

Another factor suggests that high spots receive smaller amounts of water than even the opportunity time and infiltration curve implies. Qayyum and Hussain (1974) have shown that for some soil textures and certain head differences, the amount of water that infiltrates into the soil is a function of the depth of water on the surface. The result will be to increase the rate at which water enters the low areas and decrease the rate of entry into the high spots.

The primary points of the above discussions are that high spots in a field:

1. cause overirrigation because the farmer continues to apply water until the high spot is covered.

2. result in an even greater difference in amount of water stored in the soil than that explained by subtracting the elevation difference from the average amount applied.

3. contribute to salinization and reduced agricultural production.

EFFECT OF A GRADE

Fields in Pakistan are assumed to be level meaning free from undulations but also without any grade. Based on

standard design criteria, basins with zero grade appear to be necessary because of the low infiltration rate of the soils. However, graded fields are commonly encountered. When farmers irrigate graded fields as if they were level (zero grade), wastage of water results.

Figures 5 and 6 give the results of an irrigation of a graded field that slopes down (0.3 ft. in 150 ft.)from the nucca. The farmer applies water until the entire field is covered with water. When the nucca is closed, water accumulates at the lower end of the field resulting in excessive ponding and wastage of water. Proper irrigation of this field requires that the nucca be closed some time before the water reaches the end to prevent or reduce ponding.

Another circumstance is the case of the field sloping up from the nucca. Figures 7 and 8 give the results of this irrigation circumstance. Excessive water must be added to the field to provide the head to push the water uphill. The higher end of the field is underirrigated while the lower end is grossly overirrigated (Figure 7). A much larger quantity of water is required to irrigate the field.

Both cases of graded fields with the traditional irrigation techniques result in considerable overirrigation, which when continued on a long term basis result in waterlogging.

TRADITIONALLY LEVELED FIELDS

Leveled fields do exist under traditional farming conditions. With millions of fields involved some leveled fields will exist. Additional fields may be level because farmers expend extra effort. This can be achieved by leveling while water is applied or by carefully noting the high areas and leveling after the irrigation.

Perhaps the most important method used by farmers to achieve leveled fields is to subdivide their fields into smaller and smaller areas and level within the bunded area. In several areas where the discharge available for irrigation is small (usually less than 1.0 and even less than 0.5 cusecs), fields as small as 0.25 acres are common and bunded areas as small as 0.1 acres are frequent. In one study near Lyallpur where a number of fields had been observed, more than 50 percent of the 200 irrigations observed were on bunded areas of less than 0.3 acres. By subdividing his field into small bunded areas the farmer decreases the range in elevations encountered, makes it easier to use the results of watching water spread to level his field and can more efficiently cover all of a small area when a low discharge is agailable for irrigating the field.

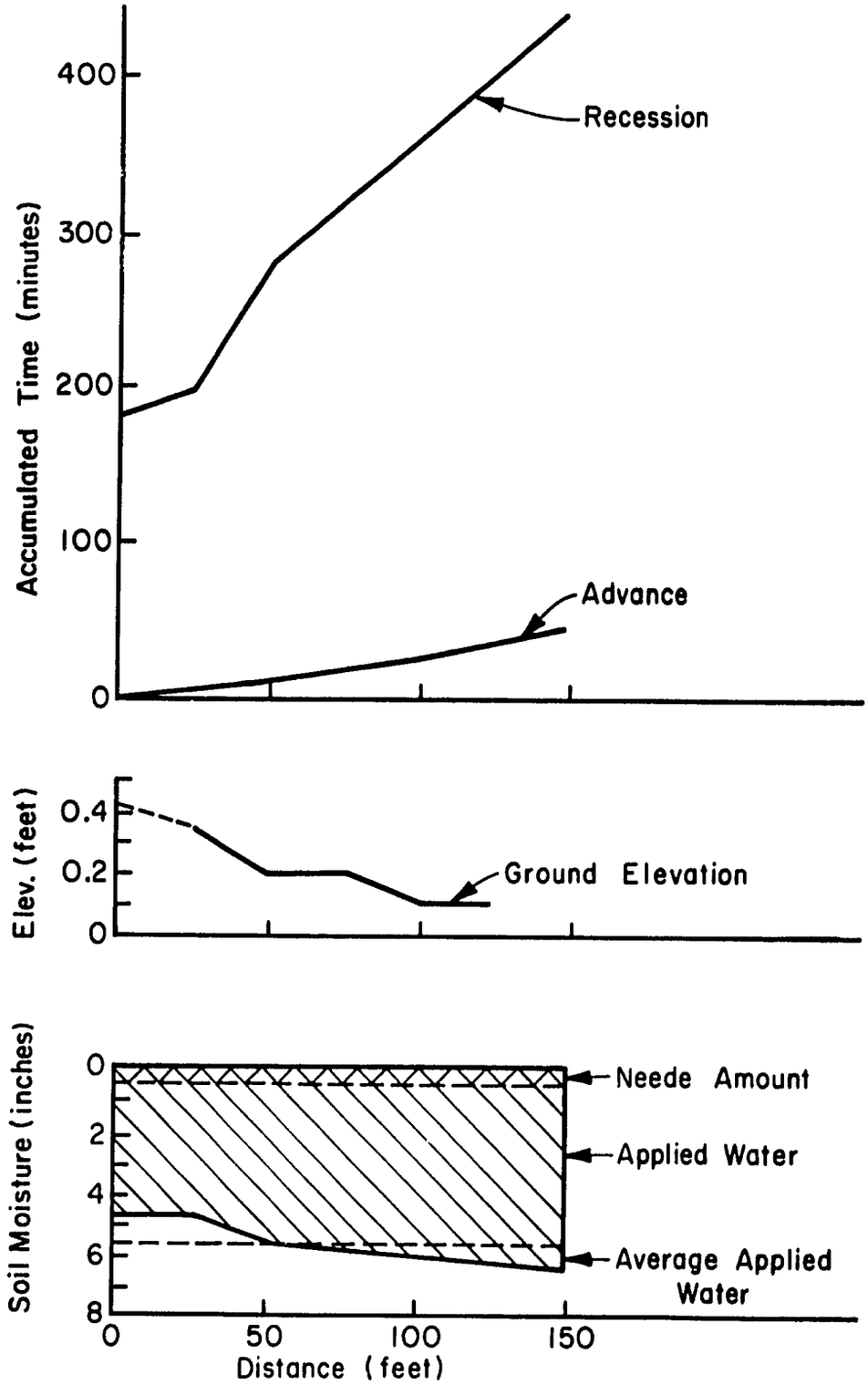

Figure 5. Water distribution as affected by a field sloping downhill from nakka at Mona Project Tubewell #122, on May 8, 1973, for sugarcane crop.

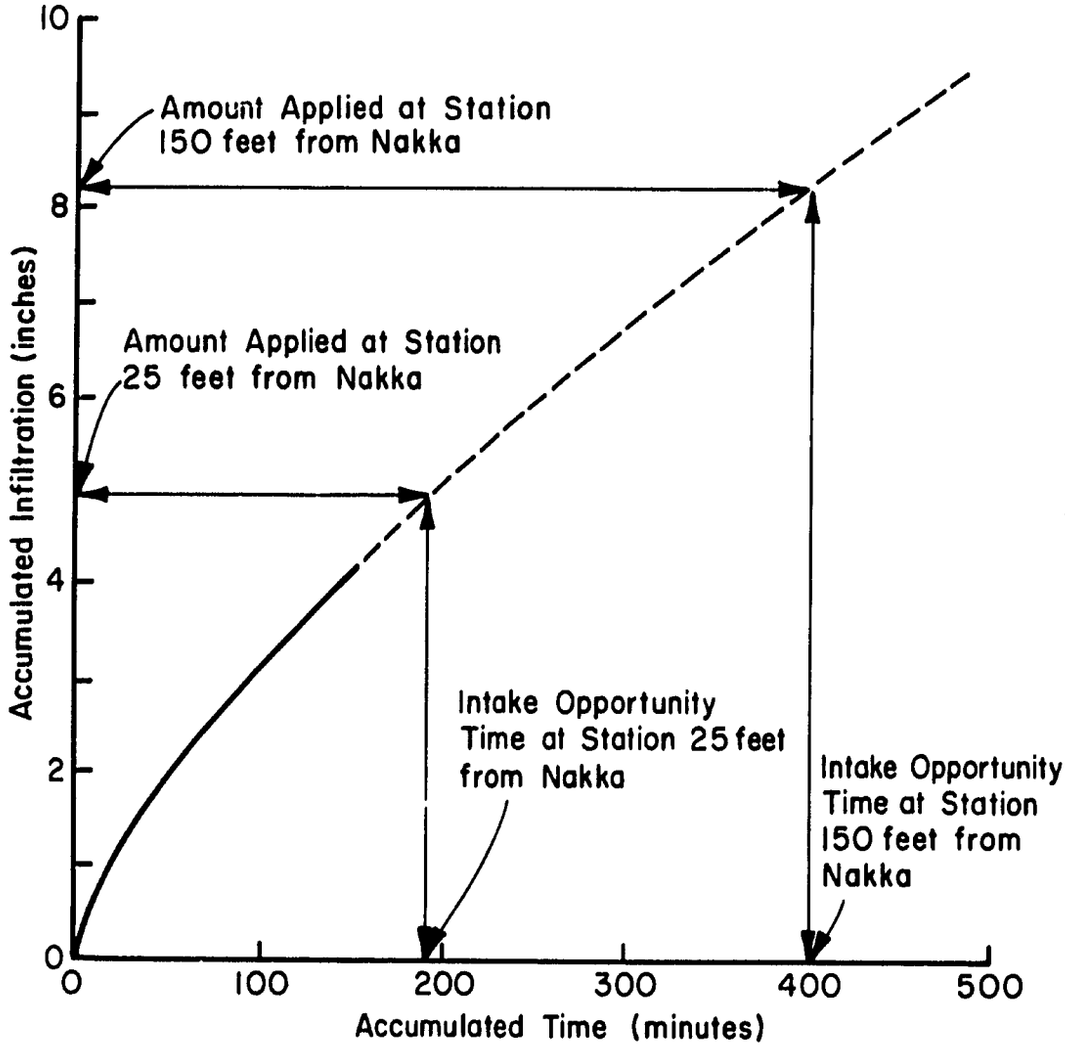

Figure 6. Average soil infiltration relationship from field sloping downhill from nakka at Mona Project Tubewell #122, on May 8, 1973, for sugarcane crop.

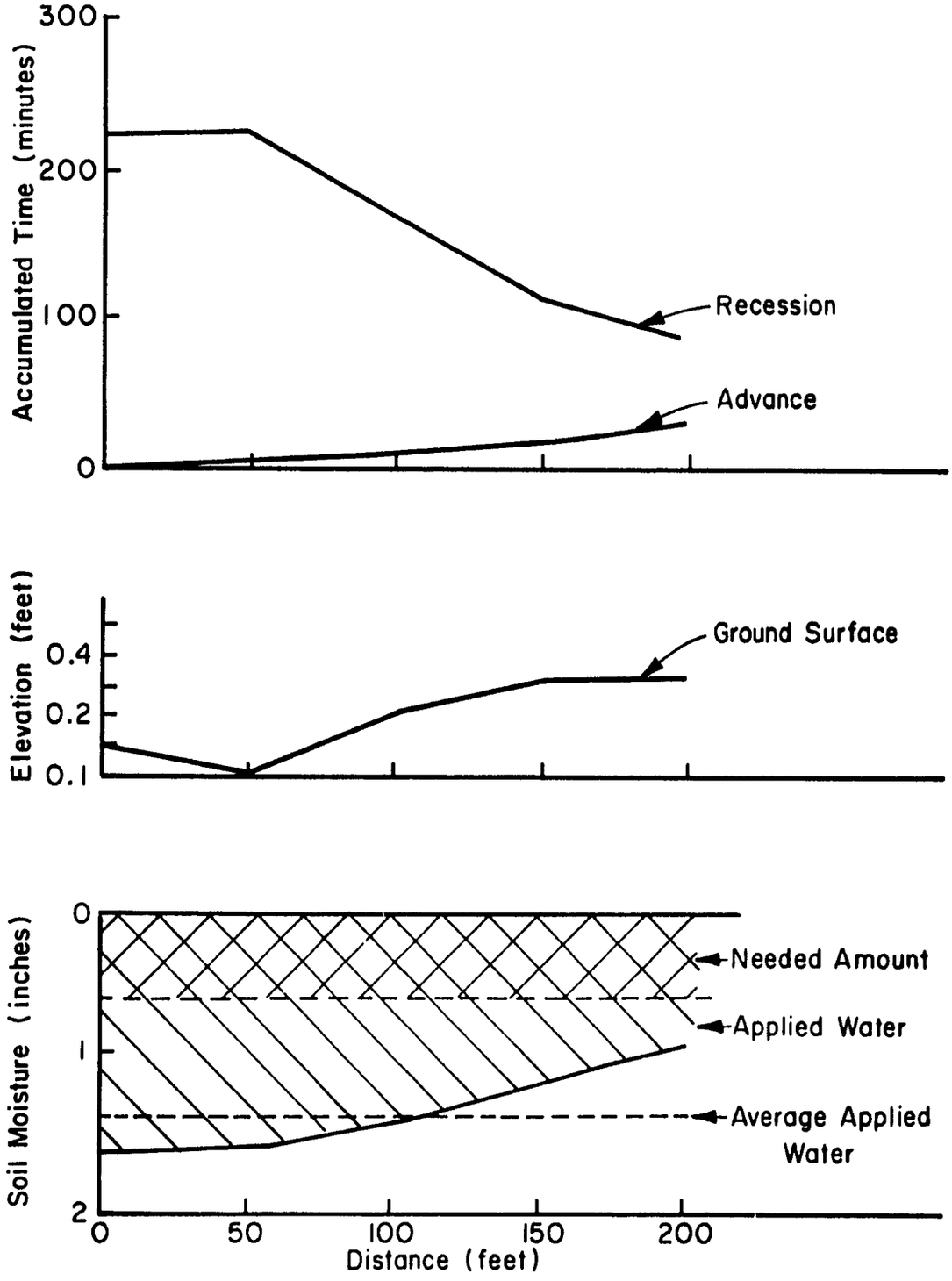

Figure 7. Water distribution as affected by a field sloping uphill from nakka at Mona Project Tubewell #122, on May 8, 1973, for sugarcane crop.

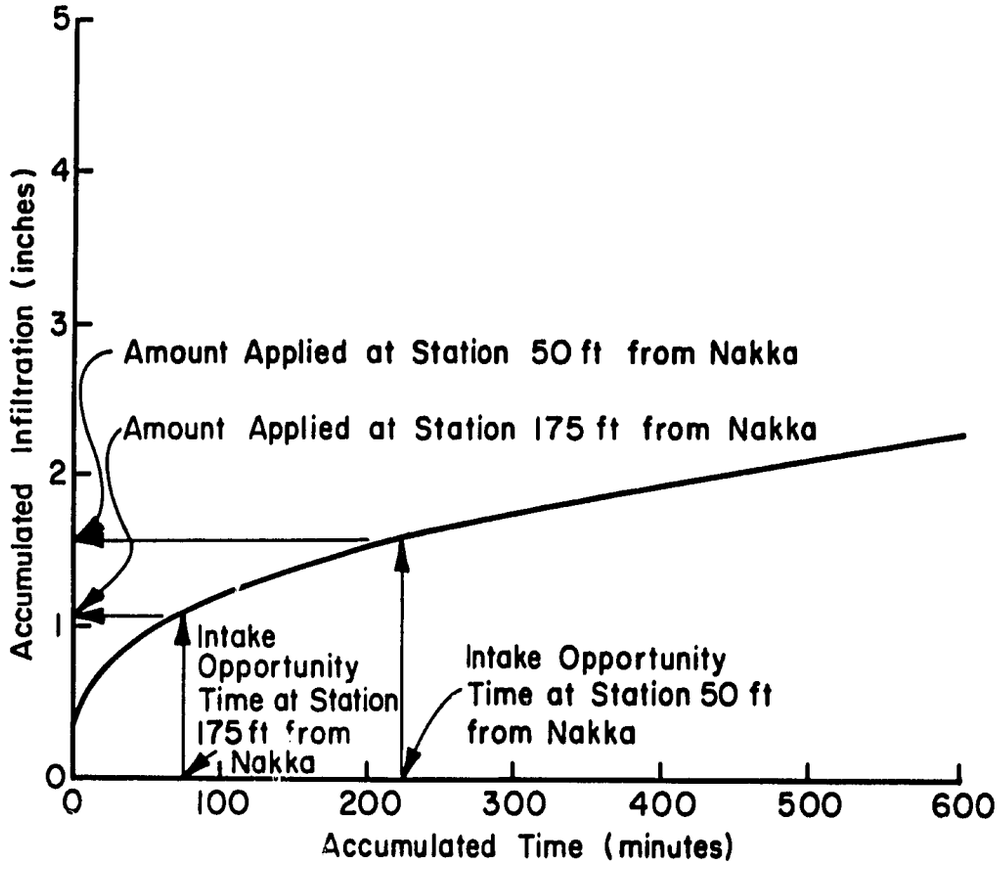

Figure 8. Average soil infiltration relationship from a field sloping uphill from the nakka at the Mona Project Tubewell #122, on May 8, 1973, for sugarcane crop.

PRECISION LEVELED FIELDS

As part of an on-farm water management demonstration program at the Mona Reclamation Experimental Project, a six acre parcel of land at tubewell 122 was leveled and planted to wheat for the rabi 1974/75 season. Borders were constructed 28 feet wide and 660 feet long and irrigated with plastic siphon tubes. At regularly scheduled irrigation on March 10, 1975, infiltration advance and recession, and application efficiency measurements were obtained. Figure 9 presents the plotted infiltration data from 3 borders irrigated, with replicated infiltration curves for two of the borders. Figures 10, 11, and 12 presents the advance and recession data taken for the three borders 5R2, 8R2, and 9R1 respectively.

The most important features of these data are the extremely uniform irrigations obtained. The overirrigation obtained was a part of the treatment design for high irrigation application.

COMPARISON APPLICATION EFFICIENCIES OF LEVELED AND UNLEVELED FIELDS

The amount of water needed in the root zone compared to the amount that is put on the field during an irrigation is a measure of the farmer's ability to do a good job of irrigation. We call this "field application efficiency" and define it as:

$$\text{Field application efficiency} = \frac{\text{Amount of water needed in root zone} \times 100}{\text{Amount of water supplied at nucca}} = 100\%$$

Ten measurements during an irrigation of leveled, partially leveled and unleveled fields at Mian Channu are listed in Table 1. Two leveled fields at Mian Channu had an average efficiency of 85 percent; 15 percent more water was applied than could be stored in the soil. Four other leveled fields were irrigated in which the efficiency was 100 percent and the water applied was not sufficient to fill the root zone reservoir with water that had been removed by the growing plants. On leveled fields when the crops are at the stage of growth resulting in a high consumptive use rate and use water rapidly, farmers should ensure putting on enough water. In case that is not possible they should irrigate longer or more frequently. On leveled fields, only an average of 5 percent of the water was wasted by overirrigation.

On unleveled fields, only two fields and a total of three irrigations have been observed. The average efficiency was 55 percent or almost twice as much water was applied as could be stored in the soil. The excess water is overirrigation and goes to ground water and is one of the primary

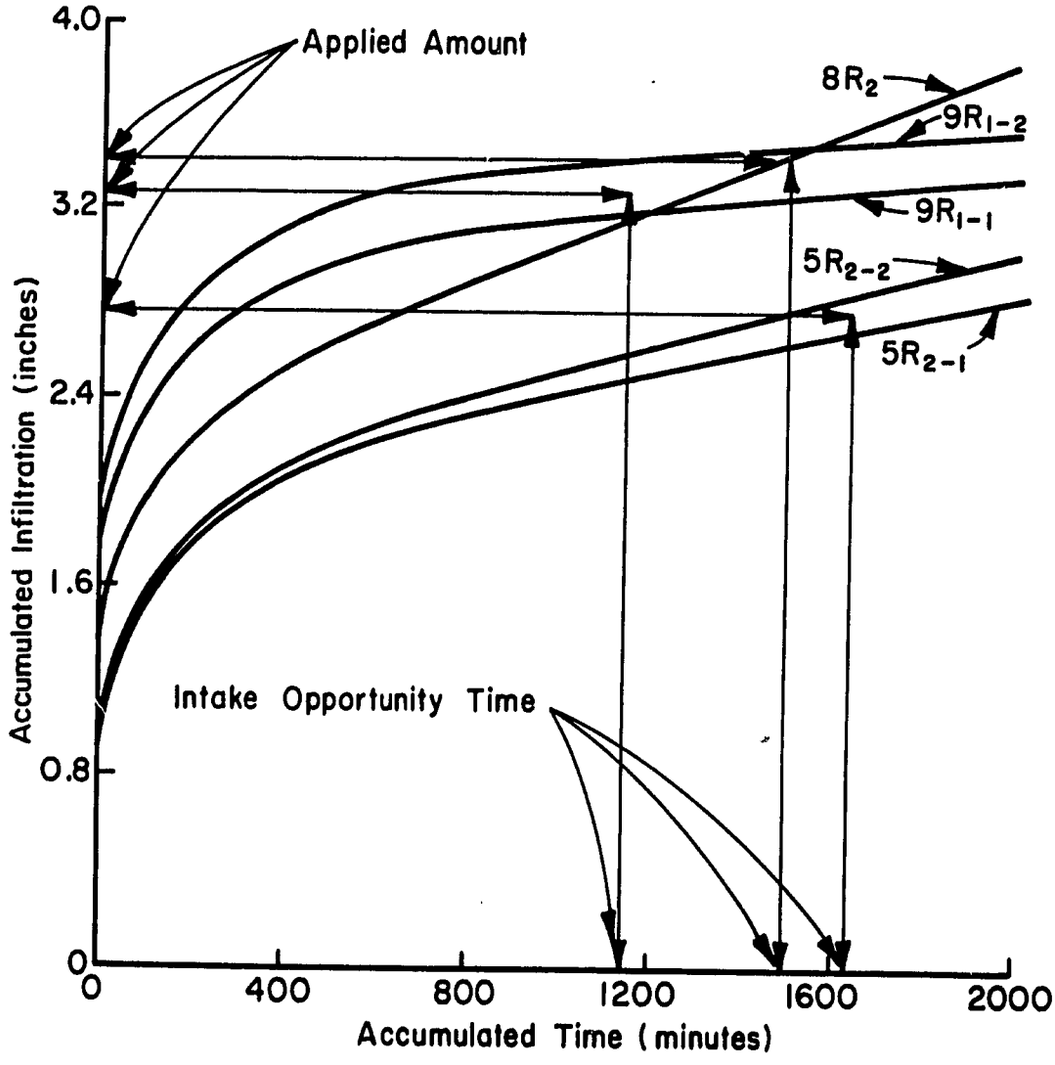

Figure 9. Average soil infiltration relationship at Mona Project Tubewell No. 122, March 10, 1975, for wheat border irrigated plots.

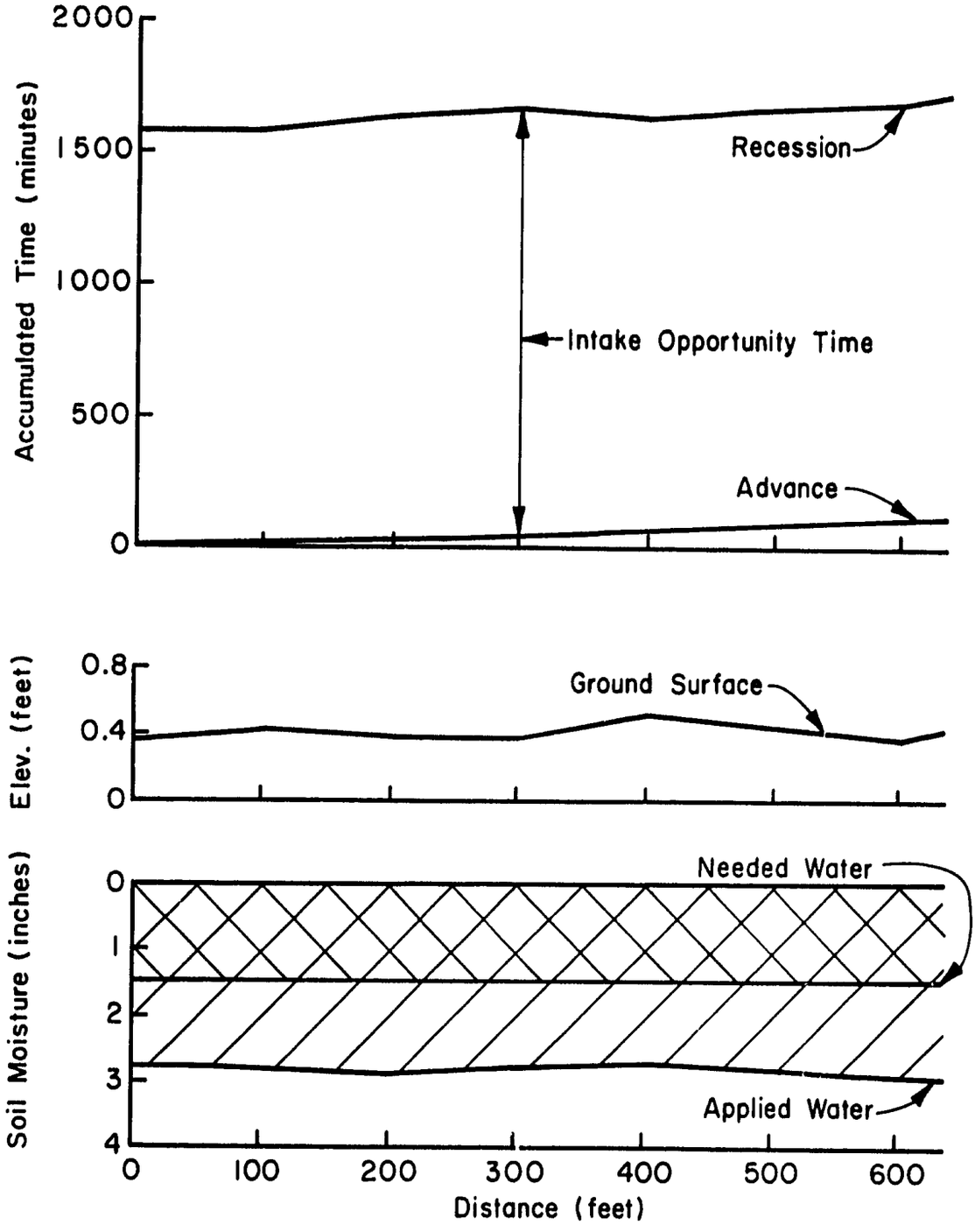

Figure 10. Effect of level border irrigation on water distribution at Mona Project Tubewell #122, Plot 5R2 on March 10, 1975, for wheat crop.

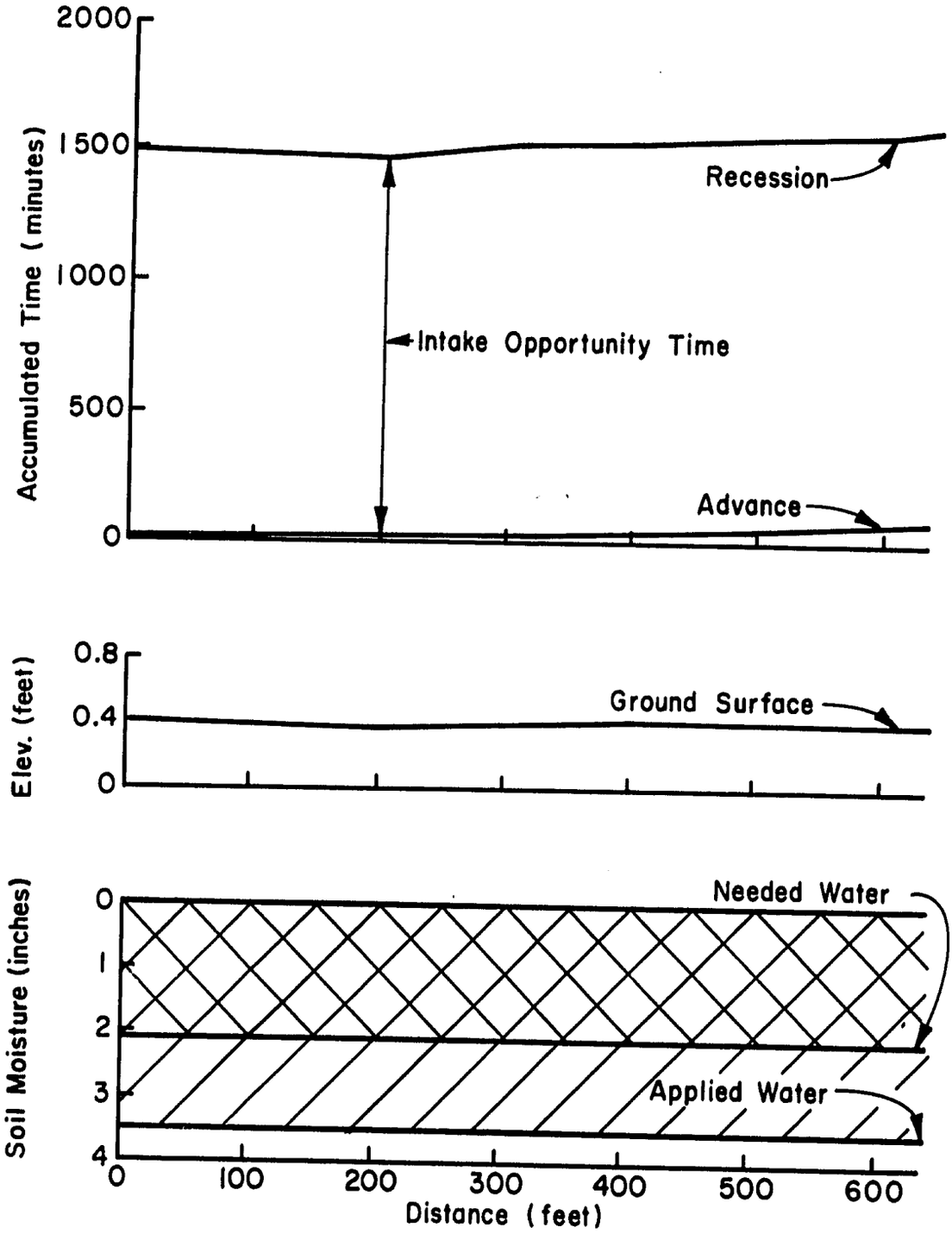

Figure 11. Effect of level border irrigation on water distribution at Mona Project Tubewell #122, Plot 8R2, on March 10, 1975, for wheat crop.

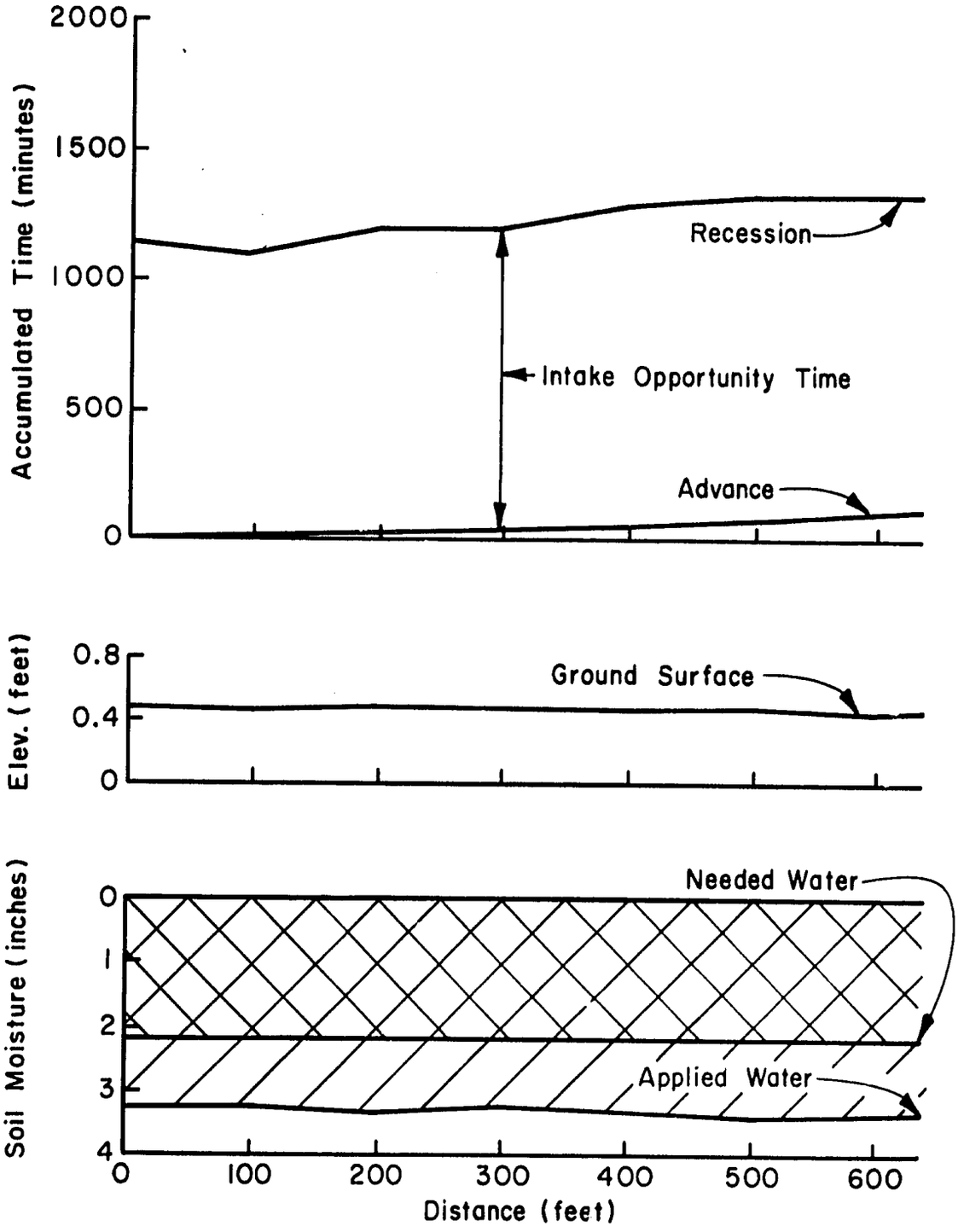

Figure 12. Effect of level border irrigation on water distribution at Mona Project Tubewell #122, Plot 9R1, on March 10, 1975, for wheat crop.

Table 1. Comparison of cotton irrigation application efficiencies[1] for leveled and traditional fields near Mian Channu

Date	Field Description	Date of Last Irrigation	Soil Moisture Deficiency (in.)	Application (Ac.in./Ac.)	Application Efficiency (Percent)
June 20, 1975	Leveled, Furrow	June 13, 1975	1.0	1.2	80
June 20, 1975	Traditional	Rauni	1.2	2.9	40
Sept. 10, 1973	Leveled, Furrow	Before rains	3.3	1.9	100*
Sept. 11, 1973	Traditional	Before rains	1.5	2.8	55
Sept. 12, 1973	Partially leveled	Before rains	5.6	2.5	100*
Sept. 13, 1973	Leveled	August 13, 1973	3.0	2.9	100*
Sept. 13, 1973	Leveled	August 13, 1973	2.9	3.3	90
Sept. 13, 1973	Leveled	Before rains	3.0	2.6	100*
Sept. 13, 1973	Leveled	Before rains	3.0	1.6	100*
Sept. 13, 1973	Traditional	Before rains	2.4	3.5	70

[1] Irrigation application efficiency = $\frac{\text{amount of water stored}}{\text{amount of water applied}}$

*Represents underirrigation, when a field receives insufficient water, the amount of water stored is the amount of water applied.

causes for waterlogging and salinity. In addition, this waste of applying too much water to unleveled fields reduces the acreages of crops that a farmer can grow. It also reduces the yield of the crops he grows as all fields are not irrigated according to crop needs. Thus, the crop suffers from soil moisture stress and yield is reduced. Many observations on unleveled fields at several other locations in Pakistan have shown that unleveled fields frequently receive two to four times more water than optimally needed. With a given quantum of water, more crop acreage can be grown if properly leveled.

CONCLUSION

Precision land leveling is not only a necessary prerequisite for successful efficient surface irrigation in Pakistan, but it is also necessary to avoid the problems of salinity and waterlogging. In irrigated areas which have evaporative demand in excess of rainfall as in Pakistan, unleveled fileds are the first contributors to waterlogging due to overirrigation and salinity due to underirrigation. The importance of precision land leveling thus cannot be overemphasized in an arid region like Pakistan where stable agriculture is possible only with irrigation.

BIBLIOGRAPHY

Clyma, Wayne, Arshad Ali and Mohammad Ashraf. 1975. Irrigation Practices and Application Efficiencies in Pakistan. Joint Contribution of Colorado State University and the Directorate of Mona Reclamation Experimental Project, CMO, WAPDA, Bhalwal, January.

Clyma, W. and G.L. Corey. 1974. The Importance of Farm Water Management in Pakistan. Colorado State University, Water Management Research, Pakistan, Field Party Report No. 2, September.

Cox, M. and T. Dempster, 1975. Private communication.

Criddle, W.D., Sterling Davis, C.H. Pair and D.G. Shockley. 1956. Methods for Evaluating Irrigation Systems. USDA, SCS, Agriculture Handbook No. 82, Supt. of Doc. Washington, D.C.

Halderman, A.D. 1966. Irrigation When? How Much? How? Bulletin A-20 The University of Arizona, Cooperative Ext. Ser. and Agri. Expt. Sta. Tucson.

Merriam, John L. 1968. Irrigation System Evaluation and Improvement, Blake Printery, 1415 Monterey St., San Luis Obispo, California.

Qayyum, M.A. and G. Hussain. 1974. Effect of Water Head on the Infiltration Rate of Soils. Directorate of Mona Reclamation Experimental Project, CMO, WAPDA, August.

Wu, I-pai and A.A. Bishop. 1970. Simple Graphic Solution to Express Infiltration as a Function of Length and Run Time, ASCE, Irrigation and Drainage Division IR3, pp. 233-240, September.

Appendix 34

SOYBEAN EMERGENCE AS INFLUENCED BY METHODS OF IRRIGATION, PLANTING, AND STRAW APPLICATION

S.A. Bowers and Tran Thi Anh-Dao[1]

March 24, 1975

Objective

To determine methods for improving soybean emergence on a Delta silty clay soil.

Introduction

Although soybean production is relatively recent in the Mekong Delta, it is rapidly becoming a major Delta crop. Most present production is primarily confined to the lighter textured, nonpuddled, levie soils of Chau Duc Province. On the heavier textured puddled soils, typical of most of the Delta, production has not been as successful. One serious problem concerns emergence. Poor stands frequently result due to the weak emergence characteristic of many soybean varieties and the compacted soil. Thus, the experimental intent was to determine simple management techniques for improving soybean emergence.

The soil, a silty clay (60 percent clay, 31 percent silt, 9 percent sand) had recently been planted with paddy rice. One month prior to the experiment the soil was plowed and roto-tilled. On March 24, 1975, just prior to planting, the soil was plowed again and roto-tilled twice.

After soil preparation, beds were constructed 15 cm high, 5.4 meters long, and 0.40 meters wide. Straw, 2mt/ha, was incorporated into certain beds as indicated below. Each bed was then planted with 2 rows 30 cm apart. Plant space within the row was 10 cm except where 2 seeds were planted in each hill; in this case, the plant spacing was 20 cm.

The seed planted was Multivar M 80, an Indonesian variety. All seed was innoculated with "Nitracin" and treated with molybdenum prior to planting. Planting depth was approximately 3 cm.

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[1]Project Advisor, Mekong Delta Soils Project, University of Cantho, Cantho, Vietnam and Vietnamese Project Employee.

The experimental design was split plot with the following treatments:

Main plot treatments

I_1 - sprinkle irrigation

I_2 - flood irrigation

I_3 - furrow irrigation

Sub plot treatments

S_o - no straw applied

S_1 - straw surface applied (2mt/ha)

S_2 - straw incorporated (2mt/ha)

Sub-sub plot treatments

P_1 - punch planting (open hole, 10 cm spacing)

P_2 - 1 seed/hill (covered, 10 cm spacing)

P_3 - 2 seed/hill (covered, 20 cm spacing)

The factorial combination of the above treatments resulted in 27 individual treatments. When replicated 3 times, the experiment consisted of 81 plots. Sub-sub plot size was 1.8m x 5.4m.

The sprinkling treatment was applied with a hand held hose until the seed zone was saturated. This is a common Vietnamese method; water was added until the beds were completely covered. When the seed zone was saturated, excess water was drained away. Furrow irrigation consisted of filling the furrows (but not covering the beds) and allowing water to move across the beds under tension.

The incorporated straw treatment was to reduce the strength of crust formed by the irrigation treatments. The straw mulch was to reduce the evaporation rate and thus allow seedlings to emerge before the crusts dried and strengthened.

Similarly, planting treatments were selected to enhance emergence. It has been shown that seeds placed in a narrow open hole (punch treatment) readily germinate and emerge without crusting problems. With covered seeds, two seeds per hole, the emergence pressure should be doubled with a resulting ease in emergence. Figures 21 and 22 (Appendix 1) show the plot layout and treatments.

TABLE 1. Soybean emergence by plot and replication. 120 seeds = 100% emergence

Treatment	REP I	REP II	REP III	AV.
$W_1S_oP_1$	66	103	97	88.7
$W_1S_oP_2$	86	104	76	88.7
$W_1S_oP_3$	89	112	92	97.7
$W_1S_1P_1$	62	101	96	86.3
$W_1S_1P_2$	71	111	96	92.7
$W_1S_1P_3$	95	106	120	107.0
$W_1S_2P_1$	95	108	82	95.0
$W_1S_2P_2$	93	93	86	90.7
$W_1S_2P_3$	99	92	92	94.3
$W_2S_oP_1$	94	86	102	94.0
$W_2S_oP_2$	104	86	91	93.7
$W_2S_oP_3$	99	86	102	95.7
$W_2S_1P_1$	100	77	102	93.0
$W_2S_1P_2$	96	88	102	95.3
$W_2S_1P_3$	104	106	101	103.7
$W_2S_2P_1$	88	85	98	90.3
$W_2S_2P_2$	102	94	98	98.0
$W_2S_2P_3$	96	101	104	100.3
$W_3S_oP_1$	103	106	107	105.3
$W_3S_oP_2$	108	106	107	107.0
$W_3S_oP_3$	118	100	108	108.7
$W_3S_1P_1$	101	101	106	102.7
$W_3S_1P_2$	113	97	115	108.3
$W_3S_1P_3$	107	102	108	105.7
$W_3S_2P_1$	104	97	105	102.0
$W_3S_2P_2$	110	102	106	106.0
$W_3S_2P_3$	109	90	120	106.3

TABLE 2. Analysis of variance for soybean emergence

Sources	df	Sum of Squares	Mean Square	F
Main Plots				
Replications	2	228.0741	114.0370	0.1888
Irrigation	2	2288.2222	1144.1111	1.8951
Error (a)	4	2414.8148	603.7037	
Sub Plots				
Straw	2	42.7407	21.3703	0.1755
IxS	4	79.0371	19.7592	0.1623
Error (b)	12	1461.3333	121.7777	
Sub-Sub Plots				
Planting	2	654.8889	327.4445	6.3022**
IxP	4	201.5560	50.3890	0.9698
SxP	4	151.8149	47.9537	0.7304
IxSxP	8	318.6291	39.8286	0.7665
Error (c)	36	1870.4445	51.9567	

Coefficient of Variation = $\frac{\sqrt{51.9567}}{7971/81}$ = 7.32%

**Significant at the 0.01 level.

TABLE 3. Separation of planting treatment mean (Duncan's MRT*)

P_1	P_2	P_3
Punch	One seed/hill	Two seeds/hill
95.26_a	97.81_a	102.15_b

*Values followed by different letters are significantly different at the 0.95 level.

This experiment was planted and irrigated on March 28, 1975. Emergence counts were recorded daily until all apparent emergence ceased; the last emergence count was on April 7, 1975.

Results and Discussion

Table 1 shows emergence by treatment and replication. Based on 120 seeds per sub-sub plot, the experiment average emergence was 82 percent. With a seed germination rating of approximately 90 percent prior to planting, the overall emergence must be considered very good. Such emergence must be related to seedbed preparation, which was superior to that normally seen in this area.

Table 2 shows the analysis of variance for emergence counts. In this case, the emergence counts were found to be normally distributed and thus no transformation of data was required. The analysis shows that only planting treatments resulted in significant emergence differences (0.01 level).

Table 3 shows the significant differences between planting treatment means. The "two seeds/hill" gave significantly higher emergence than the other two treatments; they did not significantly differ from one another. The poorer showing of the punch planting treatment was possibly related to the difficulty in establishing narrow holes in the rather cloddy seedbed.

Figure 1, of this section, shows the average cumulative emergence versus time for the three planting treatments. The superiority of the "2 seeds/hill" treatment was established from the beginning and maintained throughout the emergence period.

It is noteworthy that irrigation treatments did not result in the crusting and compaction anticipated. While flooding and sprinkling did form slight crusts, the crusts were weak; apparently there was little aggregate dispersion. Consequently, other treatments were not rigorously tested.

Despite the lack of significant differences due to irrigation method, treatment averages imply a probable advantage in furrow (tension) wetting. The emergence averages due to sprinkling, flooding, and furrow treatments were 93.4, 96.0, and 105.8 respectively. The lack of significance may be a function of the split plot design. Here, main plot treatment effects are measured with much less sensitivity than are sub plot and sub-sub plot treatment effects.

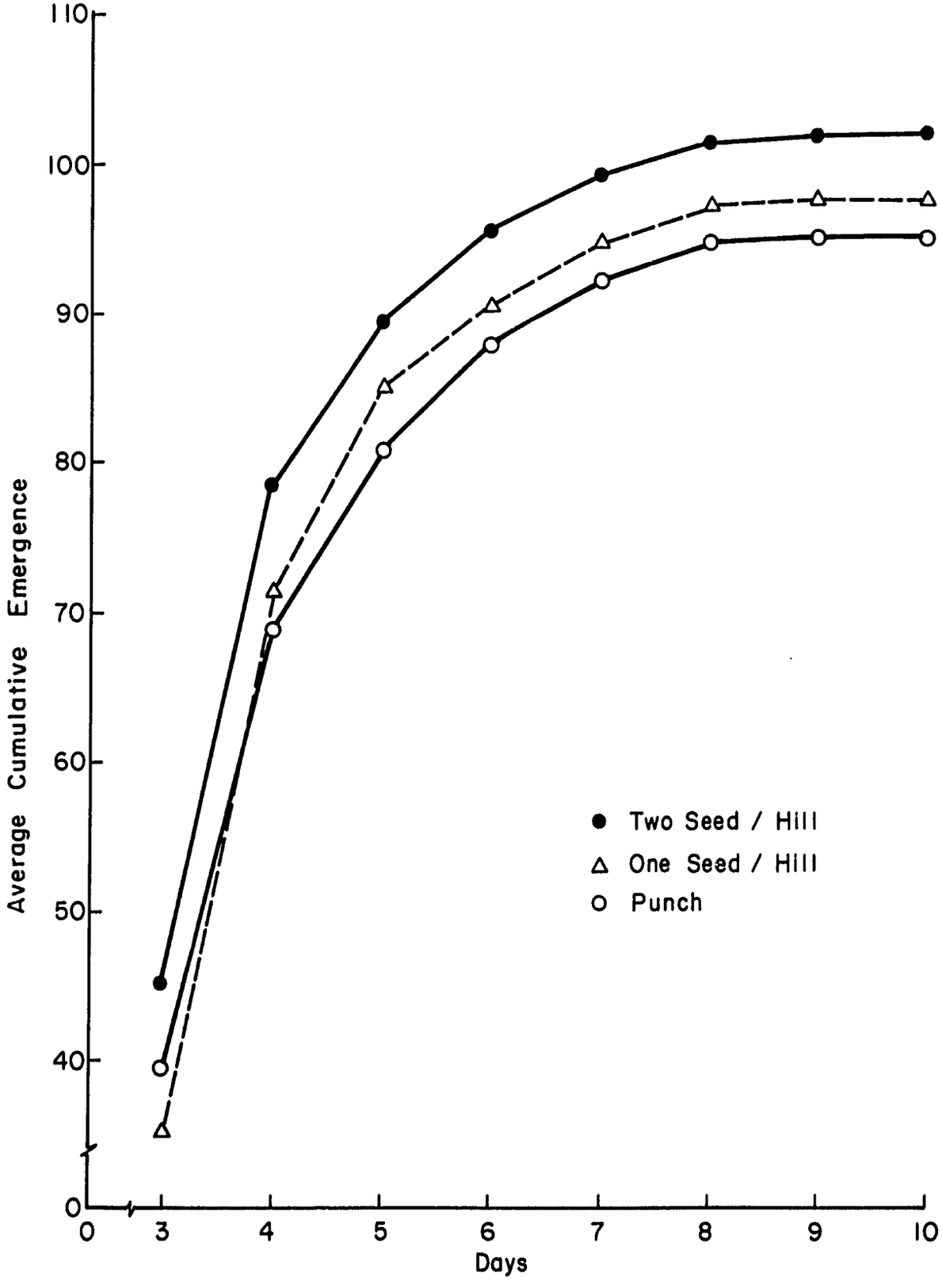

Figure 1. Cumulative soybean emergence for three planting methods.

Conclusion

Experiment results indicate that good soybean stands can be realized on Delta heavy clay paddy soils through proper seedbed preparation and good quality seed. While significant differences in emergence due to irrigation were not detected, the data imply an advantage in wetting the seed zone by furrow (tension) methods. In addition, stand improvement can result through the planting method employed; "two seeds/hill" resulted in significantly greater emergence.

APPENDIX 35

RECOMMENDATIONS FOR TRICKLE AND SPRINKLER IRRIGATION IN PAKISTAN

Jack Keller and Charles M. Burt[1]

INTRODUCTION

This report is based on a field trip and study, 7-19 April, 1975 as requested by Mr. Malik Khuda Bakhsh Bucha through USAID/CSU mission in Islamabad. The excellent field trip arrangements and field assistance provided by Dr. M. Anwar Khan were greatly responsible for the high efficiency and productivity of this study.

The purpose of this study was to investigate the practicality of using trickle or sprinkle irrigation to obtain better on-farm water management (higher water use efficiencies) at specific problem areas. These areas included the following:

1) Sandy lands in the Thal Desert which are underlain with groundwater of reasonable quality,

2) Sandy and undulating riverine areas,

3) Sandy high areas within the principal irrigated zone in all regions,

4) Fringe areas or where water is either saline or extremely scarce.

We managed to visit representative sites in all of the above areas. We talked to farmers who were dealing with each type of problem and discussed soils, economics, input costs and management strategies with various government officials and irrigation pipe (plastic and cement asbestos) suppliers from whom we obtained the Irrigation Input Cost Data and the Crop Data.

The inefficiency of irrigation, probably 20% or less on sandy rough lands, is well known. Thus the attractiveness of highly controlled irrigation which has the potential to increase efficiencies to 80% or more. Furthermore, the use of such irrigation methods which utilize pipe to convey the water directly to the consuming plants makes the development

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of the most sandy lands and rough topography practical even with relatively saline waters. Thus existing water supplies can be greatly extended and a totally new class of lands becomes available for irrigation and can be made available for development by the application of new technology.

There is little question as to the technical feasibility of such methods as trickle and sprinkle irrigation which have already been substantiated on extensive installations throughout the world. The question we face is whether such methods or special adaptations of them are sociologically and economically practical for Pakistan at the present time. In view of this we considered the following systems:

1. Conventional trickle irrigation which is a system for supplying filtered water (and fertilizer) directly on or into the soil. This sytem provides optimum soil water conditions when properly designed, installed and managed and requires a minimum of labor. Most of the system components could be manufactured in Pakistan. However, at the beginning the emitters would need to be imported. In the future, the emitters could no doubt be manufactured locally under license agreement. Descriptive material dealing with the pros and cons and the general features of trickle systems is included. We anticipate that the installed cost of standard trickle irrigation systems in Pakistan will be in excess of Rs. 5,000 per acre including the cost of the well and pump.

2. A special adaptation of hose-fed small basin irrigation. We utilized the general concepts available from trickle irrigation and conceived of a unique system for Pakistan which will incorporate many of the advantages of trickle irrigation while eliminating some of the filtration problems, reducing costs and increasing labor requirements. In essence this form of irrigation involves using portable hoses to supply water directly to small basins around each tree. The hoses would be systematically moved within the orchard to complete an irrigation every four days on sandy soil. The systems could be redesigned for a longer irrigation interval where soil conditions permit. We have estimated that the costs of these systems including tubewells will be approximately Rs. 2,500 per acre.

In these systems the water will leave the tubewell, pass through a simple strainer, a fertilizer injection device, flow meters, and through pipelines that feed the hoses described above. The water will only exit from the system at and into the basins provided at each tree and there will be no opportunity for losses except through poor distribution or overirrigation of the basins. If the laborers systematically move the hoses to water a new set of trees every twelve hours, the efficiency of the system should be in the neighborhood of 90%.

3. Conventional hose pull sprinkler irrigation which is a system where small sprinklers are supplied at low pressures to irrigate the entire area between the tree rows. These systems have been used extensively in California and have mainly fallen out of favor because of the relatively high labor requirement for moving the sprinklers every day. The general layout and design for hose-pull sprinkler systems is for sandy soils which require a four-day irrigation interval. System costs will be approximately Rs. 3,250 per acre including the well and pump. By using only one sprinkler with twice the discharge a similar layout can be readily converted to an eight-day interval system for use on slightly heavier textured soils.

An advantage of this system over the trickle or hose-basin systems described earlier is that the entire area between trees will be irrigated and thus can be utilized for low growing crops which is a common practice in Pakistan for new tree plantings. The hose-basin and hose-pull sprinkler systems have similar mainline and manifold layouts and require the same inlet pressures. Therefore, the two concepts can be intermixed on any given installation. Thus, for new plantings the sprinkler concept can be employed and as the trees reach maturity the system can be converted to hose-basin, which would eliminate weed growth and water losses in the center strips.

4. Center pivot sprinkler systems where water is sprinkled from a pipeline suspended above the crop which is rotated around a stationary pivot point to automatically irrigate a large circular field. Water powered machines can be designed to irrigate fields in excess of 200 acres.

Such a system could be used to irrigate 400 acres of winter grain by moving it back and forth between two fields and also have the capacity to irrigate 200 acres of a summer crop such as soybeans. Thus, the system could provide irrigation to 400 acres of crop land with 150% cropping. The system should have a water supply of at least 2 1/2 cubic feet per second. It could be nozzled for low pressure operation when used on sandy soils and should provide optimum irrigation conditions with efficiencies approaching 85%.

We do not recommend center-pivot irrigation, however, except for large scale development projects where expert management is available to operate a large number of machines at a given site. The cost of a complete installation as described above would be approximately Rs. 600,000 most of which would involve imported equipment. The pressure requirements for center-pivot irrigation systems is 50 psi at the pivot point inlet.

RECOMMENDATIONS

System Selection

All of the above systems are capable of providing high water use efficiencies under good management. However, we are particularly enthusiastic about the possibilities for the hose-fed basin and hose-pull sprinkler concepts because:

1. They are relatively low cost (Rs. 2,500 - 3,250 per acre) systems with reasonable labor requirements (one man for 10 to 20 acres) for Pakistani conditions.

2. The basic components for the system can be manufactured from polyethylene plastic which is made in Pakistan by Synthetic Chemicals Company, Ltd., using sugarcane molasses as the basic raw material. Synthetic Chemicals Company, Ltd. also has extrusion facilities which we have been told by Mr. Furquan M. Khan, Sales Executive, are capable of producing the necessary hoses and distribution network pipelines (at present they do not have the necessary dies but we were informed they have the capability of machining them as well as molds for fittings.) Thus, the systems require very little importation of materials.

3. The systems are interchangeable as described above. That is, when the trees are young the sprinkler concept can be utilized and when they become more mature the system can be converted to the hose-basin concept to conserve water and approach the optimum growing conditions found under trickle irrigation.

4. The energy requirements for either system is low. For a full 80 acre system, that is a system with 80 acres of mature orchard under optimum moisture conditions in midsummer, only 10 brake-horsepower is required for the above ground portion (i.e. to provide the extra pressure in water, delivered at the surface, to force it through the trickle or sprinkler system) of the system. This is equivalent to an extra 60 feet of lift. Thus the net energy requirements per unit of water effectively applied for these systems will only be about half as much as is required for a traditional system with an application efficiency of only 20%, and a lift to the surface of 40 to 50 feet.

5. These systems can be used on practically any type of soil and topography. They are particularly interesting for application on undulating lands and coarse textured soils where traditional surface irrigation methods are most inefficient.

In fact, through this new technology, sandy textured soils can become particularly suitable for high value fruit

and vegetable cropping. Since there is no suitable technology for the development of these lands available in Pakistan today, they are commanding a market value between Rs. 1,000 and Rs. 3,000 per acre even where the groundwater supplies are known to be adequate. This is in contrast to those lands which are under traditional irrigation development and are selling for Rs. 8,000 - 12,000 per acre. This large differential in land values can more than pay for the development costs for these hose-type systems which ranges from Rs. 2,500 per acre for the hose basin system to Rs. 3,250 per acre for the hose sprinkler system.

6. In addition to the high water use efficiency of these systems they can also accommodate round-the-clock pumping. Once set the system needs little or no attention during the night. Thus, a given tubewell water supply can be used to its maximum level. For optimum growth conditions of mature trees during the summer, we would recommend that the water supply be capable of producing approximately 1 cfs per 80 acres. The water supply could probably be reduced to approximately 3/4 cfs and still produce near optimum results on 80 acres in the areas where the climates are milder. However, we do not recommend extending these systems beyond this point especially where they are installed on loamy sands. Of course, when trees are young, or during the winter months, more area can be irrigated, but it will probably not be worthwhile to extend the hose-type systems to irrigate any more than 80 acres with 3/4 cfs.

During the winter when there is excess pumping capacity we would recommend either pumping less hours or supplying winter moisture to some marginally surfaced irrigated patches from the ends of the manifold lines. We realize that a 1 cfs well usually supplies some water to more than 80 acres. With the low application efficiencies this can only be accomplished by marginal irrigation practices or by having much of the area out of production at any given time. Upon investigating the situation in the field we found that often only about 20 acres are under irrigation during the summer from a 1 cfs well.

Before trying to pinpoint water requirements any further, we need to deal with specific areas and crops.

7. We feel that the hose systems will not only offer higher water use efficiency which may allow as much as four times as much land to be irrigated under extreme conditions but also the productivity per unit of land irrigated may be doubled.

8. Since these systems apply water very uniformly, they also provide a means for efficiently applying nitrogen fertilizer. We believe that the efficiency of nitrogen fertilizer may be doubled by precise water management practices. This is especially true where fertility levels are being used.

9. The labor regime for these systems is not excessive and can be done in a systematic manner. The labor requirement for the hose-basin system involves an early morning shift and a late afternoon shift. One man should be able to handle 10 or more acres. The hose-pull sprinkler system also requires two shifts per day. Although there are twice as many hoses to move the labor requirement will be about the same because setting up the sprinklers is faster than laying the hoses in the basins.

10. Even though very careful filtration is unnecessary, contamination in the water can cause blockage of hoses and sprinklers. Furthermore, the system can be damaged by careless activities such as cuts from hoeing and digging tools or kinks in the hose caused by sharp bends.

The main management function is to safeguard the equipment from abuse and immediately repair any damaged components, make certain that the water is not excessively contaminated, and make certain that the system is systematically moved on a time schedule. The flow meters provided in the system should provide a means for keeping a watch on the quantity of water applied and thus noting any irregularities caused by broken lines stoppages or malfunction of the pumping units.

11. The repair and maintenance of the hose-type systems is relatively simple since the hoses can be repaired with simple connectors and no special tools are required. The main functions of a maintenance program are to assure that sediment does not deposit near the ends of the line thus lines should be periodically flushed and to keep all components in good repair.

12. The operating costs per unit of production of these systems should be even less than for the conventional low efficiency surface irrigation methods which use tubewell water. The reduced power requirements mentioned earlier will more than offset the anticipated equipment, maintenance and labor costs associated with the systems.

13. The hose systems are adaptable to farms where several owners operate under a given tubewell. However, the land should be parceled in a systematic way so that each owner has a square parcel of land which is fed from his own individual manifold. In this way he can be responsible for his own fertility injection system and screening device. Systems can be designed for economic subdivisions as small as 5 acres each with little effect on the overall system costs.

14. The hose-fed basin system should be suitable for high salinity waters. Of course, the suitability of the system for any given water will depend on the crop to be grown and the soil conditions. In general high frequency irrigation provides the best crop environment where saline waters must be utilized.

We do not recommend using the hose-fed sprinkler systems where waters are highly saline, however. This is due to the increase in salinity which is produced by evaporation directly from the water droplets and the salinity which will deposit on leaf surfaces due to the spray application. With highly saline waters there is little hope for any significant long term productivity from the area between the rows, therefore, we would recommend going directly to the hose-fed basin concept even on young trees.

15. The hose-fed basin system should be suitable for any of the wide spaced tree crops such as oranges, nuts, mangos, papaya, guava, chikoo and palm trees. It could also be adapted for some of the closer growing trees such as bananas.

The hose-fed sprinkler system is especially adaptable to tree crops planted on a 20 x 20 foot spacing where a low growing crop is desired between the trees in a new planting. The hose-fed sprinklers should also be adaptable to certain vegetable crops which are particularly adaptable to sandy soils such as carrots and potatoes. The use of such sprinklers on commercial truck crops has not been a common practice in the USA, however, such sprinklers are extensively used in urban and rural areas for home lawns and vegetable gardens. Considering the labor availability in Pakistan, it would appear that these systems would be suitable for row crops where walking and moving the hoses will not cause excessive crop damage.

Systems Not Presently Recommended

At this time we do not recommend the use of conventional trickle irrigation systems. This is because of the relatively high costs involved and the sophisticated filtering necessary to keep these systems in proper operating condition. In Pakistan the labor savings afforded by trickle irrigation systems may actually be a disadvantage. This is especially true in view of the fact that the movement of hose-fed basin and sprinkler irrigation systems will provide labor opportunities for work which is relatively pleasant and does not require a great deal of muscle effort or skill. Thus it is suitable for young and old alike.

We believe that while trickle irrigation may provide even better growing conditions, the systems we have described above should also provide near optimum conditions. Thus, we see little argument to use trickle irrigation which requires almost twice the capital as the above systems, needs greater skills and management input, and also requires the importation of more of the system components.

We have also rejected the use of center-pivot and typical aluminum pipe sprinkler irrigation systems because we feel that while they may look economical on paper they would require such large imports of machinery and materials that they are not nearly as attractive as the hose-fed systems which can be manufactured locally. Furthermore, these sprinkler systems

are mostly adaptable to low-growing crops and are not generally suitable for trees.

Center-pivot systems can be applied to vegetable production as well as grain and pulse production. However, we would not recommend their use except for essentially underdeveloped areas where foreign investment capital is available for large commercial farming operation activities.

Optimum Sites and Crops

The hose systems would be adaptable on any of the soil or topography conditions which we visited. As for the most optimum sites to begin with we would recommend the following:

1. The green belt area near Karachi and areas in the Qetta region where water rather than land is the main limiting factor to production. In addition the crops which can be grown in such areas have added value. For example, the region where there is adequate water, soils and climate for apple production is very limited in Pakistan and increasing the water use efficiency in such areas would have a potential to significantly increasing the productive capacity for this crop, i.e., doubling or tripling it. Another example is the green belt around Karachi were the proximity to the metropolitan area commands a premium for vegetables, fruits, and fodder. Here water supplies are also very limiting and it would be quite practical to increase the productivity of the area by severalfold with better water management practices.

2. There are vast regions in the northern and western portions of the Thal desert with adequate groundwater of suitable quality for development. These areas appear suitable for citrus and other fruit trees as we saw some of the best evidence of this on a small orchard during our visit there. Transportation facilities are already sufficient to allow for the rapid development of this area for export crops.

We did not have the opportunity to check out water quality-soil adaptability relationships and winter temperatures and of course that should be done before proceeding further. We do not recommend at this time trying to develop the tops of the dunes but rather suggest that the swales for flat areas between dunes should be developed first. Such areas are numerous in extent and somewhat protected from the more severe wind and weather conditions found on dune tops. The lower, flatter areas also have better and more fertile soils which fall in the loamy sand and in some cases even the sandy loam class. It is easier to manage water and fertility on these soils than it would be on the almost pure sandy areas found at the top of dunes which also are unstable during windy periods.

3. There seem to be some rather extensive fringe areas around all of the irrigated lands where water supplies are quite limiting and the irrigated areas could be significantly

extended by better water management practices. Some of these areas, especially the sandy zones which also lie within the irrigated areas would be interesting sites for the application of the hose-fed systems.

From the strategic standpoint, however, such sites would appear to have a lower priority for this type of development than those mentioned above. We would like to point out, however, that the sandy soils found in strips and knolls throughout the main irrigated area of the Indus Basin are well suited for fruit and vegetable production. At present these areas are often underdeveloped due to water management problems even where adequate water supplies are available. We suspect that there may be over a million acres of such land scattered throughout the Basin which would not be overlooked.

4. Although the riverine areas appear to have rather important agricultural potential due to the relatively low fertility of the soils and the fact that they are subject to overflow we would give them a low priority for consideration of development by hose-fed systems. Furthermore, we feel that where lands are subject to overflow the system would be vulnerable to extreme damage and hesitate to suggest their use at such sites.

ADAPTATION AND DEMONSTRATION INSTALLATIONS

We found a number of interesting fruit and vegetable crops which would be very profitable to irrigate with the hose-type system. In the beginning we would suggest demonstration installations on orange, apple, mango or nut tree crops, as well as potatoes and carrots.

Development of Complete Package

There is still some development work to be done to organize the package for the hose-fed basin systems. Such things as the proper outlets must be selected or found and the way of laying the supply tube into the basin and size of basins should be studied. In general we know approximately what should be done but feel that a certain amount of testing and organization of potential equipment is still needed. Therefore, we recommend first of all a brief investigation program to completely organize the strategy and then some simple tests in various types of soils to see what the best approach is for feeding water to the basins. Such activities should fit well within the existing CSU water management study programs.

Various hose-fed sprinkler packages are already available for direct importation and trial. However, we do suggest some study is needed since we will be using hose materials developed and produced in Pakistan which may not be exactly the same as those used elsewhere. This will require some study as to flexibility and durability of the products.

Furthermore, we would like to recommend that the simple sprinklers be manufactured in Pakistan and feel that investigation of suitable materials and products is in order.

As consultants we could take care of the initial stages of developing these packages and outlining the programs for their testing as well as doing any design work necessary for demonstration facilities. We can do this with a minimum of time and expense at our home office since we already have much of the product information and necessary data on hand.

Need for Field Demonstration

If after careful consideration of the practicality of hose-fed systems by agricultural specialists, economists and decision makers, it is decided that such systems have merit for further consideration in Pakistan, we recommend that an adaptive research site and demonstration installations be set up. We would not recommend going to more than one site initially since:

1. Adaptive research is needed to test equipment management and labor ideas.

2. Some water movement and growth studies are needed.

3. Demonstration of the techniques involved is important for training and better conceptualization of the concepts involved.

Once a suitable demonstration equipment package is available we would recommend extending the program to include sites in at least two additional areas. We would like to see sites on medium textured as well as sandy soils. Furthermore, a site should be selected where there is a very small water supply of a fraction of a second/foot to demonstrate how much land can be handled with a small amount of water.

Demonstration Site Selection

We feel that the initial adaptive research and demonstration site should be selected where there is assurance for visitation by public officials, professionals, farmers and interested parties without undue inconvenience. While it would be ideal to place such a site in a very sandy area to demonstrate the possibility of irrigating soils which are most difficult to handle by surface means, we do not consider this to be an essential site requirement.

In view of the above, we feel that the Agriculture Research Council's farm near Islamabad would be a practical location. The soils are loamy textured, somewhat rocky and uneven and therefore the systems would demonstrate their adaptability for such site conditions. Furthermore, there

is already an adequate tubewell and sufficient land for the program which we would recommend. Furthermore, the existing office facilities and personnel at the site along with the proximity to the Agricultural Research Council's central office and CSU/USAID Mission center in Islamabad should provide an excellent opportunity for developing the needed coordination and technical backup.

We would like to point out that if a decision is made to go ahead with a demonstration program, it should be conducted as a priority item or not at all.

We would like to see the demonstration begin with approximately 10 acres of plantings with mainlines sized for its extension up to a maximum of 80 acres depending upon the well capacity. We suggest that some of the newer varieties of almonds, pecans, peaches, apricots and strawberries may be interesting for consideration in the Islamabad area. Under trickle irrigation those crops which are climatically adaptable for this zone should do extremely well.

The initial demonstration site could be subdivided to try various hose-basin packages along with hose-fed sprinklers. Any mixture of fruit and nut trees along with vegetable and forage crops could be grown. As the facility is expanded it could also be used for varietal trials in plant material selection.

After the first year of operation if the program still appears viable, and suitable equipment packages have been identified, the original facility should be expanded and at least two additional demonstration sites selected. For these sites we would recommend a private citrus orchard in the Thal area, an apple orchard near Quetta, a private farm near Karachi or a public research station in the southern part of Sind as likely candidates. We would like to see at least one of these sites on very sandy soils and in the hands of progressive private management. The site sizes could be anywhere from 5 to 80 acres depending on the water supply and the amount of optimism. However, we recommend that even where larger sites are selected that the initial installations begin with a 10 acre system and be expanded in a systematic way.

In addition to demonstrating the concepts on a field basis there is also a need to determine what special environmental problems exist which may limit the functional ability or durability of the systems in Pakistan. Such things as: damage by people, rodents, insects and birds; management and labor problems; lack of durability due to improper materials and extreme climatic factors; and stoppage and blockage of pipelines due to sediment or incrustations should be well understood before becoming overly optimistic and proceeding with these systems on a large scale.

Obviously the overall economics of the systems will be highly dependent upon the life expectancy of the components. We are hopeful that the underground pipelines will last from 20 to 40 years and the surface hoses will last in excess of 8 years. For the hose-basin system the hoses which are the most vulnerable component make up about 25% of the system. For the hose sprinkler systems the hoses and sprinklers make up about 35% of the overall system cost. Thus, we are hoping for an average economic life of the system in the neighborhood of 20 years due to the longer expected life of the underground pipeline network.

Support and Management Skills Needed

As consultants we would be in a position to develop the necessary design for the initial pilot systems if we are supplied with standard field data giving soil, topography, water supply quality and quantity, and desired cropping program. We would also be in a position to complete such designs in a matter of days (of course the time requirements would depend upon the exact job to be done). At any rate the input time would be rather insignificant when measured against the entire project.

In addition to designing the initial systems we would be in a position to adivse CSU on the purchase of the equipment for shipment to Pakistan. We recommend that standard equipment be imported for the initial installations, however, we would like to see some hose and pipes of Pakistani manufacture also used if available. We want to point out that we are depending upon the ultimate capability of the Synthetic Chemicals Company, Ltd. to provide the needed polyethylene pipe and hose materials if this pipe system is to become a viable irrigation alternate for Pakistan.

We recommend that Charles Burt come to Pakistan for a six-week to two month stay to supervise the installation and start up procedures for the initial adaptive research and demonstration system. He should not come, however, until the equipment has all been landed in Pakistan and delivered to the site and the preliminary site field activities have been completed. This would include land clearing, fencing and an adequate water supply complete with the needed pressure, flow capability and tie-in piping.

To ensure the success of an adaptive research and demonstration program it will be essential that at least one high-level researcher who is an experienced and innovative field man be assigned exclusively to this endeavor. In essence we want to stress that the project should not be undertaken at all unless it is considered a priority item. It might even be useful if the project or research management be given the opportunity to travel to Iran, Southern Europe, Australia or the USA where he would have the opportunity to see trickle irrigation installations. We extend an invitation

for him to come to the USA where we could arrange to show him both trickle and hose-fed sprinkle installations being installed and operated. We could also involve him in some commercial design activities for these systems.

The cost for the above adaptive research and demonstration program can be estimated from the attached system design costs given in the appendices and your existing knowledge of cost estimates for these types of activities in Pakistan.

SUMMARY AND CONCLUDING REMARKS

From the above it should be clear that we are rather enthused about the possibilities of using hose-fed basin and sprinkle irrigation systems in Pakistan. At this time we do not recommend the use of standard trickle irrigation systems or sprinkle irrigation except under specific management conditions.

We feel the hose-fed concept is particularly adaptable to Pakistan since it makes a reasonable compromise between labor and resource inputs. These systems should provide optimum water management on all types of soils for a variety of vegetable and tree crops. Furthermore, from the information we have gathered, most of the components of these systems can be manufactured from locally available resources by existing industries.

We would like to reemphasize that these systems use existing technology that in some cases is different enough that some adaptive research will be necessary before the final delivery packages can be developed. We want to precaution against over-optimism before developing and testing suitable systems from locally manufactured goods. There remains a question of system durability and the capability to manufacture the equipment locally at the present time. However, we do not anticipate any insurmountable problem in terms of developing a suitable product from the technical standpoint and achieving the hoped for results described earlier.

We would also like to stress the need for careful management on these types of systems and it should be demonstrated that there is sufficient quantity and quality of management available in the farm communities for their operation. We are hopeful that we can design relatively simple packages and set them up in a way in which they can be understood and operated by indigenous personnel. We believe however, that the best opportunities for these systems exist on new lands rather than lands which have already been fragmented into many small, irregular holdings.

APPENDIX 36

EFFECTS OF DELAYING THE FIRST IRRIGATION ON THE DEVELOPMENT OF YIELD COMPONENTS IN SEMI-DWARF WHEAT[1]

Noor Muhammad Chaudry - M. Ibrahim - Jerry B. Eckert[2]

This paper contains the results of a preliminary study conducted by the Cereals Section, Punjab Agricultural Research Institute in Lyallpur, Pakistan. These initial results indicate that the development of the several yield components are differentially influenced by moisture stress occurring at different points in the morphological development of the wheat plant. More adequate experimentation is currently underway to definitively establish these relationships.

The Problem

Several authors reporting research from the Indo-Pakistan subcontinent (2,3) note the critical nature of the first irrigation for wheat and suggest 21 days after planting (d.a.p.) as ideal. This irrigation has been suggested as necessary for crown root development and tillering. The importance of precisely timing this first irrigation has not been verified in Mexico, the source of the geno-type, or in other countries where growing conditions and cultural practices differ. It seems apparent from this comparison that the critical nature of timing of this irrigation is derived from the particular set of seed-bed preparation practices that characterize India and Pakistan. These include a heavy preplant "soaking dose" irrigation followed by a series of plowings and plankings spread over several days during which as much as half of the available moisture may be lost from the surface 15 centimeters.[3] From this starting point

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[1]This study was supported in part by the United States Agency for International Development through Contract No. AID/csd-2162.

[2]Respectively Assistant Botanist (Cereals) P.A.R.I. Lyallpur, Physiologist P.A.R.I. and Agricultural Economist, Colorado State University.

Prepared for presentation to CENTO Panel Meeting on Optimum Use of Water in Agriculture, held at Nuclear Institute for Agriculture and Biology, Lyallpur, March 1975.

[3]Measurements on a common local loam soil with a field capacity of between 18 and 20 percent and a permanent wilting point of 6-7 percent indicate a moisture percentage of approximately 12 percent prevails in the upper 15 centimeters at planting following native cultural practices.

moisture losses continue from surface evaporation and transpiration resulting in plant moisture tensions that could retard adequate root extension or tillering early in the plant's life.

This experiment was developed to test the effect of varying delays in the first irrigation on wheat yield and its components. Wright (3) has reported Indian research on the effects of delaying the first irrigation on wheat but his observations are limited to measured yield only. The research reported here specifically sought to determine if the timing of the first irrigation would have sufficiently different effects on individual yield components to warrant more intensive investigations.

Methods

The variety Chenab-70 was planted November 9, 1973, emerged one week later and was harvested April 25, 1974. A fertilization of 112-56-0 kg/ha,[1] was standard throughout a field that had been substantially depleted of nutrients by a thick summer crop of unfertilized sorghum. While there was only one replication, two samples, each of 5 rows x 3 meters length, were harvested from each irrigation plot and averaged for the data presented here. Two measurements per plot were taken for headed tiller numbers per meter of row and 1000 grain weight and 20 heads per plot were measured for spikelet number and grains per spikelet.

Irrigations were begun 14, 21, 28, 35, 49 and 63 days after planting as shown in Table 1. An additional unirrigated treatment was included to observe plant development and yield on residual moisture along. All treatments except the latter received a total of four irrigations. Irrigations were approximately 7.6 cm. (3 inc.) each. Rainfall during the season amounted to 3.7 cm. only.

Following photomicrographs by Bonnett (1), the development of the shoot apex was recorded. Of particular interest were the dates on onset and completion of spikelet differentiation in order to determine if this process was affected by moisture stress treatments before or during.

Results

Data on the expression of the various yield components and the resulting relative estimated yield are presented in Table 2 and summarized graphically in Figure 1. Estimated yields, the product of the four yield components, declined as

[1]Equal to 100 pounds of nitrogen and 50 pounds of phosphate nutrients per acre.

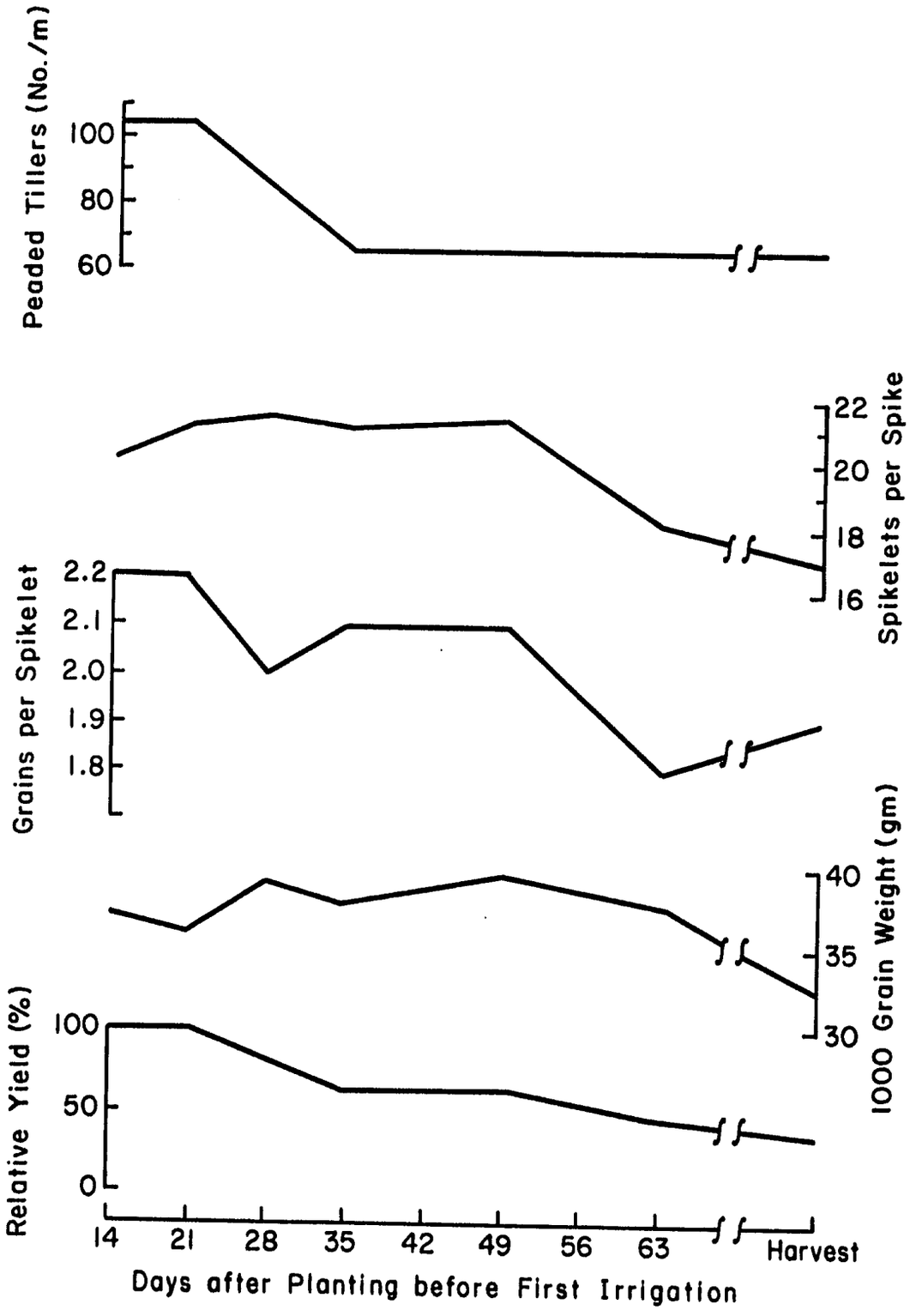

Figure 1. Yield components associated with varying delays in application of the first irrigation.

Table 1. Irrigation treatments and crop stage at first irrigation.

Treatment Number	Irrigation Schedule First (d.a.p.)	Irrigation Schedule Others (d.a.p.)	Crop Stage at First Irrigation
T-1	14	64,92,123	3rd leaf emerging, crown root node swelling
T-2	21	75,106,129	3rd leaf complete, 4th emerging, 1st tiller appearing, crown root started
T-3	28	87,113,141	4th leaf complete, 5th emerging, 2 tillers formed, 3rd started, 2 crown roots 1-2" long.
T-4	35	87,113,141	5th leaf complete, 6th emerging, 4th tiller started
T-5	49	87,113,141	5-6 tillers complete
T-6	63	92,113,141	Effective tillering nearly complete
T-7	No irrigation applied		

Table 2. Plant characteristics and yield associated with delays in the application of first irrigation.

First Irrigation Applied (d.a.p.)	Plant Height (cm.)	Headed Tillers (#/m.)	Spikelets per head	Grains per Spikelet	1000 Grain Weight (gm.)	Relative Yield (%)
14	104	106	20.2	2.2	37.1)	100
21	102	105	21.2	2.2	36.1)	
28	99	85	21.4	2.0	39.1	81.1
35	101	66	21.2	2.1	37.8	63.3
49	100	64	21.4	2.1	39.6	64.9
63	89	66	18.1	1.8	37.9	46.5
None	82	64	16.8	1.9	32.7	35.5

irrigation was delayed beyond 21 d.a.p., reaching 46 percent of maximum at T-6 and 35 percent when grown without irrigation.

Results

The number of headed tillers was reduced significantly as the first irrigation was delayed from 21 to 35 days after planting. At 35 d.a.p. a new level, some 60 percent of maximum, is established which appears to remain unchanged regardless of stress developed at later stages. This suggests that under these conditions the number of headed tillers is sensitive to stresses occurring only between 25-35 d.a.p.

Except for the slightly lower reading in T-1, spikelets per head remained constant through T-5. This parameter then dropped significantly as the first irrigation was further delayed from 49 to 63 d.a.p. This pattern is explained by examining the relationship between the incidence of stress and the timing of the spikelet differentiation process.

Preliminary observations from the preceding year had indicated 40-49 d.a.p. as the period of spikelet differentiation on normally irrigated and fertilized wheat at Lyallpur. Accordingly observations of apical meristem development were begun at 39 d.a.p. Results, as presented below in Figure 2, suggest that successively longer periods of stress in the early growth stages delayed the onset of spikelet differentiation even though soil moisture was restored before differentiation began. T-1, T-2 and T-3 indicate that differentiation is completed in approximately 20 days under well watered conditions.

More prolonged stress continues to retard the onset of differentiation. However, all treatments but T-1 and T-2 show a definite cut-off date, approximately January 10 or 62 d.a.p. in 1973-74, at which point differentiation of glumes begins. The result is that if irrigation is delayed beyond approximately 30 d.a.p., the combination of the delayed onset of differentiation and the apparently fixed cut-off date shorten the total period for spikelet initiation.

T-6 yields two observations of interest. First spikelet differentiation required eight days, from 54 to 62 d.a.p., even though no irrigation had yet been given. Second, the entire process was completed before irrigation and it was only this treatment and T-7 (residual moisture) in which spikelet numbers declined significantly.

Apparently, even though early stress can affect the timing and length of spikelet differentiation, spikelet numbers are unaffected unless serious stress prevails during

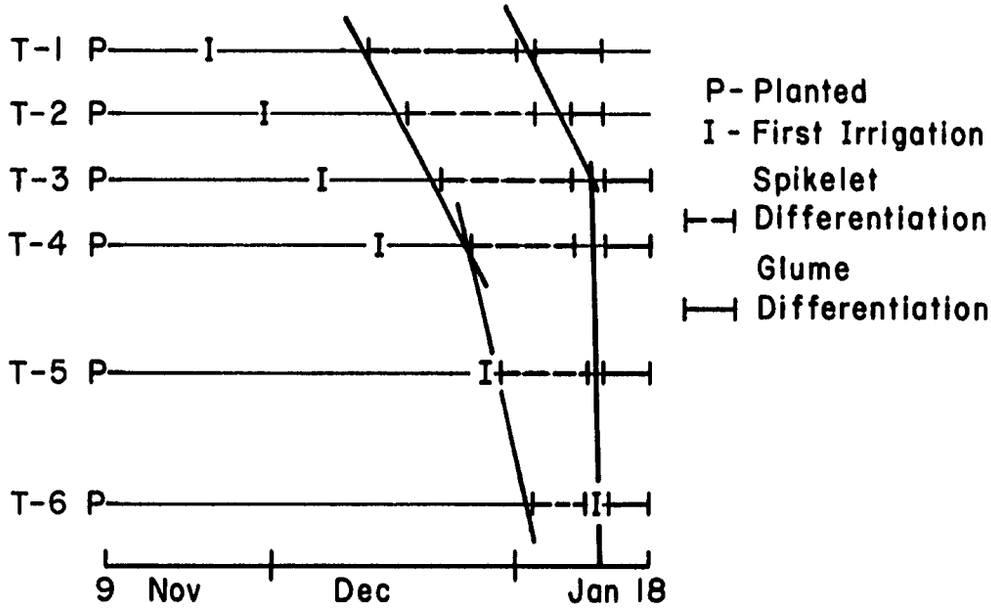

Figure 2. Apex differentiation related to timing of first irrigation.

the differentiation process itself. To summarize these points it appears that, 1) the plant responds to early moisture stress by delaying the onset of spikelet differentiation, 2) the differentiation process was completed on or before Jan. 10th under Lyallpur conditions in 1973-74 regardless of its date of onset, 3) even under severe stress conditions some 8-9 days are required and 4) spikelet numbers are unaffected regardless of the length of the process as long as soil moisture is replenished before differentiation begins.

Grains per spikelet show, with some variation, a steadily decreasing trend beginning at T-1. Only T-6, however, was below earlier treatments by an amount that was significant at the 90 percentlevel. Evidently serious moisture stress beyond 49 d.a.p. caused inadequate pollination or aborted grains.

Thousand grain weight showed essentially no change through T-6 then dropped some 14 percent when stress continued to develop throughout the grain filling stage. Shriveled grains were widely noted in the T-7 samples. Grain composed 33-35 percent of total dry matter in all treatments except T-7 where, due to the lower 1000 grain weight, grain declined to 28 percent of total dry matter.

The economic consequences of delaying the first irrigation can be substantial as shown by the declines in relative yield experienced with successively longer delays. The primary source of loss comes from reduced tillering. A good farmer should be able to grow 40 maunds of Mexican wheat per acre by appropriately managing all inputs. With this potential, delaying the first irrigation from 21 to 35 d.a.p. can reduce gross income by Rs. 587 per acre to 63.3 percent of its unstressed level.

There is essentially no further change if irrigation is then further delayed until 49 d.a.p. Approximately 300 additional rupees are lost per acre if irrigation is not given until 63 d.a.p.

It seems unlikely that farmers would allow wheat to go as long as 7-9 weeks without applying water. In a practical cropping circumstance then the most important variable seems to be moisture management between 21-35 d.a.p. wherein tiller numbers can be strongly influenced. Due to the linear decline in tillers, relative yield declined 2.6 percent a day throughout this two week period. Again assuming an unstressed yield potential of 40 maunds per acre, delays in the first irrigation result in a loss of Rs. 42 for each day beyond 21 d.a.p.

REFERENCES

1. O.T. Bonnett, Inflorescences of Maize, Wheat, Rye, Barley and Oats: Their Initiation and Development, University of IL, Agricultural Experiment Station Bulletin 721, Urbana, 1966.

2. Indian Agricultural Research Institute, Five Years of Research on Dwarf Wheats, New Delhi, 1968.

3. Bill G. Wright, "Critical Requirements of New Dwarf Wheat for Maximum Production", paper presented at the International Seminar on Wheat Improvement and Production, Lyallpur, 1968.

Appendix 37

WATER AND FERTILIZER INTERACTIONS IN WHEAT PRODUCTION[1]

S.A. Qureshi, Noor Muhammad Chaudhry and Jerry B. Eckert[2]

The Problem

Making accurate recommendations to farmers requires an understanding of both the physical and economic characteristics of crop response to inputs. Water and nutrients are two inputs which have important interrelationships affecting each other's profitabilities. Considerable research has been completed on the response of various crops to fertilizer in Pakistan. Yet the water variable in these experiments has almost never been quantified. Responses of crop production to water inputs are not available nor are coefficients for water-fertility interactions. Recommendations to farmers are usually made for each input separately rather than for combinations of inputs such as irrigation and fertilization.

This research study was designed to estimate the response of wheat to irrigation and fertilizer inputs in such a manner that would permit derivation of economically optimum input combinations. Nitrogen-irrigation interactions were stressed. From the calculated optima, a series of recommendations are developed.

Methods

The variety Chenab-70 was planted in a 5 x 6 incomplete factorial design, replicated thrice, during the 1973-74 season. Nitrogen fertilizer applications of 0, 50, 100, 150 and 200 pounds per acre were applied at sowing. The experimental area had been previously sown with a dense depletion crop of unfertilized sorghum. Plot splits received 50 and 150 pounds per acre of phosphate. All nutrients were applied at sowing.

Irrigation treatments included 1, 2, 3, 4, 5 and 6 irrigations. Each irrigation was controlled at 3 inches by use of siphon tubes of known flow characteristics and then relating head differences with application times for

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[1]Prepared for CENTO Panel Meeting on Optimum Use of Water in Agriculture to be held at Nuclear Institute for Agriculture and Biology, Lyallpur, March, 1975.

[2]Cereal Botanist and Assistant Botanist (Cereals), Punjab Agriculture Research Institute, Lyallpur and Agricultural Economist, Colorado State University Water Management Field Team, respectively.

a known plot size. The number of irrigations in a given treatment were distributed throughout the growing season to optimally meet crop needs. Previous research at Lyallpur and elsewhere in the Subcontinent as well as estimated evapotranspiration patterns determined the timing of irrigations and the length of irrigation intervals in relation to stage of crop growth. Details are given in Appendix I.

Multiple regression techniques were used to estimate the nitrogen x water x phosphorous irrigation surface. Only applied fertilizer units are included in these calculations. Water inputs were enumerated in centimeters and included all irrigation water plus 3.6 cm rainfall and 18.3 cm net depletion of the root zone, (available moisture at planting minus available moisture at harvest). The one irrigation treatment therefore, utilized about 30 cm of water (3.6 + 18.3 + 7.6).

Results

The estimated equation defining the production response relationships is given in Equation 1 below. Yield and applied nutrients are in kg/ha and water is in hectare centimeters. Figures in parentheses are standard errors of the coefficients.

$$1)\quad \text{Yield} = 109.0 + \underset{(1.47)}{15.73\,N} - \underset{(.00629)}{.05448\,N^2} + \underset{(2.205)}{3.151\,P} + \underset{(9.20)}{51.21\,W} -$$

$$\underset{(.0933)}{.3388\,W^2} + \underset{(.01008)}{.09325\,NP} - \underset{(.00000027)}{.00000158\,(NP)^2} + \underset{(.0267)}{.1938\,(NW)} -$$

$$\underset{(.00000187)}{.00001385\,(NW)^2} - \underset{(.03827)}{.08467\,(PW)}$$

This equation explains 92 percent of the variation in yield that occurred in the experiment. It can be used to predict yield from various combinations of inputs with a standard error of the estimate of 347.2 kg/ha (3.8 maunds). All of the individual coefficients except P and PW are significant at the 99 percent level, and PW is significant at the 95 percent level.

Figure 1 shows the response surface for two inputs, water and nitrogen, with phosphate held constant at 112 kg/ha (100 lb/ac). It is apparent that fertilizer is the prime contributor to higher yields within the input ranges considered. This reflects the fact that even limited water supplies were properly timed to minimize plant moisture stress during periods of crop sensitivity. Under this water management condition, yields in excess of 40 maunds can be obtained with as little as 30 cm of water combined with adequate fertilizer. Thirty centimeters of water requires

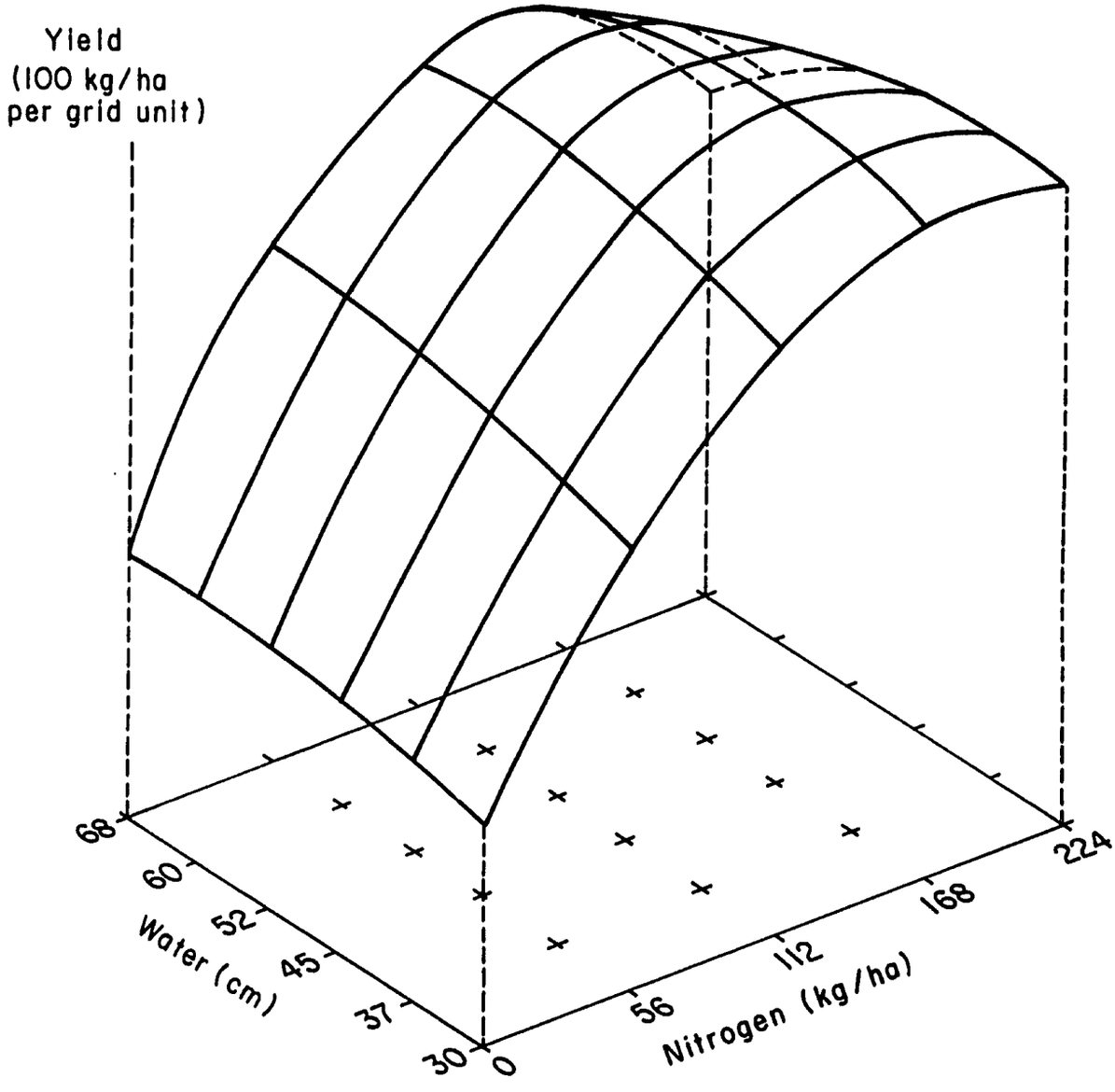

Figure 1. Production response to nitrogen and water inputs.

only a good wattar[1] condition at planting, one irrigation correctly timed at 21 days after planting and a little rain.

Yields decline at high levels of nitrogen and irrigation applications. Two causes were observed. The moderately susceptible Chenab-70 suffered some rust attack that became heavier with high input combinations. Presumably the combination of a very thick, lush canopy and a somewhat extended growing season increased the variety's vulnerability on these plots. The second cause was lodging, the incidence of which increased with high input combinations. Later irrigations in the 5 and 6 irrigation treatments extend the period in which the soil surface is partly fluid and in combination with the heavier crop canopy create conditions for lodging during early March winds.

Table 1 presents the structure of the marginal products of nitrogen and water, each with the other input held at specified levels and with phosphorus held constant at 1 bag of TSP per acre. Because of their interaction, the level of nitrogen affects the productivity of water in this surface, and conversely.

Not shown in either Figure 1 or Table 1 is the N x P interaction which also fit a quadratic form. Application of a given amount of phosphorus gave larger returns as nitrogen levels increased up to about 112 kg/ha (100 lb/ac) after which the apparent productivity of phosphorus declines as shown in Figure 2. Presumably this is again related to the incidence of rust and lodging at higher nitrogen levels which constrained the plants' ability to respond fully to applied nutrients.

Economically Optimum Input Applications

Marginal value products (MVP) are determined by multiplying the marginal physical products (MPP) by the unit price of output (P_y).

To maximize profits farmers expand their input usage receiving a smaller incremental product for each additional unit applied until the MVP of the last unit exactly equals

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[1]Wattar is a moisture condition that permits working the soil without compaction yet retains the moisture needed for germination and emergence. At wattar available moisture in the surface 15 cm (6 in) is from 1/4 to 1/2 depleted while the rest of the profile is essentially at field capacity if an adequate preplant irrigation has been given.

Table 1. Marginal Physical Products of Irrigation Water and Nitrogen Applied to Semi-Dwarf Wheat, Lyallpur, 1973-74 (in kg/ha)*

With Nitrogen Constant At	Marginal Products of Water — Water Input Levels					
	30 cm	37 cm	45 cm	52 cm	60 cm	68 cm
0 kg/ha	26.14	21.40	15.98	11.23	5.81	0.39
56 kg/ha	34.38	29.04	22.92	17.57	11.45	5.34
112 kg/ha	37.42	30.25	22.05	14.87	6.67	-1.53
168 kg/ha	35.24	25.02	13.35	3.14	-8.54	-20.21
224 kg/ha	27.85	13.39	-3.16	-17.63	-34.17	-50.71

With Water Constant At	Marginal Products of Nitrogen — Nitrogen Input Levels				
	1 kg/ha	56 kg/ha	112 kg/ha	168 kg/ha	224 kg/ha
30 cm	26.62	18.71	10.66	2.61	-5.45
37 cm	28.20	19.34	10.56	1.78	-7.00
45 cm	29.74	19.88	10.08	0.28	-9.52
52 cm	31.07	20.18	9.33	-1.52	-12.38
60 cm	32.61	20.34	8.10	-4.14	-16.38
68 cm	34.12	20.30	6.47	-7.36	-21.19

* Phosphate application assumed constant at 56 kg/ha.

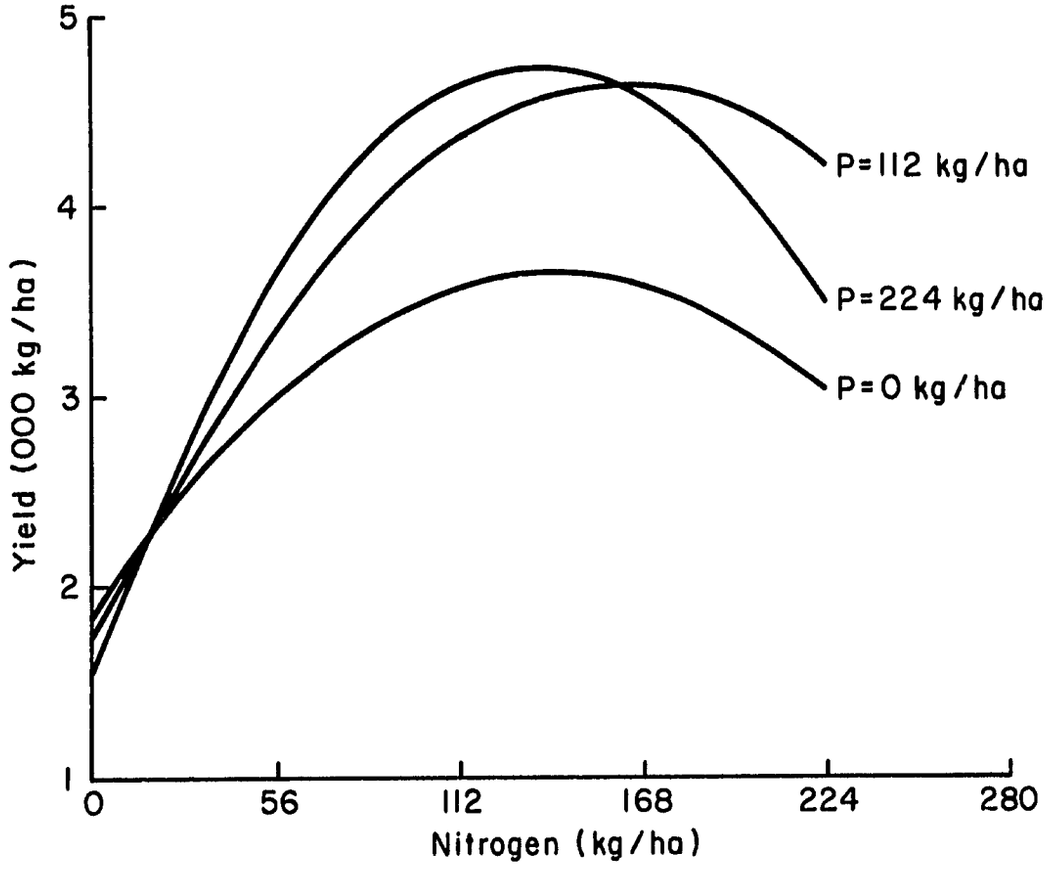

Figure 2. Effects of selected combinations of N and P on wheat yields.

its cost (P_{x_i}). The high profit point for a single input is defined by Equation 2.

2) $MVP_{x_i} = MPP_{x_i} (P_y) = P_{x_i}$.

Accumulating price terms into ratios, equations 3, 4 and 5 when solved simultaneously define a three dimensional high profit point for applications of water nitrogen and phosphorous.

3) $MPP_w = \frac{P_w}{P_y}$

4) $MPP_n = \frac{P_n}{P_y}$

5) $MPP_p = \frac{P_p}{P_y}$

As is obvious, the prices of inputs and outputs determine economically optimum application levels. We have defined profit maximizing input combinations for several resource and price situations below. In all cases output price has been assumed constant at Rs. 40/maund (1.0717 Rs/kg).

A. Current Input Prices: Nitrogen is priced at 3.30 Rs/kg when purchased in its most common form, urea, at controlled prices. Phosphate is priced here as available in its most common local form, diammonium phosphate (DAP) after deducting the value of nitrogen contained in DAP at the above rate. Phosphorus therefore costs 2.00 Rs/kg. Water is priced in this first estimate at an approximate pumping cost of 3.24 Rs/hectare centimeter (Rs.40/AF) at the well. This value is adjusted to reflect a combined delivery and application efficiency of 25 percent. Pumped water effectively stored in the root zone for plant use thus costs Rs. 12.97 per hectare centimeter (Rs. 160/AF).

Under these price conditions the most profitable input combination would be 42 cm (16.44 inches) of water, 148 kg/ha (132 lb/ac of nitrogen and 167 kg/ha (149 lb/ac) of phosphorus. Yield would be 4735 kg/ha or 51.36 maunds per acre of wheat. The high rate of phosphorous application estimated here is surprising. It reflects the depleted nature of the soil obtained by the unfertilized kharif depletion crop and the slow rate at which phosphorus becomes available to plants. On fields that routinely received phosphorus or were not subjected to constant cropping, the optimum phosphorous dose would be considerably less. Nonetheless, the data suggest that in comparison to other nutrients phosphorus may be underpriced at present.

Forty-two centimeters of water would have required 2.5 irrigations of three inches (7.6 cm) each in addition to stored soil moisture and rainfall in 1973-74. This is a very low number of post planting irrigations when compared to the range, 4-7, that is considered normal in different parts of Punjab. This emphasis will appear throughout these calculations; that high yields are possible with limited irrigation numbers as long as irrigations are optimally managed and adequate fertilizer is used. In this case a yield of 4735 kg/ha (more than 51 md/ac) was obtained with only 2.5 irrigations (20 cm) of water applied after planting.

B. Water Valued at its Productive Value: The above set the price of water at its pumping cost. More appropriately water should be valued according to what it produces. We take the marginal productivity of water at the third irrigation for moderate to high fertility levels as indicative of the possible productivity of water under current cropping systems. Averaging the MPP_W figures from Table 1 for 56 and 112 kilograms of nitrogen we get an estimated value of 24.10 Rs/hectare centimeter (24.78 Rs/ac in). This figure is consistent with independent estimates of Jameel Khan who obtained values ranging from 22-25 rupees per acre inch (4).

With water priced to reflect its productivity, profit maximization occurs at 33 cm H_2O (13 inches), 150 kg/ha nitrogen (133 lb/ac) and 175 kg/ha phosphorus (156 lb/ac) with a yield of 4605 kg/ha (50 md/ac). In this instance the higher price of water caused less of it to be used [11 cm (4.4 inches) as compared to 20 cm (7.9 inches)]. Because of the substitutions involved, higher levels of nitrogen and phosphorus were necessary to maximize profits.

C. Water Priced at Zero: At present farmers are assessed for their water on the basis of a flat fee per acre irrigated from canal supplies. The assessment applies whether the field is irrigated once or several times. In effect, then, the water assessment (abiana) becomes a fixed charge levied against the first irrigation and all subsequent irrigations from canal water have a cost of zero.

Under this institutional circumstance, the only constraint to continued expansion of the number of irrigations is when total product begins to actually decline ($MVP_W < 0$). Allowing all three inputs to be variable the high profit point is 142 kg/ha (127 lb/ac) of nitrogen, 157 kg/ha (140 lb/ac) phosphorus and 53 cm (21 in) of water.

If, however, phosphorus is constrained at 56 kg/ha in an effort to more closely approximate the natural phosphatic fertility of the soil and we assume no further phosphate is added as is the usual case, optimum input levels are 132 kg/ha (118 lb/ac) of nitrogen and 62 cm (24 in) of water.

This is very nearly the same as two bags of urea per acre combined with five 3-inch irrigations which is a fairly good approximation of input levels actually used by more progressive farmers.

The flexibility of the economically optimum irrigation level with respect to price should be noted. One result of the current structure of abiana pricing is to lead farmers acting individually to use 2.5 times as much water per acre (5 irrigations vs. 2) as they would use if water were priced to reflect its value to Pakistan.

The implication of these comparisons is clear. If water is valued appropriately and farmers know the best timings and methods of irrigation they should not be applying more than two irrigations following planting and should use their additional water instead to expand wheat acreage as much as possible. Note, however the critical assumption that farmers know the optimum timing and techniques of irrigation and are able to apply them.

D. With Only One Bag of Phosphate/Acre: Farmers are not yet convinced of the utility of phosphatic fertilizers. In part this is because at current low cropping intensities the natural release rate of phosphorus from the soil meets a major portion of crop needs. As cropping intensifies, the need for phosphorus will be increasingly felt. In fact, research by the University of Agriculture, Lyallpur has shown that the importance of applying phosphorus fertilizers has increased each year since Mexican wheats with their higher yields were introduced. (1)

We can, however, approximate the farmers' situation by constraining phosphorus applications to one bag DAP or TSP per acre, or an application rate of 56 kg/ha. Profits are then maximized with 49 cm (19 in) of water and 147 kg/ha (131 lb/ac) of nitrogen assuming again that the price of water equals its pumping cost. Yield on the experimental production surface at these input levels would be 4227 kg/ha (45.8 md/ac) however with a less depleted soil yields could be higher with the same applied fertilizer.

These yields (in excess of 45 maunds per acre) were obtained with 49 cm of water used. Under the conditions that prevailed, which are not unrepresentative for much of Punjab, 3.6 cm were available from rain and 18.3 cm from moisture stored in the soil after the preplanting irrigation. Only four irrigations of 7.6 cm (3 inches) each are needed to supply the remainder. In fact results are even better if the first irrigation after planting is only 5 cm (2 inches).

E. With Limited Water and Phosphate: To simulate the situation of a farmer who has limited (although fully

controlled) water supplies and only uses one bag of phosphorus per acre we estimated the economically optimum nitrogen application for two post plant irrigations (37 cm total water) and 56 kg/ha of phosphorus. Optimum nitrogen fertilization under these conditions is 160 kg/ha (143 lb/ac) and the resulting yield will be 4034 kg/ha (43.8 md/ac).

One conclusion is obvious from this calculation. If water is applied correctly, even if it is in limited supply, rather high yields are still possible. To a certain extent additional nitrogen can offset a reduced water supply profitably.

Summary

Chenab-70 was grown experimentally under different combinations of water, nitrogen and phosphorus inputs. A production response equation was estimated by multiple regression to portray the three dimensional response surface. Soil nutrients were depleted to a uniformly low base before planting, hence response to applied nutrients was substantial. Economic optimization required high levels of both nitrogen and phosphorus.

Irrigation water was given in a sequence approximating normal farmer practices for Pakistan. A heavy preplant (rauni) irrigation was given which essentially established field capacity throughout the potential root zone. Eighteen centimeters of water were eventually utilized from this source and an additional 3.5 cm were obtained from rainfall. Recent research has shown that consumptive use of water under well irrigated conditions may be a s little as 35 cm for the wheat crop. (2) Preplant irrigation and rain supplied some 62 percent of this amount with the result that yield response to post-planting irrigations was not dramatic. This pattern was reinforced by optimal timing of post-plant irrigations. Hence, the one irrigation treatment, bringing water supplied up to 83 percent of consumptive use, was applied at the right time for maximum contribution to root extension and sink development. Little additional contribution was to be expected from further irrigations. The flat response to water, however, did leave the economically optimum irrigation level more sensitive to changes in water price than was the case for applied nutrients.

At high irrigation levels combined with high nitrogen levels, canopy conditions were such that lodging occurred and the variety's susceptibility to rust was expressed. Yield depression resulted with these input levels.

Recommendations

A. Irrigation Application: High yields can be obtained with adequate fertilization if irrigation water is properly managed. To permit maximum yields, plant moisture stress must be avoided during two critical periods. The first is approximately 21-35 days after planting during which time the number of headed tillers is determined and crown root development begins. Reduced tillering due to stress and inadequate nutrition at this time is probably the most important factor limiting yields in Pakistan. Adequate root extension ensures that moisture stored at lower profile depths (up to 5 feet) will be available to minimize the incidence of stress during later stages.

On wheat planted at watter following a preplanting irrigation, the most important irrigation is the one given at 21 dap. If a farmer can give only one post-planting irrigation, it should be at this time. However, since soil moisture depletion at 21 dap is largely confined to the surface 30 cm (12 inches) and the remainder of the profile cannot hold more water, a very light irrigation of 2.5 - 5 cm (1 - 2 in) should be applied. To do so usually requires a precisely leveled field, appropriately shaped fields and an adequate flow of irrigation water. Achieving these management conditions, however, is important since any water in excess of what can be held in the surface 30 cm will pass on through the profile to ground water carrying much of the applied nitrogen with it.

The second critical stage of plant sensitivity to moisture stress is during flowering. With adequate root systems the probability of severe stress occurring at this time is reduced. Furthermore, winter rainfall in Pakistan's Punjab often meets part of the plant's water needs during flowering. Nevertheless if a farmer can apply two irrigations the second should be given at early boot stage so that only minimal plant moisture stress occurs during the rapid physiological acitivity characterized by booting and flowering. Available moisture averaged throughout the profile should not be more than 30 percent depleted during flowering if yield reductions are to be avoided. (3)

The amount of water to be applied at this time depends on the extent to which the profile is depleted. Depending on crop growth, winter weather and the frequence and amount of earlier irrigations this amount may range between 5 and 10 cm (2 - 4 in). Again, as with all irrigations, over-irrigation should be avoided to conserve leachable nutrients.

If farmers wish to apply 3 - 4 irrigations they should be timed as they were in this experiment as shown in Appendix I. All irrigations before March 1 should probably be no

more than 5 cm in depth. Irrigation after March 1 may be heavier as soil profile depletion indicates. Where heavy doses of nitrogen are used, more than 52 cm of total water (approximately 4 post-planting irrigations) is not recommended if rust and lodging are to be avoided. Even with a rust resistant variety lodging will reduce yields at high combinations of water and nitrogen. On poorly fertilized fields, say one bag of urea per acre, water inputs may be expanded up to 5 or 6 irrigations but only if water is priced well below its true value to the country. Water priced at its pumping cost or particularly at its abiana assessment rate is seriously underpriced by this criterion.

B. Nutrient Applications: Our soil was purposely depleted of nutrients to trace the full range of the nutrient response functions. These recommendations should be viewed with that background. Similar fertility levels can be obtained with lower inputs at the start of the season if appreciable residual nutrients are already present in the soil. The problem with relying on residual nutrition is that preplanting irrigations, which push the water through and below the root zone to ensure field capacity throughout, will carry soluable nutrients such as nitrate nitrogen down with the wetted front. Nutrient losses by leaching can be substantial even before the season starts for this reason.

For farmers giving four irrigations and only one bag of DAP or TSP per acre, nitrogen may be profitably applied up to 147 kg/ha (131 lb/ac) to a depleted soil. If only two irrigations are possible, maximum profits are attained at 160 kg/ha (143 lb/ac) of nitrogen. Both cases will yield more than 4000 kg/ha (43 md/ac).

When phosphate is not limited and higher applications may be given, economically optimum application levels at four irrigations are 142 kg/ha (127 lb/ac) of nitrogen and 159 kg/ha (142 lb/ac) of phosphorus. Yield will be 4768 kg/ha (51.7 md/ac) which is slightly higher than the three dimensional high profit combination. This occurs because we set water inputs at 52 cm (four irrigations of three inches each) whereas economics would limit water applications to slighly less than four full irrigations even if water is priced only at its pumping cost.

At the two irrigation level where water supplies total 37 cm, maximum profits occur at 149 kg/ha (133 lb/ac) of nitrogen and 171 kg/ha (153 lb/ac) of phosphate. Yield at this input combination is 4675 kg/ha or 50.7 maunds per acre.

Differences between these recommendations, while statistically significant, are not practically important. A generalized recommendation can be made that nitrogen can be applied up to 140 kg/ha (125 lb/ac) for two, three or four irrigations as long as the irrigations are properly timed. Two bags of urea and one of DAP per acre will be very profitable to the farmer. On phosphorous poor soils an additional bag of DAP or TSP can be profitably applied as well. However, in the interests of maximizing the total product of the nation's supply of fertilizer it is advisable to provide DAP and Urea in equal amounts and recommend one bag of each per acre for wheat cultivation.

Benefit cost ratios of these optional recommendations are given in Table 2 for farmers applying four irrigations. For this table figures are in inches and pounds per acre for ease of reference. From these calculations it can be seen that while the farmers own calculations may lead him to very high fertilization levels it is in the interests of Pakistan to recommend only one bag each of Urea and DAP per acre. Four bags (2 Urea and 2 DAP) return only Rs. 1214 in produce if they are all applied on one acre but return Rs. 1534 in wheat if they are spread over two acres.

Table 2. Benefit-Cost Ratios for Various Fertilization Recommendation Options*

Fertilization Level		Yield** (md/ac)	Yield** (Rs/ac)	Cost of Fertilizer (Rs/ac)	Added Value	Benefit-cost Ratio
Unfertilized	(0- 0-0)	20.1	805	-	-	-
1 bag Urea/acre	(50- 0-0)	32.7	1307	75	502	6.7:1
1 bag DAP/acre	(20-50-0)	26.4	1055	75	250	3.3:1
1 Urea & 1 DAP	(70-50-0)	39.3	1571	150	767	5.1:1
2 bags Urea/ac	(100- 0-0)	39.0	1559	150	754	5.0:1
2 bags DAP/ac	(40-100-0)	33.8	1352	150	547	3.6:1
2 Urea & 2 DAP	(140-100-0)	50.5	2018	300	1214	4.0:1
2 Urea, 1 DAP, 1 TSP	(120-100-0)	49.6	1982	280	1177	4.2:1

* Water inputs held constant at four 3-inch irrigations.

** Yield valued at 40 Rs/maund. One maund 37.32 kg.

References

1. Ahmed Saeed Khan, Derivation of Fertilizer-Crop Response and Optimum Levels of Fertilization for Various Crops/Areas, prepared under Grant No. FG-Pa-172(A17-ERS-15), University of Agriculture, Lyallpur, 1974.

2. Ghulam Haider, M.A.R. Farooqi and C.J. deMooy, "Consumptive Use of Water by Wheat Under Optimum Management Conditions", paper presented to the NIAB-CENTO Workshop on Optimum Use of Irrigation Water in Agriculture, Lyallpur, 1975.

3. Indian Ministry of Agriculture, Handbook on Irrigation Water Management, New Delhi, 1971.

4. Muhammad Jameel Khan, Economics of Farm Mechanization and Water Development Policies in Pakistan: A Case Study, unpublished Ph.D. thesis, Colorado State University, Ft. Collins, 1974.

APPENDIX I

Experimental Treatments

Irrigations:

Treatment No.	No. of Irrig.	Days after planting, assuming a November 10 planting date
I-1	1	21
I-2	2	21, 70
I-3	3	21,63,84
I-4	4	21,63,84,105
I-5	5	21,63,84,105,119
I-6	6	21,63,84,105,119,133

Nitrogen:

N-1	0
N-2	50 lb/ac or 56 kg/ha
N-3	100 lb/ac or 112 kg/ha
N-4	150 lb/ac or 168 kg/ha
N-5	200 lb/ac or 224 kg/ha

Phosphorus:

Plot splits received 50 and 150 lb/ac (56 and 168 kg/ha)

Incomplete Factorial Design:

	I-1	I-2	I-3	I-4	I-5	I-6
N-5	X		X		X	X
N-4		X		X		
N-3	X		X		X	X
N-2		X		X		
N-1	X		X		X	X

APPENDIX II

Marginal Physical Product Formulas

The marginal physical product is obtained by taking the partial derivitive of the estimated production function with respect to the input desired.

Hence, given the equation:

$$Y = 109 + 15.73N - .05448N^2 + 3.151P + 51.21W - .3388W^2 + .09325(NP) - .00000158(NP)^2 + .1938(NW) - .00001385(NW)^2 - .08467(WP)$$

we have the following marginal products:

$$\frac{dY}{dN} = 15.73 - 2(.05448)N + .09325P - 2(.00000158)P^2N + .1938W - 2(.00001385)W^2N$$

$$\frac{dY}{dP} = 3.151 + .09325N - 2(.00000158)N^2P - .08467W$$

$$\frac{dY}{dW} = 51.21 - 2(.3388)W + .1938N - 2(.00001385)N^2W - .08467P$$

APPENDIX III

Conversion Factors

1 kilogram = 2.2046 pounds

1 hectare = 2.47 acres

1 kilogram/hectare = .893 pounds/acre

1 centimeter = .394 inches

1 hectare centimeter = .972 acre inches

1 maund = 82.286 pounds

= 37.325 kilograms

Appendix 38

WATER MANAGEMENT AND NITROGEN FERTILIZER MOVEMENT AND UTILIZATION IN SOILS[1]

W.D. Kemper, Wayne Clyma, Rehmat Ali and Ghulam Haider[2]

Introduction

The low average yields of kharif crops in the Indus Basin are not indicative of the potential of this region for crop production. Even yields obtained at research stations under reasonably high fertilizer applications are often lower than those obtained under carefully controlled water management in other locations with similar climates. The large difference between the highest yields obtained and the average yields of farmers and experiment station plots where reasonable amounts of fertilizer have been applied under adequate irrigation indicates that some of the management practices are restricting yields. The possibility that water applied as irrigation, particularly in conjunction with heavy rainstorms that often occur during the monsoon season, may be leaching part of the mobile nitrates from the plant root zones, should be considered in this regard. Nitrate is one of the most essential and the most costly input in the high crop production picture and it becomes a highly mobile component of the soil system soon after its incorporation in the soil. Consequently preliminary assessment of what may be happening to nitrate in the soils of the Indus Basin was considered worthwhile.

Measured Rates of Downward Movement of Anions and Water

When rainfall or irrigation water are applied to soil surfaces, the water moves downward in the soil displacing most of the water, which was previously in the soil, to greater depths. Some mixing between the inhabitant and intruding water takes place, particularly when the intruding water has sufficiently large pressure to force its way into the larger pores and therefore moves more rapidly down through the profile. Continuous pores such as old root channels, worm

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[1]Paper prepared for presentation at the CENTO Water Management Conference, March 3-5, 1975. Portions of this research were supported by Contract 2162-d of the U.S. Agency for International Development.

[2]Chief of Party and Agricultural Engineer, Colorado State University, Water Management Research Contract/Pakistan and Senior Research Officers, Soils and Reclamation, and Agronomy and Extension, Mona Reclamation Experimental Project, WAPDA, respectively.

holes, etc., facilitate this intermixing of the applied and the residual water.

Cultivated or Disturbed Soils

Smith (1972) and Kemper, et al, (1974) have measured the downward movement of nitrate and similar anions in lysimeters and have found this downward movement to be from 1.0 to 1.3 times as fast as the average downward movement of the water. The distance of downward movement of the water is equal to the depth of water applied divided by the volumetric water content at field capacity. That is, where a four inch application of water is applied in a soil with field capacity of 0.2 grams of water per gram of soil and a bulk density of 1.4, water movement will be 4"/(0.2 x 1.4) = 14.3". Assuming that the ratio of velocities of the nitrates and the water is about 1.1, the average downward movement of nitrates would probably be about 1.1 x 14.3 inches = 16 inches.

Undisturbed Soils (Below the Plow Layer)

In these regions where the root channels and worm holes persist for many seasons and therefore, in sum, make up a large portion of the pores through which water moves, movement of nitrate may exceed the average movement of the water by factors of 1.3 to over 1.6 (e.g. Thomas and Swoboda 1970). Reasons for this large difference in average flow rate include the fact that nitrate ions are excluded by electrical forces from small pores and other places where the water moves slowly and are forced into the larger pores where downward velocity of water is much higher than the average water velocity. Consequently, if four inches of water are applied to an undisturbed soil layer with a volumetric water content at field capacity of 0.28 cc per cc of soil, downward movement of the nitrate will probably range from 1.2 to 1.6 times 14.3 inches or from 17 to 25 inches depending on pore size characteristics of these soils.

Irrigation Applications, Climatic Conditions and Potential Leaching in SCARP areas of the Indus Basin

Rabi Season

Average applications of water measured (Clyma et. al., 1975) in the first irrigation following planting of wheat (Mona area, 1972) was seven inches (of which almost six inches was in excess of need!). The average volumetric water content of these soils is about 0.3 cc of H_2O per cc of soil at field capacity. Assuming that fertilizer applied as urea has been converted to nitrates prior to this irrigation and assuming a ratio of nitrate velocity to water velocity of 1.1 (which is probably an underestimate for the undisturbed portion of the soil profile), the average downward displacement

of nitrogen would be 1.1(7/0.3) = 26". At this growth stage the wheat roots only extend about 6 to 12 inches into the soil (unpublished observations of S.A. Qureshi and J.B.Eckert, G. Haider and Rehmat Ali) and consequently such irrigations remove fertilizer in the form of nitrates from the reach of the plant roots.

Even had the farmers applied a three-inch irrigation at this time, since the ratio of nitrate to water velocities in undisturbed soil is probably higher (assuming 1.4 for the ratio in the undisturbed region gives an average for this ratio of about 1.25) the downward displacement of nitrogen would have been about 1.2(3/0.3) = 12.5" which would still carry most of N beyond the reach of the plant roots.

Successive irrigations measured during the winter months of rabi seasons by (Clyma, et al, 1975) generally show irrigation in excess of needs which continues the downward movement of nitrogen faster than root extension. This process is illustrated in Figure 1, which represents the approximate location of nitrate fertilizer applied at seeding time in relation to root zone of wheat when irrigations are on the schedule indicated, and involve about 3" of overirrigation per irrigation.

The assumption is made in Figure 1 that the fertilizer is applied the day before seeding. During the first three weeks diffusion tends to distribute the fertilizer throughout a larger volume of the soil and could broaden the zone which the N occupies to 3 to 5 inches of soil (e.g. Qayyum and Kemper, 1962). However, for at least part of this period the N, if applied as urea, is in the NH_4^+ form which is absorbed to the negatively charged clay particles and is much less mobile than the negatively charged NO_3^- or the electrically neutral $(NH_2)_2CO$. Another factor which keeps the N near the surface during this period is the upward movement of water to the soil surface which is normally moist and evaporating during this period of time. This convective movement of water toward the surface tends to keep the mobile ions within the top two inches of soil (e.g. Todd and Kemper, 1971).

When the next irrigation is applied, as indicated at about three weeks in Figure 1, the moisture deficiency in the top 18 inches of the soil profile is generally less than two inches (Clyma, et al, 1975). The average application of water measured by Clyma et al (1975) in the Mona area for this irrigation was seven inches resulting in an average overirrigation of over five inches. In some areas lands have been more precisely leveled (e.g. in the vicinity of Lyallpur) and in non-SCARP areas water is not as readily available. Such precise leveling and shortages of water undoubtedly reduce the over application of water. However, a limited number of estimates of soil moisture deficiencies and measurements of water applied in non-Scarp areas indicate that even

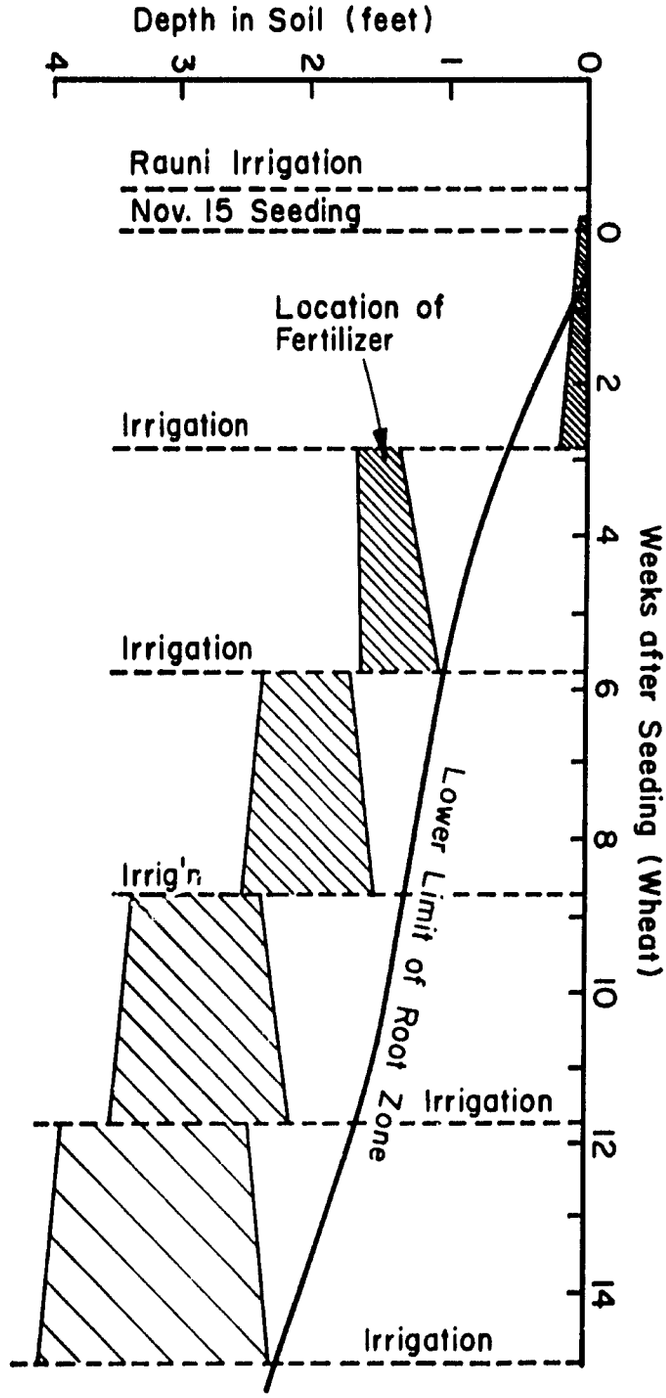

Figure 1. Nitrate location as affected by time and irrigation (Irrigation according to text).

in these areas most farmers are overirrigating by from one to four inches at this irrigation.

Assuming that an average of 4.5 inches of water is applied to get water across the loose, open surface of these soils, which have not been irrigated since they were cultivated, downward displacement of the fertilizer to average depths of 16 to 20 inches would be expected, depending on soil texture. The hydrodynamic dispersion which takes place as the water in the largest pores moves faster than the water in the smallest pores will broaden the zone in which the fertilizer is distributed as indicated in Figure 1. As the root zone approaches the fertilizer zone an inch or two of upward movement of the water and included NO_3^- may take place in response to suction gradients imposed by the plant roots.

Growth rates of roots which are relatively high during the November-December period tend to decrease as the soil becomes colder in January and the first part of February and increase again as the weather becomes warmer.

The average potential evapotranspiration of water has been estimated from climatic data (e.g. Clyma, 1973) from pan evaporation and from soil depletion measurements (Haider et al, 1975) and for the months of December and January and in the northern Punjab appears to be down around 0.07 inches per day. Consequently, only about 1.5 inches of water is used within the three-week period indicated preceding the second and third irrigations. Consequently, when the farmer applies another 3 or 4 inch application of water to his field per irrigation (a normal application in SCARP areas), 1.5 to 2.5 inches of overirrigation occurs moving the fertilizer and water down into the soil another 6 or 10 inches at each of these irrigations. During February evapotranspiration increases and there is considerably less overirrigation at the 12 week irrigation. However, even if the root system catches up with the NO_3^- at this stage, the plant will have suffered deficiency in the earlier stages of growth which help determine yield.

Kharif Season

Average application of water per irrigation measured during kharif season in the Mona area was 4.6 inches (on 25 fields of maize, sorghum, alfalfa, cotton, oilseed and vegetables). Assuming a velocity ratio of nitrate to water of 1.3, this average irrigation would displace nitrate downward by 1.3 (4.6/0.3) = 20". During the early stages of growth this again removes nitrate from the root zone. Even during later stages of growth when roots have extended down to two or three feet of depth, portions of the nitrate already a foot or two deep in the soil would be pushed beyond the reach of the roots.

If an irrigation application of 4.6 inches is followed by a three-inch rainfall, as occurs occasionally during the monsoon season, the removal depth for nitrate would probably exceed 32" which takes the nitrate down beyond the roots.

Similar tendencies for overirrigation were measured (Clyma, et al, 1974) on sugarcane and these data are a strong indication that a large portion of the applied nitrogen fertilizer is being leached below the root zone.

Since nitrification (conversion of NH_4^+ to NO_3^- proceeds about four times as fast at 86°F, as at 50°F, more of the applied fertilizer will be in the mobile NO_3^- form during kharif than during rabi season. Consequently, a given amount of excess water during kharif will result in the removal of a larger portion of the applied fertilizer than if the same amount of excess water is applied during the rabi season.

Definition and Solutions of the Problem

These tendencies for overirrigation are common throughout irrigated systems where farmers are not able to measure their water or control its delivery (e.g. Bos and Nugteren, 1974). These are often the same systems where nitrogen fertilizer is the most costly input in the crop production system.

Research (e.g. at the Nuclear Institute at Lyallpur) and farmer trials have shown that yields can be increased by splitting the N fertilizer into two or three increments and applying these to assure N supply at critical growth stages. Since under these conditions plants may absorb most of the applied N before the next irrigation, leaching losses of N are generally decreased. However, this procedure does not decrease the wastage of water and its subsequent contribution to rising water tables and salinization, and careful application of additional increments of N to a crop is expensive and time consuming.

Mixing urea into the soil by cultivation and irrigating after it has been converted to NH_4^+ but before it is converted to NO_3^- would result in reduced leaching since NH_4^+ is absorbed into the soils. However, the timing of urea application and irrigation would be critical and the processes of urea hydrolysis and nitrification often overlap.

The most complete solution to the leaching problem is application of adequate but not excess water. To the farmer, at the mercy of the weather, uncertain canal supplies and uneven land surfaces, this often appears to be an insurmountable task.

However, land can be precision leveled at reasonable cost to allow even distribution of water over the surface of a field. Some farmers have developed this ability. Help will soon be available to others via the Precision Land Leveling Program organized by the Integrated Rural Development Program and the U.S. Soil Conservation Service. The dependability and amount of water delivery can be improved by improvement and lining of watercourses. Studies on various designs and materials are now in progress at the Mona Reclamation Experimental Project. The amount of water flowing in a watercourse can be measured with simple flumes and this information could be made available to farmers each day by tubewell operators.

Reasonable estimates of potential crop water use can be made from weather data for whole areas and these estimates can be related to actual water use on the basis of coefficients now being developed (or soon to be developed) for specific crops at several research locations in Pakistan (M.R.E.P., or Agricultural College of Sind, PARI at Lyallpur, Land Reclamation Department).

Rainfall particularly during the monsoon season is an uncontrollable factor. However, drainage of excess surface water following an unneeded rainfall could reduce nitrate leaching. Surface drainage facilities are generally not available to the farmers' fields. In many areas major drains have been constructed by WAPDA and are maintained by the Irrigation Department. Many watercourse command areas have branches of these drains as one of their boundaries. However, there is generally no legally recognized or workable connection from these drains to the farmers' fields. Evaluating the beneficial effects of surface drainage to farmers' fields is part of the water management project at Mona Reclamation Experimental Project. Results of this study will be used to help make decisions as to whether "the missing links" (channels connecting fields to Irrigation Department drains) should be constructed. Pending such drainage becoming available, farmers can often arrange to drain (this will often require use of a low lift pump) excess rainwater from fields where it is not needed, to rice fields, or fields needing excess water for salt removal. It will require additional well planned studies to determine whether these practices are practical and bring a good return to the farmer for his labor and investment.

Savings of applied N fertilizer and increased crop production may be a major part of such benefits. Realizing the dangers of extrapolating, the following statement is limited to the area and time of sampling. Based on the measured applications of water and soil moisture deficiencies at time of irrigation, it appears highly probably that most of the nitrate present in the soil at the time of irrigation is commonly leached out of the root zone.

Literature Cited

1. Bos, M.G. and Nugteren, J. (1974), On Irrigation Efficiencies in Developing Countries, Wageningen University. Publication #19, International Institute for Land Reclamation and Improvement, P.O. Box 45, Wageningen, The Netherlands.

2. Clyma, Wayne (1973), Evapotranspiration and Irrigation Water Requirements for Pakistan. Bulletin of the Irrigation, Drainage and Flood Control Research Council, Vol. 3, No. 2, pp. 1-8.

3. Clyma, Wayne, Ali, Arshad and Ashraf, Moh'd (1975), Irrigation Practices and Application Efficiencies in Pakistan. CSU and Directorate MREP, CMO, WAPDA, Bhalwal, Jan.

4. Haider, G., Farooqi, M.A.R. and deMooy, C.J. (1975), Estimate of Consumptive Use of Water for Wheat Under Optimum Management Conditions, (In press).

5. Kemper, W.D., Olsen, John and Hodgdon, Alan (1974), Fertilizer or Salt Leaching as Affected by Surface Shaping and Placement of Fertilizer and Irrigation Water. Accepted for publication in Soil Science Society American Proc.

6. Smith, S.J., (1972), Relative Rate of Chloride Movement in Leaching of Surface Soils. Soil Sci. 114:259-263.

7. Qayyum, M.A. and Kemper, W.D. (1962), Salt Concentration Gradients in Soils and their Effects on Moisture Movement and Evaporation, Soil Science 93:333-342.

8. Thomas, G.W. and Swoboda, A.R. (1970), Anion Exclusion Effects on Chloride Movement in Soils, Soil Sci. 110: 163-166.

9. Todd, R.M. and Kemper, W.D. (1971), Hydrodynamic Dispersion Coefficients near an Evaporation Surface. Soil Science Soc. Amer. Proc. 35:1-5.

APPENDIX 39

ECONOMICS OF IMPROVED SOIL AND WATER MANAGEMENT FOR FODDER PRODUCTION IN THE SHADAB

M. Hanif, H. Ali, F. Ali and C.J. deMooy[1]

The Water Management Research Sections of the Integrated Rural Development Project (IRDP) and Colorado State University (CSU) in Pakistan are cooperating in a series of practical studies on farmers fields aimed at defining improved agronomic practices for all the major irrigated crops and to introduce the most profitable improvements to the farmer for his acceptance. The present paper deals with a first attempt to gain acceptance for improved practices in fodder productions.

Summary

Demonstration plots with fodder crops of maize and sorghum were laid out on private farmers' land in the Shadab Pilot Project near Lahore. Fertilizer and farm water management improvements were included in the trials. Local water supply problems minimized the water management inputs but fertilization almost doubled the production of fodder. The cost/benefit ratio of the suggested improvements for maize fodder was 100:647 and that for sorghum was 100:738. These values should carry sufficient weight to motivate the farmer into a change of practice once the new techniques have been introduced to him.

Introduction

The Shadab Pilot Project occupies a gateway position to Lahore-township where a heavy demand exists in the market for animal fodder. The proximity of the Shadab to a large and ready market has helped it to emerge as a fodder supplying belt. A socio-economic survey conducted by IRDP in cooperation with CSU also indicated this trend in the cropping pattern of the area. It was observed that farmers generally do not adopt improved farm management practices for fodder production, especially the application of fertilizer or sound irrigation practices. Simple field demonstrations combining the effects of good fertilizers and water management are being conducted at various locations in the Punjab Province.

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[1]Agronomist, Director and Development Assistant, Integrated Rural Development Project and Professor of Agronomy, Colorado State University, respectively.

Procedures

Maize and sorghum fodder crops were grown in field plots located at the Shadab Pilot Project of the Integrated Rural Development Project (IRDP), Lahore. The fields were part of a series of demonstration plots consisting of two treatments each. The details of the experimental treatments were as follows:

1. Traditional Management

No fertilizer was applied. No restrictions were placed on the farmer concerning irrigation practices to be followed. All management was conducted as customary in the area.

2. Improved Management

The fields were plowed 4 to 6 times and planked 3 times to obtain a fine seedbed. Nitrogen was applied at sowing at the rate of 50 lbs per acre in the form of urea. An additional 25 lbs of nitrogen was applied at first irrigation. Irrigations were planned to be applied when the soil moisture of the 0 to 2 inches layer increased to a tension of 5 bars. The amount of irrigation water to be applied was the quantity required to bring the rooted depth of soil to field capacity.

Three fields with similar history were selected in close proximity and with the particulars shown in Table 1. The previous crop was wheat in each case. The soil was medium textured and free from salinity and alkali problems. Bicarbonate extractable phosphorous was 4 to 5 ppm. Field capacity determined at site was 27 percent be weight and permanent wilting point was 12 percent. The moisture tension curve was determined in the laboratory* on samples from 0 to 6 and 12 to 18 inches depth. The mean for the two layers is shown in Figure 1. The 5 bar tension level occurred at 13 to 14 percent moisture.

The moisture deficit was determined by soil sampling and gravimetric moisture analysis. Soil samples were taken at one foot interval to a depth of 4 feet as necessary in relation to rainfall and irrigation.

Good seedbeds were prepared by 4 to 6 plowings with the desi plow and 3 plankings. Rainfall amounting to 1.3 inches was received after rauni irrigation on June 1. Sowing was by broadcast method followed by plowing and planking. The maize variety at Sites 1 and 2 was J1. Desi variety of sorghum was sown at Site 3. Some voluntary growth of cowpeas

*Laboratory analysis by Water and Soil Investigation Division, WAPDA (CMP), Lahore.

Table 1. Trial field characteristics, Shadab 1975.

Trial Number	Farm	Fertilization Previous Crop	Experimental Crop	Rauni Irrigation		Sowing	
				Inches	Date	Rate (Seers/acre)	Date
1	Muhammad Saleem	50 lbs N/ac	Maize	3.5	May 28	32	June 5
2	Malik Jan Muhammad	50 lbs N/ac	Maize	3.5	June 1	32	June 7
3	Muhammad Hussain	0	Sorghum	3.5	June 1	16	June 6

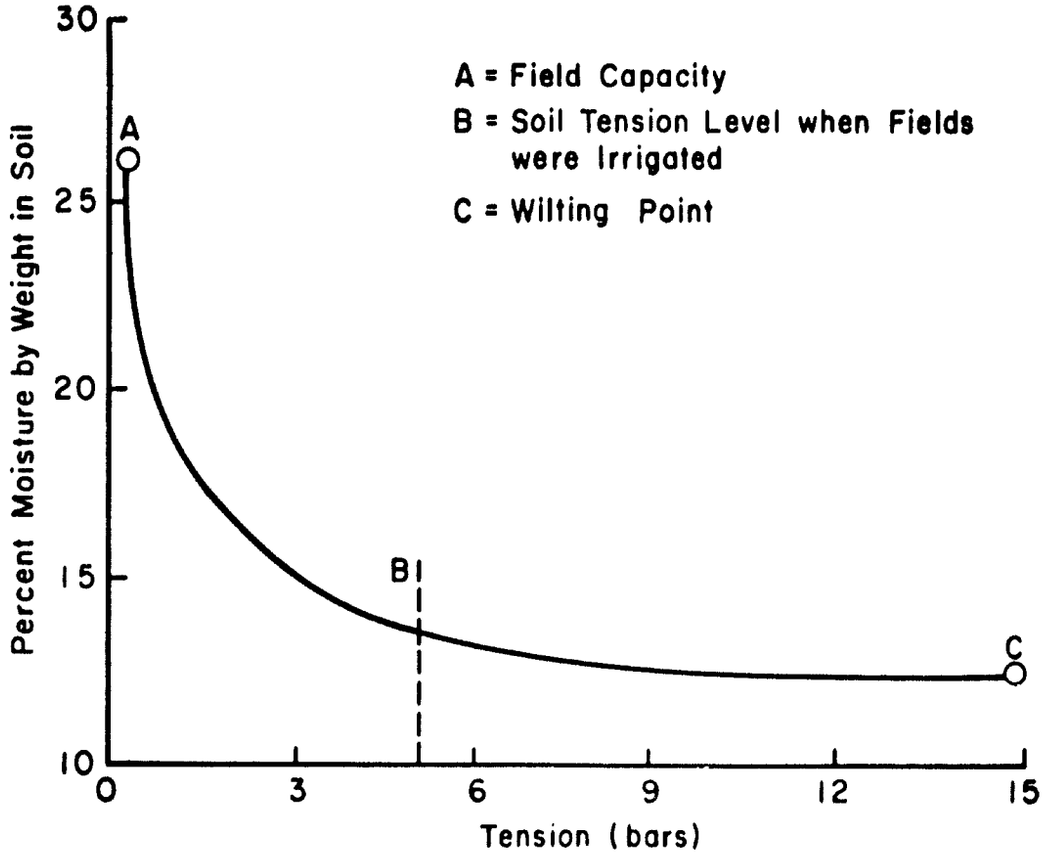

Figure 1. Moisture characteristics of soils, Shadab, 1975.

occurred and was allowed to remain. Two replications were laid out at this site. The plot size was approximately 1/4 acre.

The maize fodder was harvested on August 7 and 8 and the sorghum on August 25. Three squares with dimensions 11 x 11 feet were placed at random and harvested from each plot and the yields recorded on a green weight basis.

Results and Discussion

The crop yields and amounts of water applied to each plot are presented in Table 2. The data show that the yield of fodder was almost doubled from the improved practices. The yield of maize fodder produced under traditional practices at Site 1 was 193.5 maunds fresh weight per acre and with improved practices 373.5 maunds per acre. At Site 2 the fields with traditional and improved practices yielded 234 and 405 maunds per acre, respectively. The mean yield values for the 2 sites are 213.8 and 389.3 maunds per acre for traditional and improved practices, respectively. Most of this effect was due to the fertilizer treatment because canal closure interfered with the water management at all 3 sites. Site 1 was irrigated twice, i.e. June 17 and July 20; Site 2 once on July 14 and Site 3 once on July 11. The data in Table 2 show that there was little difference in the amount of water applied between the control treatment and improved practices.

The economic interpretation of the yield differences is based primarily on the cost of fertilizer investment. The cost of production for 1 acre of maize under traditional practices was Rs. 453 and with improved practices Rs. 571. The value of the corp, however, increased from Rs. 1069 to Rs. 1946 as a result of improved practices (Table 3). The net profit from 2 months of farming was raised from Rs. 615 to Rs. 1375. The net profit realized by the farmer from 1 acre of fodder produced under improved practices exceeded that from traditional production by a factor 2.23X. The cost/benefit ratio for the improvement was 100:647.

Similar profits were obtained from fertilizer application to sorghum. The cost of production for 1 acre of sorghum was Rs 505 under traditional management and Rs 629 when fertilized. The value of the fodder increased from Rs 1080 to Rs 2115 (Table 4). The net profit increased from Rs 574 to Rs 1486 which amounts to a profit ratio of 2.59X. The cost/benefit ratio for fertilizer application to sorghum was 100:738. Such favorable cost/benefit ratio's are more than sufficient to motivate the farmer.

In the light of these results, it is evident that the farmers should be informed of the economics of fertilizer use

Table 2. Amount of water applied and yield of fodder plots at Shadab (maunds/acre)

Site	Crop	Treatment	Water applied after rauni irrigation		Yield (maunds/acre)
			Irrigation (inches)	Rainfall (inches)	
1	Maize	Control	5.7	9	193.5
		Improved	5.2	9	373.5
2	Maize	Control	3.2	9	234.0
		Improved	2.7	9	405.0
3	Sorghum	Control	3.0	11	216.0
		Improved	3.1	11	423.0

Table 3. Costs and returns of production of maize fodder under improved and traditional practices under the conditions prevailing at Shadab, 1975.

	Traditional Practices (Rs/acre)	Improved Practices (Rs/acre)
COSTS		
Lease of land		
80 days @ Rs 600/acre annum	131.51	131.51
Land Preparation		
5 plowings @ Rs 15 per plowing	75.00	75.00
3 plankings @ Rs 5 per planking	15.00	15.00
Fertilization		
75 lbs of nitrogen @ Rs 1.50/lb.N	0	112.50
Cost of application	0	10.00
Sowing		
Cost of labor	15.00	15.00
Cost of 32 seers of seed @ Rs 40/maund	32.00	32.00
Irrigation		
Cost of water applied @ Rs 10/ acre-inch	45.00	40.00
Wages of farmer @ Rs 1.50/day	120.00	120.00
Land revenue and water charge	20.00	20.00
TOTAL COST OF PRODUCTION	453.51	571.01
RETURNS		
Value of crop		
213 maunds @ Rs 5/maund	1069.00	--
389.3 maunds @ Rs 5/maund	--	1946.50
PROFIT		
Net profit	615.49	1375.49
Difference in net profit from improved practices		760.00
Profit ratio improved/traditional practices		2.23X
Cost/benefit ratio for improved practices		100:647
Cost/benefit ratio improved practices		100:738

Table 4. Costs and returns of production of sorghum fodder under improved and traditional practices and under the conditions prevailing at Shadab, 1975

	Traditional Practices (Rs/acre)	Improved Practices (Rs/acre)
COSTS		
Lease of land		
100 days @ Rs 600/acre annum	169.38	169.38
Land preparation		
6 plowings @ Rs 15 per plowing	90.00	90.00
3 plankings @ Rs 5 per planking	15.00	15.00
Fertilization		
75 lbs of nitrogen @ Rs 1.50/lb.N	0	112.50
Cost of application	0	10.00
Sowing		
Cost of labor	15.00	15.00
Cost of 16 seers of seed @ Rs 40/maund	16.00	16.00
Irrigation		
Cost of water applied @ Rs 10/ acre-inch	30.00	31.00
Wages of farmer @ Rs 1.50/day	150.00	150.00
Land revenue and water charge	20.00	20.00
TOTAL COST OF PRODUCTION	505.38	628.88
RETURNS		
Value of crop		
216 maunds @ Rs 5/maund	1080.00	--
423 maunds @ Rs 5/maund	--	2115.00
PROFIT		
Net profit	574.62	1486.12
Difference in net profit from improved practices		911.50
Profit ratio improved/traditional practices		2.59X
Cost/benefit ratio improved practices		100:738

in fodder production. Possibly the net profits can be increased even further under optimum water management. This remains to be investigated. Similar demonstration plots should be conducted on a large scale throughout the province where a market exists for animal fodder.

In the interest of self-sufficiency of food the Government of Pakistan is supporting improved practices which will lead to increased cereal production. It appears from the data presented in this paper that the present fodder acreage could be reduced to one-half merely by optimum use of fertilizers without change in total fodder production yet making land available for wheat and rice culture.

Appendix 40

Discussion Paper
on
INTENSIVE TRAINING PROGRAM FOR ON-FARM WATER MANAGEMENT FIELD EXTENSION WORKERS WITH FOCUS ON THE PUNJAB

Alan C. Early, Max K. Lowdermilk, Sam H. Johnson III

The purpose of this discussion paper is to examine the need for trained personnel to work intensively with farmers to improve their on-farm water management systems and irrigation practices. Much of the effort devoted to water management research in Pakistan by Colorado State University (CSU) has focused attention on the poor condition of on-farm watercourses and farmers water management practices*. USAID/CSU results indicate that the majority of the water losses occur not in the major distribution systems but after the water passes the mogha and enters the watercourse. While considerable resources have been invested in improving the Magor Canal distribution system and providing additional water storage, almost no resources have been invested in improving on-farm watercourses, land leveling and training farmers to efficiently utilize their scarce resource of water. The forthcoming USAID-GOP "On Farm Water Management Loan"** is designed to channel resources into the previously neglected on farm watercourse level sector. However, unless specific steps are taken to train personnel to work at the on-farm level the "Water Management Loan" will not produce the desired results.

The focus of this paper is on the training of the extension field workers who will be required to help implement the on-farm aspects of the USAID-GOP "Water Management Loan" and who will teach farmers how to maximize benefits gained from physical watercourse improvements. This extension worker can help the farmers to more effectively use the services offered by other technical departments such as the Precision Land Leveling Program (PLLP), The Agricultural Development Bank, or W.A.P.D.A. (SCARP). He will remain at the farm level to advise and assist farmers individually and collectively to continue to improve their farming methods and maintain their watercourse system for increased farm production.

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*Project Review Paper, "On-Farm Water Management" by USAID Mission to Pakistan Project Development Team, Islamabad, January 31, 1975 (see especially pp. 3, 4, and 10). "Water Management Alternatives for Pakistan, a Tentative Appraisal" by Jerry Eckert, Niel Dimick, and Wayne Clyma, June 1975.

**See "Organizational Proposal - Water Management Scheme" by Murray Cox, Team Leader PLLP Lahore, June 19, 1975, p. 16.

In this paper the following topics are discussed:

1. Background and need for training;
2. Who is to be trained;
3. Institution responsible for training;
4. Philosophy of training;
5. Aims and objectives;
6. Methodologies;
7. Content of training; and
8. Evaluation procedures - supervision.

I. Background and Need for Training

CSU field surveys and other studies* in the Punjab provide ample data that farmers for the most part are not currently receiving advisory services from the existing Agriculture Department extension staff in sufficient quantity or quality. This is in part due to the lack of training and lack of facilities provided for workers. Also a study of the Agriculture Department institutional problems reveal that this old line department established over 100 years ago as a result of the Indian Famine Commission Reports has been unable to innovate substantially to meet the needs of today.

Several facts gained from studies and experience in Pakistan suggest that a training program would be timely. They are:

1. Limitations of the present system;
2. Lack of any on-farm advisory personnel to assist farmers;
3. CSU findings related to on-farm problems;
4. Expressed need by farmers for assistance; and

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*Appendix I-A reports data from a 1970 study and a watercourse study in 1975 now in progress.

Max K. Lowdermilk, "Diffusion of Semi-Dwarf Wheat Production Technology in the Punjab of Pakistan", Ph.D. Dissertation, Cornell University, 1970.

Max K. Lowdermilk, Wayne Clyma, and Alan C. Early, "Physical and Socio-economic Dynamics of a Watercourse in Pakistan: System Constraints and Farmer Responses", Report in Progress, Colorado State University, 1975.

5. Government of Pakistan and the USAID Mission to implement a far-reaching program which will increase crop production and levels of living for rural people.

Recent conversations with the Minister of Agriculture of the Punjab focused on this issue. He is of the view that the present selection, training and supervision of agricultural assistants and field assistants is greatly inadequate.

To date no department has given much attention to water management problems of farmers. Consequently it is no surprise that data from a recent watercourse study in progress* indicate that farmers have little knowledge about: (1) major water losses and ways to reduce losses; (2) crop water requirements at critical growth stages; (3) water movement in soils; (4) detrimental effects of over and under irrigation; (5) development of root systems; (6) plus a host of other water-plant-soil relationships. As farmers begin to move out of traditional agriculture it is a bold assumption that they can learn how to combine factors of production simply by the costly trial and error method.

Modern agriculture is a complex system; therefore farmers increasingly need a continuous flow of research information and farm level management advisory services. The GOP is now aware of the potential importance of a comprehensive on-farm water management program. Efforts by CSU/USAID plus the pressures of water shortage and continuing food deficits have all combined to focus official attention on need for the development of a sound water management program for Pakistan of which trained on-farm personnel should become a key component.

II. Manpower to be Trained

In recent conversations with the Minister of Agriculture of Punjab on July 6, 1975, it was learned that the Punjab Department of Agriculture is planning to innovate several organizational changes. The plan calls for departmental decentralization and entails moving EADAs to the Tehsil level and giving AAs more time in the field. The new plan calls for Assistant Directors (ADs) at the 73 Tehsils who were formerly EADAs. The number of Agricultural Assistants and the Field Assistants under them will be increased. The first increase will include about 200 more Field Assistants and

*See study "Physical and Socio-Economic Dynamics of a Watercourse in Pakistan's Punjab System Constraints and Farmers' Response." pp. 78-84, forthcoming CSU Field Party Report. Also see a study of 16 watercourses which is now being conducted by Early, Lowdermilk and 6 Pakistani Engineers in 5 major cropping areas of the Punjab.

50 more Agricultural Assistants in the Punjab. Organizationally the District Directors (19) will be under 5 Regional Directors who are under the Director General. Soil-water, reclamation, economics, and marketing, plant protection, and extension in the new plan will be combined and only the agricultural engineering section will have a specific directorate. Both ADs and AAs will most likely be provided motorcycles. Along with these changes other innovations may also be introduced.

It is proposed that training be given to Agricultural Assistants currently employed by the Department of Agriculture and to the EADA or new Assistant Directors over time in a phased manner. At the same time capability should be developed at the Agricultural Universities in the field of on-farm water management so that future BSc. and MSc. graduates in agronomy, economics, agricultural extension, and agricultural engineering will have water management training. This would require building up the capabilities of the engineering, agronomy, and social science departments.

We do not have data on the output of engineers, agronomists, economists, etc., at the Agricultural Universities and Colleges at this time, but it should be easily available. For example, the University of Agriculture, Lyallpur, in Agricultural Extension presently has a very small output of graduates with extension training and needs more capabilities in this crucial area. The following table shows the total output of extension trained graduates only.

TABLE 1. Master of Science and Bachelor of Science Extension Graduates, 1970-1973*

YEAR	MASTERS GRADUATES	B. Sc. GRADUATES	TOTAL STUDENTS
1970	9	20	29
1971	12	19	31
1972	11	15	26
1973	8	9	17
TOTAL	40	63	103

In relationship to the actual need for trained agricultural graduates at the farm level, the output of B.Sc. extension personnel is very small indeed. In terms of the projected need for the farm level water management advisors in the Punjab Province alone, this indicates a present

*Provided in a letter to Lowdermilk by Dr. Ghulam Subbani Khan, Professor of Extension, Agricultural University, Lyallpur, March 7, 1975.

problem. Most likely the output of other departments is also small. Whether it be engineers, economists, agronomists, or sociologists in the future water management field, all need careful training in methods of extension communication skills, program design, evaluation techniques, etc., to supplement their technical areas.

III. Institutional Arrangements for Training

In order to institutionalize a water management training program there are at least two alternatives. One is to establish a new organization in Pakistan for this purpose; another is to work within existing institutions and improve their capabilities. Since so little is known about institution building in developing nations and the risk of failure is substantial it is proposed that we work through existing institutions.

The question is seldom "What is optimum?", but what is feasible and possible within existing conditions of Pakistan (i.e., organizations, institutional capabilities, policies, etc.)? It is not unlikely that the capabilities of the existing Agricultural Department organization working at the farm level can be improved. Water management requires knowledge in a number of subjects all related to plant-water-soil relationships. A good training program might be the ideal way to provide means for building up the capabilities of the field staff of the Agriculture Department.

The Agricultural University of Lyallpur has made much progress since the 1950's when it was only a small education center. USAID, through a number of programs, has not only assisted in the development of an adequate physical plant with modern facilities, but has played a leading role in the training of staff members. However, few, if any, staff members were trained by USAID programs in the 1960's with a definite emphasis for on-farm water management.

The Agricultural University at Lyallpur is under the Education Department and in function is somewhat semi-autonomous. This University provides graduates for various nation building departments. Primarily its role is to provide personnel for agriculturally related organizations. The University also has facilities in its Extension and Short Course Institute for conducting special training courses of various types. Staff from relevant departments of the University assist in the training. With permission from the Vice Chancellor such courses can be offered. Since the Agricultural Department has linkages with the University we propose a cooperative arrangement where the University contracts to train x number of Agricultural Department personnel for the Agriculture Department. The men trained would then return to their respective areas as on-farm advisors with new skills

in water management and work under trained supervisors. Progressive Agricultural Department policies, incentives, and facilities could be provided to implement a sound program. Key factors will be qualified men, under capable supervision who are provided with adequate incentives and facilities. Evaluative techniques must also be evolved as tools for intensive field supervision.

The specified period of training for the existing EADA's and AA's of the Agriculture Department, would require a minimum of one year. It might be feasible to train some carefully selected FA's as well.

These men should be carefully selected from the existing department field workers and given a leave of absence for the intensive water management training program. CSU experience in training six Pakistani engineers in the field suggests that an optimum trainer-trainee ratio would be about 6:1; with ten carefully prepared Pakistani trainers, 60 men could be trained per year. If other training centers were developed and outstanding men from the first course were selected as trainers, larger numbers could easily be trained. It should be evident that the stress is on quality, however. Numbers are important, but a high quality must be maintained. A careful selection program is also important. An example of one used to select the engineers who worked on the watercourse survey with Lowdermilk and Early is shown in Appendix A.

IV. Philosophy and Approach in Training

The major philosophical tenant in the conceptualized training program is to make it ninety percent practical and conduct seventy-five percent of the training in the field. The object is to train on-farm advisors under field conditions on watercourses. This is a major switch from present agricultural training and requires input from dedicated individuals.

The first focus is on developing a corps of highly trained, motivated trainers. These trainers will then become the instructors for all subsequent training programs. In order to develop the first corp of trainers selected faculty members from the Agricultural University will work as counterparts with the individual U. S. University advisory faculty. These advisors and their counterparts will develop the curriculum and facilities and participate directly in the training of the first corps of trainers.

After the first corps of trainers is developed and trained they will then become the instruction staff for programs to train the actual on-farm extension agents. A group of six trainees will be assigned to each trainer. Their full year of training in watercourse improvement will combine two

objectives, i.e., training and development. Villages around Lyallpur provide ample sites for training and the infrequently used Irrigation Department rest houses could be used for field camps. The focus then is learning by doing; the content of training is discussed under a separate section beginning on page 12. In order to help Pakistani trainees to solve problems they must have "real" problem solving experience. They must begin to internalize concepts and to apply principles to a range of problem situations where cookbook approaches simply will not work. To assist trainers or students to internalize concepts requires much close supervision plus optimum training methods and experience. In order to accomplish training objectives the medium of instruction should be Urdu*. As the training and development activities proceed valuable research data will be collected because trainees will be taught skills in data collection for program development.

University staff members would also be invited to participate in field training activities. Special programs of field experience could be planned for university students as a part of their educational experience. Cooperators at the Agricultural Research Institute, Lyallpur, as well as other existing CSU cooperators could be utilized when needed in the training activities. Special field days and seminars would be conducted by trainees and trainers from time to time as a part of the training process. Officials could be invited to these special activities. A special program would be designed for trainees completing the course and certificates would be awarded. Once a trainee returns to his post of duty he will work under a water management supervisor who has also been trained in water management activities. The supervisor's training will be supplemented by special focus on administrative and supervisory procedures, evaluation techniques and program design. Evaluative reports of each trained man in the field will be sent back to the Training Institute as feedback to improve training procedures. The CSU trained staff members would also visit the men from time to time in the field for further evaluations.

The philosophy of this training approach can be summed up as one based on problem solving under actual field conditions with optimum supervision. The focus then is on problem conceptualization, identification, and solution, learning to think about on-farm water management problems and finding solutions under farmer's conditions. Such approaches help trainees to internalize systems approaches which are necessary for an understanding of and solving complex on-farm water management problems.

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*Experience indicates that the usual level of English even of graduates is not sufficient for teaching of concepts and principles.

Training methods and techniques utilized will be tested and evaluated continuously. (Appendix B contains a sample evaluation form currently used. Appendices C, D, and E give additional evaluation forms for extension evaluations. These are a sample only to indicate how this could be done.) Much emphasis will be given to visuals, maps, charts, case studies, problem sets, result and method demonstrations, simulations, etc. Trainers will utilize materials in the form of handouts, outlines, etc., to develop their own field books.

Special training materials based on research data in Pakistan will be designed and made available in Urdu and simple English as a part of training. Trainers and trainees will participate in the design of specified water management extension materials for farmers which will be used in the field. The CSU collection of training materials will serve as ideas only. All training materials for trainees and farmers will be tested in Pakistan. Water management training materials to a great degree must be country specific as well as language specific if they are to be useful. While there is much technology in water management that is transferable, the training of those who must implement the technology must be designed to fit the social and economical realities of Pakistan. Many B. Sc. graduates do not have a sufficient grasp of English to internalize complex concepts. They can understand principles and concepts and often think better in their mother tongue. Graduates at the B. Sc. level usually acquire only a low level of proficiency in English which is insufficient for the acquisition of certain skills and concepts.

Training is conceived as very intensive over a one year time period with constant interaction between trainees and trainers in the field and at the institute. Evaluative techniques are to be designed into the training program. The training institute will help institutionalize short in-service training programs by the Agriculture Department of approximately a week duration so that after a year in the field each trainee will have an opportunity to refresh and up-date his knowledge and skills. Field supervisors and training institute personnel will conduct these in-service institutes. Over time a team of trainers could be trained to conduct these mini-institutes from Tehsil to Tehsil on a continuous basis.

V. University to University Linkage

An expatriot component for this program is necessary to provide the specific teaching, technical, and practical as well as organizational skills for developing the training program and improving host country capabilities in agricultural universities. The American university should be selected on the basis of its capability in training and its understanding of the specific on-farm water management

problems of Pakistan. Through the Colorado State University research program over the past few years several graduate students have been trained both on-the-job and formally who can provide local leadership in the training program.

At least two carefully selected expatriots would be required for a two to three year period to assist in the design, development, and launching and evaluation of the program until Pakistani capabilities are sufficiently prepared to continue an on-going program. Foreign personnel should either be posted at the universities or reside nearby to provide sufficient opportunities to interact formally with staff members and trainees and spend long periods of time in field supervision in Pakistan. It is also especially important to spend much time in informal relaxed situations with counterparts and officials. Long experience indicates that personalism as well as professionalism is important in building necessary creditability with colleagues.

Research data generated by the CSU water management group and experience gained ideally should be utilized in the training program. Training materials which have been developed by CSU in Pakistan plus other materials based on Pakistan data will need to be prepared in Urdu and simple English.

The expatriot training team to assist in the training program from an American university should have expertise and experience in engineering, agronomy, rural sociology, economics and extension teaching and communication methods. An understanding of the culture and language is also important in intensive training activities for Pakistanis.

The proposed water management training program described in this brief discussion paper ideally follows extensive research activities by CSU in Pakistan. Ideally such a program which produces capable on-farm advisors would become the chief vehicle for transferring proven technologies to farmers in farms which they can understand and utilize.

Section VI of this paper is a discussion of tentative aims and objectives for the training program.

VI. Aims and Objectives

The broad aim is to institutionalize a cooperative training program between the University of Agriculture at Lyallpur and the Department of Agriculture which will prepare extension workers and future graduates for a role in on-farm water management advisory services.

A. Objectives

General 1. To develop capability at the Lyallpur Agricultural University in the Departments of Agricultural Engineering, Agricultural Economics, Rural Sociology, Agronomy, Soil Science, and Extension for training B.Sc. students and graduate students in on-farm water management subjects.

Specific 1.

(a) Introduce and co-teach with appropriate faculty members applied courses in water management engineering; agronomic aspects of on-farm water management; economics of on-farm water management; sociology of on-farm water management; and extension methods for on-farm water management.

(b) Develop teaching materials and outdoor laboratories to aid classroom teaching of water management courses at the University.

General 2. To institutionalize the training of selected Agriculture Department extension workers in the Short Course Extension Institute at the UAL.

Specific 2.

(a) Introduce and co-teach with appropriate faculty members sections of the short courses on engineering, agronomy, soils science, economics, sociology, and extension methods for on-farm water management advisors.

(b) Develop short course materials and outdoor laboratory facilities in villages near Lyallpur.

General 3. To establish a continuous, on-farm, water management in-service training program for on-farm water management advisors.

Specific 3.

(a) Train trainers for mini-institutes.

(b) Develop materials for mini-institutes.

General 4. To design evaluative procedures for on-farm water management supervisors to use with extension workers.

Specific 4. (a) Use experience in training and evaluation to continually up-date evaluative procedures.

(b) Develop evaluative case histories for teaching purposes.

B. Methodologies in Training

1. Introduction - short lecture - never more than 10% of time allocated to the subject.

2. First hand experience in simulated situation or university laboratory - evaluation.

3. Field observation of correct procedure - evaluation.

4. Field trial under close supervision - evaluation.

5. Field trial - supervision from distance or by cross checking - evaluation.

6. Field In-Service Training and Application with self evaluation and evaluation by supervisory officer.

VII. Content of Training

CURRICULUM

On-Farm Water Management Advisors
(One year certificate course)

		Duration
I.	Orientation	1 day
II.	Socio-Economic Skills Village Social Structure Village Decision Making Structure Communications Approaches With villagers With subordinates With peers With officials Conducting a Water Management Survey - determine needs Farmer Budgeting Exercise	2 months

III.	Agronomic skills Crop water needs Crop fertility needs Deficiency symptoms Crop scheduling Plant protection methods	1 month
IV.	Physical Engineering Skills Surveying - Taping Pacing Differential leveling Topographic surveying Watercourse design and layout Land leveling design and layout Plane table survey	1 month
	Water Measurements - Float Method Flow Meter Flume	1 week
	Soil Water Measurement - Gravismetric Touch and feel	1 week
	Conducting a Water Losses Survey Delivery losses Application losses	2 weeks
V.	Planning Water Management Improvement 1. Delivery system 2. Improved low cost nuccas 3. Improved adapted application methods 4. Land leveling 5. Irrigation scheduling	1 month
VI.	Field Practical Training Under Direct Supervision Application of all the skills obtained in Previous 6 months In field situation In selected villages In vicinity of the training site	5.5 months
VII.	Re-evaluation and Synthesis of Training Experience - at Short Course Center	2 weeks

VIII. Evaluation Procedures and Supervision

All units of study will be evaluated as well as the trainee programs. The evaluation will be continuous and personal files on the programs of each trainee will be maintained. Self evaluative approaches will be used by trainees. Continuous internal evaluative techniques will be used as well as periodic formal evaluations. As mentioned earlier once in the field the on-farm water management advisor will work under an AD who has also completed the training course plus training in supervisory techniques.

Upon successful completion of the training course, a certificate will be awarded. This certificate could become an objective measure for which the Department of Agriculture could award increments in salary and promotions. The field worker will also be evaluated while performing his tasks in the field.

IX. Conclusion

Intensive on-farm water management improvements are possible on a wide scale in Pakistan only by having trained personnel in the field to help farmers. The intensive training of personnel in methods adapted to the Pakistan situations is the first prerequisite for a successful on-farm water management improvement program.

APPENDIX I-A

The following summary of data on the extension system in the Khanewal Tehsil shows some of the areas where much must be done to improve extension's role with farmers.

Summary from Findings on Khanewal Extension System

1. In Khanewal Tehsil there are 42 field assistants (A.A.'s) who have one year of general agricultural training. Of the 34 F.A.'s interviewed 41 percent had 9-10 years of schooling. Fifty-three percent are between the ages of 25 to 30 years, 35 percent are between 31 to 35 and 13 percent are over 35 years of age. In Khanewal Tehsil there are only four agricultural assistants and all have earned the B.Sc. degree in agriculture. One of the four has recently obtained the M.Sc. degree. The only specialists who provide technical support are a plant protection officer, a horticulture officer, and a crop statistician and three crop reporters who serve all the Multan District, an area with 2.8 million acres of cultivated land and 257,164 farms.

2. Forty-seven percent of the F.A.'s had served the Department of Agriculture for less than ten years, 47 percent had served between 10-15 years, and six percent had served over 15 years. Of the 34 F.A.'s reported on transfer since employment, 21 reported 2 to 5 transfers, eight reported 6 to 10 transfers. One F.A. reported over ten transfers. One A.A. (Agricultural Assistant) reported six different assignments in twelve years of service, one reported six different assignments in nine years of service, and a newly assigned A.A. had worked in two different posts in two years of service. Only 26 percent of the F.A.'s had not been transferred outside the Tehsil while 74 percent had been given work assignments in from two to as many as seven different Tehsils.

3. F.A.'s report that in the one year general agricultural training program they studied plant protection, horticulture, general agriculture and animal husbandry. None had studied extension education, communications, teaching methods, water management, land leveling or reclamation, farm management or soils. However, 68 percent of the F.A.'s reported that their one year of training was adequate.

4. F.A.'s reported that they spend about five days in in-service training per year. However, often only one day is given to an elementary training period which often includes bringing field diaries up to date and receiving salary payments. Seventy-one percent of the F.A.'s reported that they felt their in-service training to be sufficient.

5. None of the F.A.'s reported having received special crop training at either the maize, rice, cotton, or wheat research stations. However, the A.A.'s had some short training courses at these places.

6. All F.A.'s are required to live in the Union Council where they work. However, only 82 percent of the 34 F.A.'s reported living at their Union Council headquarters. Each F.A. serves from ten to twelve villages with a total population of over 15,000 people and is supposed to serve about 1,200 acres of land. No F.A. is provided with transportation facilities but uses his own bicycle. No motorcycle or motorbike is provided the A.A.'s by the Department.

7. Field workers reported that they work an average of about 20 days in the field per month and work in the office completing diaries and other paper work for five or six days. While in the field the F.A.'s on the average report making contacts with about nine farmers. Of 31 F.A.'s reporting they set up an average of about four - five dwarf wheat demonstration plots per work year from 1966-67 to 1969-70 and in 1970-71 expected to put in an average of about seven plots each of dwarf wheat demonstrations.

8. When asked a number of questions about dwarf wheat, 15 percent of the F.A.'s could not name the late varieties of HYV of wheat recommended by the research station and the Department of Agriculture, 24 percent could not give the recommended range of sowing dates for dwarf wheat, three percent could not give the proper depth of sowing and 12 percent could not give the recommended number of days to first irrigation after sowing dwarf wheat. There were many different and often incorrect answers given to questions concerning what they would recommend to farmers concerning seed rates for late sown dwarf wheat, amounts and timing of nitrogen and phosphorous at various stages of plant developments. The same was true when they were presented six problem questions related to amounts of nitrogen and phosphorous to apply to very sandy loam soils with little or no crop residues. Often wild recommendations were given.

9. When F.A.'s were asked to give their estimates of what percentages of farmers were using various levels of nitrogen and phosphorous for dwarf wheat, methods of seeding, etc., they gave ranges which were wide of the mark in comparison to the actual reports of farmers.

10. When asked to specify the various types of work they do the F.A.'s gave the following which were listed in order of most to least mentioned: plant protection (25), demonstration plots (19), giving advice to farmers (18), fertilizer

promotion (8), teaching farmers (7), agricultural development (6), community development (5), and propaganda (5).

11. When asked what new conditions, facilities, assistance would help make their work more meaningful to themselves and more helpful for the farmers they responded with the following: transportation facilities (17), housing facilities provided by the Department (15), implements to rent to farmers (11), salary increases (7), dependable supply of insecticides and sprayers (6), radio for listening to Farm Radio Program and Market News (5), specialists for technical back-up (4) more fertilizer agencies and agencies that handle improved seed (3), reduction in areas field workers serve (3), medical facilities for field workers (2). The two major problems, transportation and housing facilities, were mentioned respectively by 73 and 56 percent of the F.A.'s.

12. When asked what extra training they felt they needed the subject areas most mentioned were: plant protection (12), citrus fruit crops (10), demonstration plots and trials (4), animal husbandry and poultry (4) cotton (2), and fertilizer (2). Only two mentioned cotton and two mentioned fertilizer. A whole range of important subjects such as rice, wheat, sorghums, HYV of cotton, water management, farm management, etc., were not mentioned.

13. When asked to write a definition of agricultural extension education for farmers, the definitions of the F.A.'s included the following major ideas presented by the number expressing the idea in their definition extension education is: educational work (1), improving and modernizing agriculture (11), giving advice to farmers (3), introducing new crops to farmers (2), setting up demonstration plots for farmers (1). Sixteen of the 34 F.A.'s did not attempt to write their own definition of extension education for farmers.

14. Seventy percent of the F.A.'s reported reading the Ziarat Nama, Agricultural Department bi-monthly paper regularly, only one field worker reported reading The Pakistan Journal of Agriculture, which contains research articles, twenty-four percent of the F.A.'s reported reading no book on agriculture in the last year, twelve percent reported reading one agricultural volume, twenty percent reported reading at least two volumes, twenty percent had read three books and twenty-four percent reported having read at least four agricultural books in the past year.

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*In the author's dissertation tables and charts are presented showing frequencies and percentages. Also a detailed discussion of that data on the Khanewal Extension System is given.

APPENDIX A. PERSONNEL SELECTION PROCEDURES

To identify personnel with appropriate attitudes, experience, and training four procedures were used.

1. The interviewee was scrutinized in an on-the-job field situation with the University before any mention of a job was made. His aptitude for the job and willingness to work long hours at tedious tasks were noted.

2. The individual was interviewed. In this interview a verbal test of basic skills and familiarity with tools of the trade was made. Also several hypothetical situations were constructed which the interviewee was asked to solve.

3. The attached Attitudinal Questionnaire was exercised by each interviewee. This was to test the person's feelings and potential reaction to various field situations.

4. The personal family background, university background and accomplishments were weighed in making a final decision.

APPENDIX B

Name of Evaluator_____

Name of Person Evaluated_____

EVALUATION OF WORK PERFORMANCE OF ENGINEERS, AGRONOMISTS, AND SOCIOLOGISTS

Watercourse Survey

Date_____

Place_____

Purpose: To improve methods of training for improved skills acquisition of persons participating in the watercourse survey team and arrive at more sound criteria for making judgments about the progress of each trainee.

Note: This is a first approximation of some evaluative points that can be utilized for the persons involved in this on-the-job training in watercourse survey methods and approaches. This is to be utilized primarily as a tool to improve the training and to improve the skills acquisition of the trainees during the field experience.

Evaluation then is necessary to help trainees to know how well they are doing. Trainees will be involved in self-measurement and the two trainers will also evaluate each trainee. The feedback from this process should be useful in improving our training methods. Evaluation is necessary only for those tasks included in the job description: Engineer, Agronomist, or Sociologist.

Evaluative Points	Scale of Accomplishment (check only one)			
	Very Adequate / Very Good	Somewhat Adequate / Good	Need Much More Experience / Fair	Still Very Weak / Poor
1. Job Performance				
A. Installing flumes	_____	_____	_____	_____
B. Reading flumes	_____	_____	_____	_____
C. Topographical surveys	_____	_____	_____	_____
1) Bench marks	_____	_____	_____	_____

Job Performance Evaluation (Continued)

	Very Adequate / Very Good	Somewhat Adequate / Good	Need Much More Experience / Fair	Still Very Weak / Poor
2) Reading instruments	_____	_____	_____	_____
3) Closing survey	_____	_____	_____	_____
4) Recording data	_____	_____	_____	_____
5) Map design to scale	_____	_____	_____	_____
D. Evaluation of ditch losses	_____	_____	_____	_____
1) Correct location	_____	_____	_____	_____
2) Correct length of time	_____	_____	_____	_____
E. Field Efficiency	_____	_____	_____	_____
F. Notes on irrigation behavior of farmers	_____	_____	_____	_____
G. Accuracy	_____	_____	_____	_____
H. Checking instruments for level accuracy	_____	_____	_____	_____
I. Crop surveys	_____	_____	_____	_____
J. Field geometry	_____	_____	_____	_____
K. Regular daily diary of work and observations	_____	_____	_____	_____
L. Moisture samples	_____	_____	_____	_____
M. Approach to farmers	_____	_____	_____	_____
N. Problem solving	_____	_____	_____	_____
O. Care in interviewing	_____	_____	_____	_____
P. Care in data recording and promptness	_____	_____	_____	_____
Q. Writing of data legibly	_____	_____	_____	_____
R. Organizes work daily	_____	_____	_____	_____

Job Performance Evaluation (Continued)

	Very Adequate / Very Good	Somewhat Adequate / Good	Need Much More Experience / Fair	Still Very Weak / Poor
S. Interviewing techniques	_____	_____	_____	_____
T. Farmer credibility	_____	_____	_____	_____
U. Working overtime to finish a job	_____	_____	_____	_____
V. Makes special notes in field books about questions	_____	_____	_____	_____
W. Observation of farmer irrigation behavior	_____	_____	_____	_____
X. Speed in work	_____	_____	_____	_____
Y. Arrives at location on time to set up instruments	_____	_____	_____	_____
2. Relationships with Team Members:				
A. Sharing work-helpfulness	_____	_____	_____	_____
B. Cooperation with others	_____	_____	_____	_____
C. Group decision making	_____	_____	_____	_____
D. Sharing leadership	_____	_____	_____	_____
E. Follows instructions of leader	_____	_____	_____	_____
F. Solving team problems	_____	_____	_____	_____
G. Management of team activities when in role of leader	_____	_____	_____	_____
3. General Attitudes about:				
A. Extra work, long hours, etc.	_____	_____	_____	_____
B. Pride in work	_____	_____	_____	_____

Job Performance Evaluation (Continued)

	Very Adequate / Very Good	Somewhat Adequate / Good	Need Much More Experience / Fair	Still Very Weak / Poor
C. Modesty	_____	_____	_____	_____
D. Frankness	_____	_____	_____	_____
E. Positive attitudes about farmers	_____	_____	_____	_____
F. Field hardships	_____	_____	_____	_____
	None	Some	Much	Very Much
G. Chapulusi or defence to trainers	_____	_____	_____	_____
H. Chumcha Gheri extreme defence to trainers	_____	_____	_____	_____

Other (Have each trainee to answer the following questions.)

1. Write a brief statement below in the space provided which will sum-up the importance of the work you are now doing for yourself and for the Pakistani farmers.

2. Write a brief statement about the general areas in which you would like to have more training and experience.

3. State very frankly how you think we can improve the following:

   a. Survey approaches.

   b. Methods of on-the-job training.

4. Why is the farmer himself the most important component of the irrigation system in Pakistan? (Any new insights?)

5. State very frankly your honest feelings when someone criticizes your work, which you have conducted with real sense of dedication and professional integrity.

Job Performance Evaluation (Continued)

6. State briefly what you would do if a farmer does not agree with you and tries to pull out your flume from the watercourse and threatens to kick you and all of your equipment from his fields.

7. Please be very frank and honest in stating your personal attitudes towards survey team members if you were a farmer. Especially when you have real shortage of water and they come and install a flume in your watercourse.

APPENDIX C

ATTITUDINAL QUESTIONNAIRE

The following are descriptions of actual work situations. You are asked to mark (✓) the statement that best represents your true feelings about the situation or the statement that is closest to what you would do under these circumstances. There are no really correct answers, as each individual will have his own set of attitudes and foreseeable actions.

1. The following situation applies: you have been given a job to measure all the irrigation applications for a given waribundi; yet an important holiday, Eid, is going to fall during the waribundi, but the farmer still intends to irrigate on his regular turn of which falls on the holiday.

_____a. I would instruct the field assistant and beldar to remain and make the measurements.

_____b. I would make arrangements with my superiors to postpone the measurements until after Eid when I return from my home.

_____c. I would stay to make the measurements as instructed.

_____d. None of the above describe my foreseeable actions.

_____e. I would do the following:_____

_____

_____

2. My superiors have instructed me to collect a set of data using a prescribed procedure. This approach according to my knowledge is very likely to insult the farmers to the point of seriously jeopardizing all future work on the watercourse.

_____a. I would follow my superior's instructions completely.

_____b. I would follow my intuition and modify the approach to avoid the insult, at the risk of not collecting all the data or of not getting exactly the right kind of data.

_____c. I would discuss the matter with my superior.

_____d. None of the above describe my foreseeable actions.

_____e. I would do the following:_____

_____

_____

3. My superiors have instructed me to do a certain job on the watercourse that I am assigned to: attaching a staff gauge to the mogha in order to obtain a rating curve for the discharge of the mogha. The farmers do not wish to have me do this because this might draw attention to the fact that they have paid to have the mogha modified from its original design specifications.

_____a. I would follow my superior's instructions without delay.

_____b. I would explain the problem to my superior so that he would make the decision.

_____c. I would explain my mission to the farmers and promise complete confidentiality about the data collected.

_____d. None of the above describe my foreseeable actions.

_____e. I would do the following:_____

_____

_____

4. I have been assigned to work directly with farmers on a given watercourse for the entire kharif season. This involves being on the watercourse often at night to measure irrigation applications and on weekends to observe and record farmer production inputs.

_____a. I would prefer to rent a room in the village served by the watercourse.

_____b. I would prefer to live with the farmer whose actions I am studying.

_____c. I would prefer to live at the Mona Colony and commute to my work as the work requires my presence.

_____d. None of the above describe my foreseeable preferences.

_____e. I would do the following:_____

_____

_____

5. I have been assigned to work on a given watercourse to observe the farmer's inputs to crop production.

_____a. I feel that farmers are basically very trusting and that I can tell them most anything or do anything that will get my assignment completed.

_____b. I know the farmers difficulties, and I will attempt to understand him, to teach him, and help him when I can.

_____c. I realize that farmers are really quite clever, and I must be very careful so that they don't use me for their purposes.

_____d. None of the above describe my attitudes.

_____e. I would do the following:_____

_____

_____

6. I have been assigned to live and work on an experimental watercourse. I realize the farmers are very hospitable toward me because I have won their confidence.

_____a. I really do expect to be taken care of while working in the field and have the farmers bring me tea or lassi whenever available.

_____b. I really don't expect too much, so I will only help myself to radishes, or sugar cane or fruit on limited occasions.

_____c. I really don't want any material thing from the farmers, but on occasion I will accept some refreshment only out of courtesy on my part as a response to their courtesy.

_____d. None of the above would describe my foreseeable feelings or actions.

_____e. I would do the following:_____

_____

_____

7. In my work on the watercourse I have been assigned several pieces of expensive equipment or measuring devices.

_____a. I will assign the field assistant or beldar working with me to look after the maintenance and security of these items.

_____b. I will personally be responsible for the security and maintenance of this equipment.

_____c. I know the farmers and that they won't harm my equipment, so security for the equipment wouldn't be a problem for me.

_____d. None of the above describe my attitude.

_____e. I would do the following:_____

_____

_____

8. Much of my work on the watercourse involves measuring water and soil moisture. Both of these jobs can be quite tedious and dirty.

_____a. I will assign my field assistant to make these measurements, after all I have trained him to do a good job.

_____b. I will personally supervise my field assistant's work to ensure precision in measuring.

_____c. I will make all measurements in the field personally and if necessary I will wade into the water to install a flume.

_____d. None of the above describe my foreseeable actions.

_____e. I would do the following:_____

_____

_____

9. In accepting a job to work with an organization, I am faced with a conflict between choosing a position which will ultimately lead me to a long career up the organizational ladder or between a job which has a short longevity but which has many opportunities for me to learn new things and increase my engineering skills.

_____a. I would accept only those positions which are sure to get me promoted in the organization.

_____b. I would accept any position however short in duration, in order to increase my skills and knowledge.

_____c. I would only want to work and to be paid for it; these other considerations don't matter to me.

_____d. None of the above describe my attitude about these matters.

_____e. I would do the following:_____

_____

_____

10. I face the problem of learning to determine soil moisture depletion by touch and feel method. After considerable experience I am still not confident.

_____a. I will continue to make measurements as directed by my superior.

_____b. I will explain my problem to my superiors and ask for guidance.

_____c. I will make gravimetric soil moisture measurements to check my touch and feel technique.

_____d. None of the above describe my actions.

_____e. I would do the following:_____

_____

_____

11. In accepting a job, I am faced with the problem of accepting a position of lower qualification and pay with the possibility of early promotion to the grade corresponding to my skills and qualifications or waiting for the right job to appear.

_____a. I would take any job now because I don't know how long it would take for the right job to come along.

_____b. I am fully willing to work hard at a job for which I am over qualified, knowing that hard work is readily repaid in promotions.

_____c. I am worried that in accepting the job with the lower qualification, I will face ridicule from my classmates and professors and will hurt my professional image.

_____d. None of the above apply to my attitude.

_____e. I would do the following:_____

_____

_____

12. A group of farmers on the watercourse to which I am assigned have come to me for help. They want me to accompany them to a local irrigation supervisor to plead their case for increased water supply from their mogha.

_____a. I should help the farmers all I can.

_____b. I should express concern for the farmers complaints and handle the matter by myself.

_____c. I should hear the grievances but should remain outside of the controversy.

_____d. I should do none of the above.

_____e. I would do the following:_____

_____

_____

13. I am working for an organization which is very powerful and has a reputation of harboring many corrupt officials.

_____a. I should be willing to criticize the organization when others do so.

_____b. I should be willing to defend the organization with my loyalties in most circumstances.

_____c. I should not criticize, for every organization has its despicable persons, but I should try to influence others by my reputable behavior.

_____d. None of the above would be my course of action.

_____e. I would do the following:_____

_____

_____

14. I have a co-worker who is not doing his job properly and recording fictitious data from no measurements.

_____a. I should convince him of his predicament and cause him to correct his behavior.

_____b. I should not talk to him but should report him immediately to my superiors since incorrect, fictitious data is unforgiveable in research activities.

_____c. I should do nothing as everybody eventually gets his due reward.

_____d. I would do none of the above.

_____e. I would do the following:_____

_____

_____

15. A dispute has arisen on the watercourse where I work. Two families which have traditionally been fighting are now at odds over an irrigation turn.

_____a. I should listen to the case and try to convince the guilty party to change his actions before I go to the police.

_____b. I should listen to the case and help the two parties to come to some reasonable agreement.

_____c. I should remain out of the proceedings as my job is not to settle disputes on the watercourse.

_____d. I should do none of the above.

_____e. I would do the following:_____

_____

_____

Appendix 41

FARM WATER MANAGEMENT EFFECTS ON WATERLOGGING AND SALINITY IN PAKISTAN[1]

Mohammad Ashraf, Wayne Clyma, and Arshad Ali[2]

Waterlogging and salinity are major problems confronting the irrigated areas of Pakistan. The magnitude of the problem is indicated by the fact that millions of acres of irrigated land have been seriously damaged. The present Prime Minister of Pakistan has recognized waterlogging and salinity as one of the major problems facing the Country and has directed that the problem receive top priority. The Working Paper for Water Resources for the Development Perspective (1975-80) prepared by the Planning Commission lays a great emphasis on Drainage and Reclamation with an allocation of nearly 5 billion rupees.

This paper will use data for the Mona Reclamation Experimental Project area, a hydrologic subunit of SCARP II to prepare a water budget to give the components of a water balance for an irrigated area and to illustrate the importance of farm water management to successful alleviation of waterlogging and salinity. Some components of a program to solve waterlogging and salinity problems in Pakistan will be presented.

HYDROLOGIC CYCLE FOR CANAL IRRIGATED AREAS

A general water balance for any area can be written based on the general equation for conservation of mass in which:

Inflow - outflow = change in storage

The specific terms of this flow equation can be written as:

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[1]Paper prepared for the Waterlogging and Salinity Conference, Lahore, Pakistan, October 13-17, 1975. Contributions from Colorado State University the University of Agriculture, and the Mona Reclamation Experimental Project, WAPDA. Portions of this work were supported by USAID/Pakistan Agreement No. 204-75 and by USAID/CSU Research Contract No. AID/ta-c-1100.

[2]Project Director, Mona Reclamation Experimental Project, Water and Power Development Authority, Bhalwal; Agricultural Engineer, Colorado State University, Water Management Research Contract, Islamabad; and Assistant Professor and Chairman, Department of Irrigation and Drainage, Faculty of Agricultural Engineering, Agricultural University, Lyallpur.

Surface inflow + Subsurface inflow + Precipitation + Imported water (canal water) - Surface Outflow - Subsurface Outflow - consumptive use - exported water = change in surface water storage + change in ground water storage

with the terms illustrated in Figure 1.

A number of studies have discussed a water balance for canal irrigated areas such as Revelle (1964), Greenman, Swarzenski, and Bennett (1967) and Atta-ur-Rehman (1971b). The concept is that before canal irrigation started the area was in hydrologic equilibrium with precipitation and recharge from rivers just equalling the discharge by evapotranspiration and discharge to rivers. No changes in surface water or ground water storage occurred on the average.

With the development of canal irrigation, losses from the delivery system (canals, distributaries, watercourses and fields) plus decreased effectiveness of precipitation combined to appreciably increase groundwater recharge. This disturbed the hydrologic equilibrium and a rise in ground water occurred. Greenman, Swarzenski and Bennett (1967) gave the average annual rate of water level rise after initiation of irrigation as 2.3 feet per year. Assuming 0.20 as the specific yield, this rate of water table rise indicates that recharge to the Mona Project area (116,000 acres) after canal irrigation to have been 50,000 acre-feet (AF) or 62,500 AF if 0.25 is assumed as the specific yield. The net annual recharge represents water retained after outflow to rivers and in evapotranspiration. After 30 years when the water table approached the surface, beneficial and non-beneficial evapotranspiration increased ground water depletion and net annual recharge had decreased to near 20,000 acre-feet according to Atta-ur-Rehman (1971). When the salinity control and Reclamation Project (SCARP) was initiated, the system was in equilibrium and inflow approximately equaled outflow.

WATER BUDGET FOR AN IRRIGATED AREA

A water budget for an irrigated area may be developed on the basis of different assumptions. The simple but realistic assumptions are:

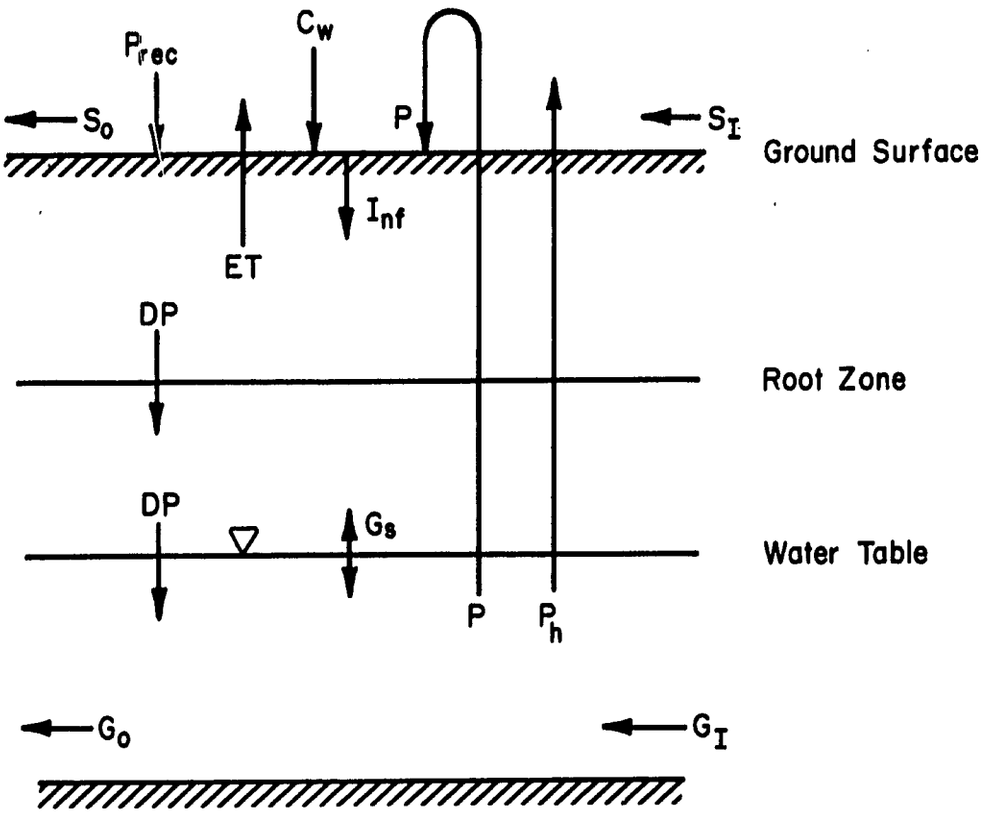
1. The conservation of mass holds where inflow equals outflow minus change in storage.

2. Flows are steady state.

Further assumptions about the system to simplify the analysis are:

3. No surface storage occurs.

4. Soil moisture storage does not significantly change from year to year.



S_o - Surface water outflow
SI - Surface water inflow
P_{rec} - Precipitation
P - Pumping
C_w - Canal water
I_{nf} - Infiltration
DP - Deep percolation
ET - Evapotranspiration
G_o - Groundwater (subsurface) outflow
GI - Groundwater (subsurface) inflow
G_s - Groundwater storage
P_h - Water use (evapotranspiration) from water table

Figure 1. Definition sketch for a water budget.

The least acceptable of the above assumptions is (2). Transient inflows and outflows from groundwater and inflows from precipitation and irrigation water violate the assumption. Monthly water budgets summed over the year would produce much more accurate results. Thus, calculations of the water balance will be in error if a groundwater inflow condition in June was an outflow condition after monsoons or in January. Further, changes in the gradients affecting flow from month-to-month can be appreciable. Further implications of this assumption will be discussed during the analysis of the data.

Using steady state and conservation of mass assumptions, three independent equations for three zones in the system in the development of a water budget can be written (Figure 1).

For the surface of the irrigated area:

$$S_I + C_w + P + P_{rec} - S_o - I_{nf} = 0 \qquad (1)$$

where:

S_I = surface water inflow

C_w = canal water inflow

P = pumpage for irrigation

P_{rec} = precipitation falling on the area

S_o = surface water outflow

I_{nf} = infiltration into the soil at the surface

For the root zone of soil water use for evapotranspiration

$$I_{nf} - ET - DP = 0 \qquad (2)$$

where:

ET = evapotranspiration both beneficial and non-beneficial

DP = deep percolation or loss to ground water from the soil water zone

For the groundwater system:

$$G_I + DP - P - P_h - G_o = G_s \qquad (3)$$

where

G_I - Groundwater inflow

P_h - Use of water from groundwater by evapotranspiration

G_o - Groundwater outflow

G_s - Groundwater storage

The above system of equations can be used to determine various components of the water budget when the remaining quantities are known. With three independent equations up to three unknowns may be determined.

PROJECT GROUNDWATER RECHARGE

A relationship can be developed from a groundwater budget for the draft on the groundwater system. This draft can then be used to hypothesize the safe yield or annual recharge to the aquifer (Todd, 1959). Equation (3) for the groundwater balance was given as:

$$G_I + DP - P - P_h - G_o = G_s \tag{3}$$

The draft on the groundwater system as defined by Equation (3) includes those terms which represent outflow from the system. Draft is thus defined as:

$$\text{Draft} = P - P_h - G_o \tag{4}$$

The direct water use from ground water, P_h, cannot be measured accurately. For the water balance presented subsequantly, P_h was combined with the deep percolation term to obtain a net recharge from the surface. In computing the draft on the groundwater basin, P_h is neglected. The effect on P_h as the water table is lowered is that direct use of water from the water table is reduced. The apparent surface and total recharge will thus increase. Thus, the modified draft will be computed as

$$\text{Draft} = -P - G_o \tag{5}$$

Draft is negative for pumpage and groundwater outflow but a rise in water levels reflects the condition when inflow or recharge exceeds the draft. The recharge that offsets draft comes from deep percolation losses from canal water as well as pumpage. The effectiveness of water use for irrigation within the project area will affect the quantity of losses from irrigation which appear as groundwater recharge. When water use for irrigation is efficient, then the water goes mostly to beneficial evapotranspiration and very little as deep percolation. The quantity of water which returns as

deep percolation from irrigation affects draft on the groundwater system through pumpage and the amount of recharge through deep percolation. Thus, the results of this analysis are based on present farm water maangement practices within the project area. Changes in farm water management practices will affect the components of the water balance.

Data from a number of Water and Power Development Authority (WAPDA) reports have presented the results of studies of the water balance for the Mona Reclamation Experimental Project (Atta-ur-Rehman, 1969; Atta-ur-Rehman, 1971a; Atta-ur-Rehman 1971b; Bhatti, 1972; and Bhatti, 1974). These data have been used to develop the annual draft for the Mona Project using Equation (5) and the basic data from the previously cited reports. These results are presented in Table 1 for the annual draft on the groundwater system.

Figure 2 shows the relationship between annual water level decline and annual draft on the groundwater system using the procedure developed by Hill and described by Todd (1959). The data in Figure 2 are used to determine a line which defines the annual draft for which there is zero change in the annual water level. The draft for which there is zero change in water level represents the annual recharge to the groundwater system and the consequent safe yield. According to Todd (1959) "The safe yield of a groundwater basin is the amount of water which can be withdrawn from it annually without producing an undesired result." In most groundwater systems the desired result is a stable water level at a depth which gives maximum annual recharge. In the Mona project area a decline in water level is desirable but information is needed concerning the amount of water that must be pumped to lower water levels. Also, knowledge of the maximum amount of annual recharge while maintaining the water level at a given depth would be of interest.

As previously explained, before pumpage was imposed in the Mona project area, recharge and discharges from the aquifer were in balance and water levels were static. Initially pumpage was at a low rate and small amounts of decline occurred with the level of recharge at 65,000 AF. The line in Figure 2 represents an approximate average for the data points and suggests that the average annual recharge or safe yield is near 180,000 AF. Actually there are several distinct periods represented in the data points. During the pre-canal, pre-project, and early periods of pumping (up to 1966-67), an average annual recharge of near 50,000 AF is indicated. As ground water development continued and pumping increased up to 1970-71, average annual recharge as indicated by those limited data points approached 250,000 AF. Pumpage has been reduced during the past several years, water levels have risen and the average annual recharge as indicated by the recent data points has decreased as more water is lost from the system as outflow.

Table 1. Annual Draft of Groundwater (in thousands of Acre Feet) for the Mona Reclamation Experimental Project

QUANTITY	PRE-CANAL	PRE-PROJECT 64-65	65-66	66-67	67-68	68-69	69-70	70-71	71-72	72-73
Groundwater Outflow (G_o)	87.0	39.0	28.0	30.0	36.0	29.0	28.0	30	28est.	26.0
Pumpage (P)	-	-	122.4	149.2	168.3	230.2	249.4	248.3	143.0	117.6
TOTAL ($-P - G_o$)	87.0	39.0	150.4	179.2	204.3	259.2	277.4	278.3	171.0	143.6
Water Level Decline (ft.)	0	+.08	-.28	-0.38	+1.5	-1.5	-0.86	-1.5	+0.73	+0.59

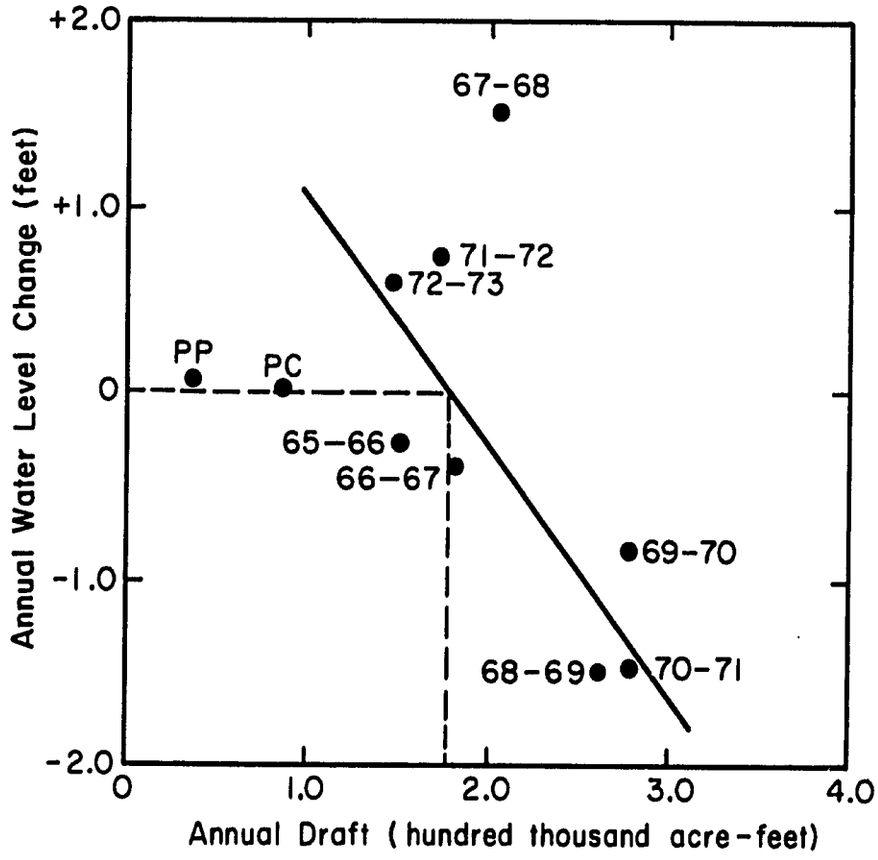


Figure 2. Relationship between annual draft and annual decline for the Mona Project Area.

When a ground water system is developed by pumping this creates a draft or depletion of the water in storage. Whether water levels decline and at what rate depends on the hydrologic conditions of the aquifer. In canal irrigated areas of Pakistan where the water table is near the surface, outflows from the aquifer are increased by evapotranspiration from the groundwater, increased groundwater outflows or decreased inflows because of hydraulic gradients and in some areas decreased surface infiltration because water levels are at or near the surface. As water levels are lowered, recharge is increased and discharges are decreased until inflow becomes a maximum and outflow becomes a minimum. At this groundwater level the indicated recharge becomes the maximum safe yield.

Pumpage in the Mona Reclamation Experimental Project decreased in 71-72 and 72-73 and a rise in water levels resulted. The annual recharge implied from these data points also decreased. Further declines in the water levels from increased draft would increase the annual recharge. At some level of draft the recharge would become a maximum and annual declines from increased withdrawals would follow a straight line of constant slope defining the maximum safe yield for the project area. Levels of pumpage in excess of 250,000 AF per year would appear to be necessary to achieve maximum recharge to the project area. Further, consistent annual drafts for additional years are necessary before the maximum safe yield of the project area can be determined. Based on the very limited data, safe yield with further lowering of the water table may exceed 300,000 AF. Other factors must also be considered such as the quantity of pumpage which returns to groundwater and a major change to more efficient irrigation practices may reduce the annual recharge substantially. Another consideration would be to decrease the importation of canal water into the project area. Under present practices to increase groundwater recharge and maximize the area's water supply, increased pumpage is necessary.

ANNUAL WATER BUDGETS

Previous water budgets have been developed for the Mona Reclamation Experimental Project by both Atta-ur-Rehman (1971b) and Bhatti (1972). The basic equation used for the overall balance was inflow equals outflow minus change in storage. The "total water budget" given by Atta-ur-Rehman (1971b) can be obtained by writing an equation for inflow, outflow, and change in storage for the outside boundaries of the system in Figure 1 neglecting the term for P_h, direct use of groundwater. The "total water budget" can be obtained by combining Equations (1), (2), and (3) into one equation without a P_h term. The resulting equation

$$G_I + C_w + S_I + P_{rec} - G_o - S_o - ET = G_s \qquad (6)$$

is solved by Atta-ur-Rehman (1971) for ET using measured quantities for all the other components of the water balance.

The groundwater water budget developed by Atta-ur-Rehman (1971b) is of the form of Equation (3) except the components of deep percolation are estimated for precipitation and canal water diversions. The component solved was "farm irrigation" minus that loss from groundwater by direct evapotranspiration. Annual recharge amounts are given but the procedures for computation are not explicitly given. Use of Equations (1), (2), and (3) will permit a direct solution for three unknowns instead of the two.

Equations (1), (2), and (3) are the steady state equations defining a water budget for a canal irrigated area. Data from the previously cited reports of WAPDA for the Mona Reclamation Experimental Project will now be utilized to develop annual water budgets for the project area. Since only three independent equations are available, only three unknowns may be determined. The three unknowns to be determined are I_{nf}, ET + P_h and DP - P_h as they are difficult to measure or compute. I_{nf} can be computed using the concepts of effective rainfall, irrigation efficiency, and the difference between surface inflow and outflow. However, effective rainfall and irrigation efficiency are very much in doubt. Thus, the infiltration will be computed. The major disadvantage of such a procedure is that errors in measurement of the other components of the balance appear in the computed term and where substantial errors occur, the magnitude of the computed term will be seriously in doubt.

Evapotranspiration can also be computed readily, especially for crops. With a high water table considerable non-beneficial evapotranspiration occurs and is difficult to estimate. Also, beneficial and non-beneficial plants consume water for evapotranspiration directly from groundwater. This is the term defined as P_h in the defining system equations. ET + P_h are combined to give the total beneficial and non-beneficial soil moisture plus groundwater evapotranspiration. In addition, the computation of the two terms, ET + P_h, permits the rearrangement of Equation (3) to compute DP - P_h or the net annual groundwater recharge from the surface to the area. Thus, ET + P_h will be computed from the water balance equations.

Deep percolation is the residual from infiltration minus evapotranspiration. However, accretions to groundwater from deep percolation can be used directly from the water table by beneficial and non-beneficial evapotranspiration. By computing a water balance at short intervals on individual fields for each irrigation and each rainfall event, deep percolation can be estimated. In this report deep percolation will be computed as the net groundwater recharge in terms of DP - P_h and will be computed from the water balance equations.

The three necessary equations rearranging Equations (1), (2), and (3) are:

$$I_{nf} = S_i + C_w + P + P_{rec} - S_o \quad (7)$$

$$ET + P_h = I_{nf} - P + G_I - G_o - SG_s \quad (8)$$

$$DP - P_h = I_{nf} - (ET + P_h) \quad (9)$$

Table 2 presents the results of the Annual Water Budget Analysis for the Mona Reclamation Experimental Project. Results of the water balance for the pre-canal period and the pre-project periods do not appear to be logical. This would appear to relate to the excessive groundwater inflow into the project area.

There are a number of limitations, however, to the application of steady state equations to an annual water budget. One of these relates to the estimates of groundwater inflow and outflow which are based on water level contour maps obtained during the month of June for the Budget Analysis. This is the period before the monsoon rainfall begins. Substantial quantities of groundwater recharge occur during the monsoon resulting in major changes or a reversal in the gradient of flow into or out of the area and result in losses in the measurement of groundwater recharge using the steady state budget procedure. This loss will, however, be reflected in the increased amounts of recharge that is estimated as the groundwater levels are lowered by increased pumping. Shorter time increments such as monthly water budgets would improve the validity of the steady state assumption and the accuracy of the analysis.

In Table 2 the negative recharge indicates loss of water from the area. During pre-canal periods this is logical since inflow to the area by precipitation and groundwater must be offset by discharges and some net discharge would be expected. The actual discharge may be less because of the assumptions concerning steady state. In the pre-project period (Table 2) some discharge or rejected discharge did occur.

With the imposition of pumping, recharge to the groundwater increased in proportion to the increased pumping. As pumping has declined in the past few years so has recharge but not directly proportional as a rise in water levels have also occurred. The net recharge in Table 2 is the estimate determined from the water budget analysis. The safe yield determined from Table 1 and Figure 2 are different because they are estimates of the average annual recharge that would occur with the water level maintained at a stated average level.

Table 2. Water Budget for the Mona Reclamation Experimental Project (All quantities in thousands of acre feet).

QUANTITY	PERIOD									
	PRE-CANAL	PRE-PROJECT 64-65	65-66	66-67	67-68	68-69	69-70	70-71	71-72	72-73
Surface Inflow (S_I)	6.0	6.0	6.0	7.5	20.0	12.0	8.2	7.0	10*	10*
Canal Water (C_w)	-	177.0	167.5	179.7	163.8	166.0	150.5	140.0	147.0	164.0
Pumpage (P)	-	-	122.4	149.2	168.3	230.2	249.4	248.3	161.0	135.0
Precipitation (P_{rec})	200.0	200.0	215.0	215.0	300.0	190.0	171.6	136.0	144.0	163.0
Surface Outflow(S_o)	24.0	24.0	24.0	28.4	60.0	38.0	39.7	26.0	35*	35*
Infiltration (I_{nf}) ($I_{nf} = S_i + C_w + P + P_{rec} - S_o$)	182.0	359.0	486.9	523.0	592.1	560.2	540.0	505.3	427.0	437.0
Infiltration (I_{nf})	182.0	359.0	486.9	523.0	592.1	560.2	540.0	505.3	427.0	437.0
Pumpage (P)	-	-	122.4	149.2	168.3	230.2	249.4	248.3	161.0	135.0
Groundwater Inflow (G_i)	180.0	120.0	132.0	138.0	126.0	160.0	159.0	150.0	145*	142.0
Groundwater Outflow (G_o)	87.0	39.0	28.0	30.0	36.0	29.0	28.0	30.0	28*	26.0
Groundwater Storage (G_s)	-	+2.0	-6.5	-9.0	+34.0	-34.0	-20.0	-35.0	+16.9	+13.7
Total Evapotranspiration (ET) ($ET+P_h=I_{nf} - P + G_i - G_o-G_s$)	275.0	438.0	475.0	490.8	479.8	495.0	441.6	412.0	366.1	404.3
Infiltration (I_{nf})	182.0	359.0	486.9	523.0	592.1	560.2	540.0	505.3	427.0	437.0
Total Evapotranspiration ($ET + P_h$)	275.0	438.0	475.0	490.8	479.8	495.0	441.6	412.0	366.1	404.3
Net Recharge ($DP - P_h$) ($DP - P_h = I_{nf} - (ET + P_h)$)	-93.0	-79.0	11.9	32.2	112.3	65.2	98.4	93.3	60.9	32.7

*Estimated since not given by Bhatti (1974)

Infiltration as computed in Table 2 is an annual steady state flow and reflects the transient conditions of heavy monsoonal precipitation only as the surface inflow and outflow is affected. Total evapotranspiration in Table 2 is the combined effects of beneficial and non-beneficial evapotranspiration from soil moisture as well as the direct use of water from the water table. The computation does not reflect the fact that the canal water plus tubewell water goes on only 60 percent of the areas as the annual cropping intensity is only 120 percent. The analysis in Table 2 is an average for total project area.

Another serious discrepancy results from the assumption about steady state of the soil moisture zone. During the annual period the applications of irrigation water and precipitation result in accretions to groundwater as deep percolation. When this water is lost from the area by groundwater outflow as a transient flow then the deep percolation is underestimated. Any analysis of the effectiveness of the use of tubewell water or canal water for irrigation will underestimate the actual effectiveness of water use. For the periods of available data the implied deep percolation appears to increase with time. This is similar to the manner that the safe yield also increases with time as the groundwater levels are lowered resulting in increased recharge and storage.

The annual water budget analysis underestimates the volume of recharge in the same way as the safe yield was underestimated. This difference may be related to the quantity of water that is used by direct evapotranspiration from the water table. First during the pre-project period when water levels were high the deep percolation component is negative implying that direct water use from the groundwater table grossly exceeded deep percolation losses. This is true even neglecting the large amount of estimated groundwater inflow into the area. The results of this analysis again show that the groundwater recharge as measured by deep percolation increases as the water table is lowered in the project area.

Because of year-to-year variations in the components of the water budget, a more informative analysis can be obtained by comparing infiltration, evapotranspiration and net recharge as three year moving averages. The results are (in hundred thousand acre-feet):

	Pre-Project	66-67	67-68	68-69	69-70	70-71	71-72
I_{nf}	359	533	558	564	535	490	450
$ET + P_h$	438	482	489	472	449	406	394
$DP - P_h$	-79	51	69	92	86	84	56

When the SCARP tubewell program reached full pumping capacity, the component of the water budget defined as infiltration had increased by 200,000 AF. (Pumpage actually increased 250,000 AF.) Total evapotranspiration increased by only 50,000 AF or by only 20 percent of the amount by which pumpage increased. Decreased precipitation beginning in 1970-71 and decreased pumpage in 1971-72 reduced the water supply as measured by infiltration by approximately 100,000 AF. Since the reduction in pumping, cropping intensities no longer are increasing. Evapotranspiration as measured by the above budget for 1971-72, has actually decreased to below the pre-project level. Groundwater levels have risen for the past several years and recharge to the groundwater as measured above has also decreased.

PROJECT EFFICIENCY

Since a water budget is generally calculated for the purpose of determining the components of the water budget, the results may be used to evaluate the components of water stored in the root zone, deep percolation and water applied. Knowledge of these components can then be used to evaluate project efficiencies. Because of the assumption of steady state and the total area, the results are only as valid as the assumptions in applying the procedures. Because rainfall, irrigation applications and deep percolation are transient phenomena, the evaluation of project efficiency will overestimate the actual efficiency. However, estimates and trends can be obtained.

From Table 2 for 1968-69 the total application of water to the area is the sum of canal water plus pumpage plus precipitation and equals 586,200 AF. The total evapotranspiration for 1968-69 from Table 2 is 495,000 AF. The project efficiency (EP) is:

$$EP = \frac{\text{Water Used}}{\text{Water Applied}} \times 100 = \frac{427,000}{586,200} \times 100 = 84\%$$

The water used includes beneficial and non-beneficial evapotranspiration plus direct use of water from the water table which is not the usual method for evaluation of project efficiency.

Water applied for irrigation consists of canal water plus tubewell water supplied for irrigation. The volume supplied to the Mona project area is given in Table 3 as 396,200 AF. For the total project area this represents 3.41 ft., but for the cropped area for a 120 percent cropping intensity, the depth is 5.68 feet. Clyma (1973) has estimated that the potential evapotranspiration for the Sargodha area for a dry year does not exceed 5.6 ft. while the water requirements (subtracting effective rainfall) were only 3.5 feet.

Table 3. Calculation of Project Efficiency for 1968-69

Water application (Canal and tubewell water):		
Volume	396,200 AF	
Depth		
Total area	3.41 ft.	
Cropped Area	5.68 ft.	
Crop Consumptive Use:		
Volume		
Crop Water Requirements		269,400 AF
Consumptive Use		188,400 AF
Depth		
Total area		1.62 ft.
Cropped area		2.70 ft.
Net Consumptive Use		1.7 ft.
Consumptive use from water table		0.42 ft.
Consumptive use to be supplied by irrigation		1.28 ft.
Project Efficiency		22.5%

Crop water requirements were calculated by Atta-ur-Rehman (1971a) for 1968-69 for the project area but were increased by a factor of 1.43 to account for watercourse losses and field losses. The 1.62 ft. consumptive use for the cropped area was corrected for average annual cropped area of 60 percent giving a depth of 2.80 ft. (Table 3). Part of the consumptive use is met by rainfall and after computing effective rainfall the net consumptive use was computed as 1.7 ft. In high water table areas a portion of the consumptive use is met from water use directly from the water table. This type of use was illustrated by Ali, Clyma and Ashraf (1975) for the Mona area for Rabi 1972-73. Studies at the Mona project have also shown that the number of irrigations for optimum yield are drastically reduced for a high water table. The annual depth of water to be supplied by 5.68 ft. of irrigation water in Table 3 was calculated to be 1.28 ft. The project efficiency calculated as a result is:

$$EP = \frac{1.28}{5.68} \times 100 = 22.5\%$$

The range in project efficiencies without correcting for effective rainfall or direct groundwater use is from 48 to 22.5 percent. The net consumptive use for a 200 percent cropping intensity for the Sargodha area calculated by Clyma (1973) ranged from 2.0 feet in a wet season to 3.5 feet

in a dry season. The poor crop stands, variable cropping patterns, transient nature of precipitation and irrigation applications and inaccuracies in estimation of consumptive use all leave considerable leeway for errors in the resulting project efficiency. However, a conclusion that annual project efficiencies are low is supported by the data.

DISCUSSION

While much more refinement on the water budget analysis for the Mona project seems to be needed, the results provided do suggest that adjustments in the components of the water budget are necessary. One strategy would be to reduce canal supplies to the areas with good quality groundwater, improve farm water management to reduce losses of the present supply and when cropping intensities increase also increase the pumpage to supply the additional water. The result will be a lowering of the water table, an increase in the annual recharge and consequent total water supply for both the Mona area and Pakistan.

A program that maximizes the use of groundwater effectively increases the total water supply. A program of planned lowering of the water table must also assure against excessive lowering by too closely spaced wells or unnecessary pumping. When the limit of increasing the water supply by planned pumpage is reached, other alternatives such as artificial groundwater recharge can be considered.

A salt balance for an irrigated area is necessary for a permanent irrigated agriculture. Salt balances for each field and area must eventually be achieved in Pakistan. The first prerequisite for a salt balance is a water balance. When a water balance has been achieved or a water budget understood, a salt balance can be achieved by proper manipulation of the components of the water budget. Further study and evaluation of the components of the water budget for the Mona project area is needed.

A study of Tables 2 and 3 suggest that major amounts of the water supplied for irrigation in the Mona project area go to groundwater. Measurements by Kemper et. al., (1975), Clyma, Ali and Ashraf (1975a), and Clyma, Ali, and Ashraf (1975b) suggest that watercourse losses and ineffective irrigation practices combine to cause much wastage of water. The estimates of the components of the water balance presented in this analysis support the same conclusion. Improving on-farm water management will alter the components of the water balance by decreasing pumpage and/or canal water supplies needed to irrigate a given area, increasing evapotranspiration and decreasing the deep percolation component. Decreasing deep percolation can be an important means for alleviating waterlogging.

REFERENCES

Ali, Arshad, Wayne Clyma and Mohammad Ashraf. 1975. Irrigation Practices for Traditional and Precision Leveled Fields in Pakistan. in Optimum Use of Water in Agriculture, CENTO Scientific Paper No. 16, Tehran.

Atta-ur-Rehman, Ch. 1971a. Hydrologic and Tubewell Performance Appraisal in Mona Reclamation Experimental Project (1965-1970) WAPDA, CMO, WASID, Pub. No. 96, Lahore.

Atta-ur-Rehman, Ch. 1971b. Evaluation of Well Performance and Water Management of Mona Reclamation Experimental Project 1965-1970. Paper No. 406.

Atta-ur-Rehman, Ch. 1969. Monitoring Studies in Mona Reclamation Project (July 1968 to June 1969), WAPDA, WASID, Pub. No. 74, Lahore.

Bhatti, Sabir Ali. 1974. Hydrologic Appraisal, Tubewell Performance and Rehabilitation of Deteriorated Tubewells in Mona Scheme (1971-1973). WAPDA, MAP Pub. No. 12, Lahore.

Bhatti, Sabir Ali. 1972. Hydrologic Appraisal of Mona Reclamation Experimental Project, WAPDA, CMO, WASID Pub. No. 129, Lahore.

Clyma, Wayne. 1973. Evapotranspiration and Irrigation Water Requirements in Pakistan. Bulletin of the Irrigation, Drainage, and Flood Control Research Council, Vol. 3, No. 2, pp. 1-8, December.

Clyma, Wayne, Arshad Ali and Mohammad Ashraf. 1975a. Watercourse Losses. in Optimum Use of Water in Agriculture, CENTO Scientific Paper, No. 16, Tehran.

Clyma, Wayne, Arshad Ali and Mohammad Ashraf. 1975b. Irrigation Practices and Application Efficiencies in Pakistan. Publication No. 36, Water and Power Development Authority, Lahore.

Greenman, D.W., Swarzenski, W.V., and Bennett, G.D. 1967. Ground Water Hydrology of the Punjab, West Pakistan with Emphasis on Problems Caused by Canal Irrigation. U.S. Geological Survey Water-Supply Paper 1608-H, U.S. Government Printing Office, Washington, D.C.

Kemper, W.D., Wayne Clyma and M.M. Ashraf. 1975. Improvement and Maintenance of Earthen Watercourses to Reduce Waterlogging and Increase Water Supplies for Crop Production. Paper prepared for presentation at the International Conference on Waterlogging and Salinity, Lahore, Oct.13-17.

Revelle, R. et al. 1964. Report on Land and Water Development in the Indus Plain. The White House, Washington, D.C. January.

Todd, D.K. 1959. Ground Water Hydrology. John Wiley and Sons, New York, pp. 200-207.

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Appendix 42

IRRIGATION SCHEDULING FOR WATERLOGGING AND SALINITY PREVENTION[1]

Alan C. Early[2]

Abstract

Over-irrigation in both quantity and frequency are important contributing factors to waterlogging and salinity. Numerous field measurements in the Punjab of Pakistan have indicated the common occurrence of over-irrigation. A number of causes for this occurrence include fields that are not level, use of irrigation methods not adapted to the crop being grown, the application of water on fixed schedule determined by the warabundi and the farmer's attempt to compensate for an unknown future by applying available water now when future supplies remain uncertain.

Irrigation scheduling, the determination of when and how much water is needed by the plant and soil system, periodically throughout the cropping season, is a straight forward, simple approach to reducing the over-irrigation which leads to waterlogging and salinity. The methodology, input data requirements, and results of irrigation scheduling for the rabi wheat crop of 1974-75 are presented. The institutional arrangements necessary for implementing irrigation scheduling are discussed as are the relationships to other water management improvements possible in Pakistan.

I. Introduction

A. Background

Leveled fields and an irrigation schedule matched to the crop and soils needs for water are essential prerequisites to avoid over-irrigation. Arshad Ali et.al., (1975)[3] presented a discussion of the micro-effects (micro - meaning within a given irrigation unit or field) of unleveled fields causing

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[1]Paper prepared for presentation at the International Conference on Waterlogging and Salinity sponsored by the Department of Civil Engineering, University of Engineering and Technology, Lahore in October, 1975. This research was supported in part by USAID Contract AID/ta-c-1100 Water Management Research in Arid and Sub-Humid Lands of the Less Developed Countries.

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[3]See appended References.

over-irrigation. This over-irrigation contributes to or results in waterlogging (the state of water table elevation which results in yield depression and generally poor growth for non-adapted species) which in turn results in salinization (the state of deposition of soluble salts in the upper soil profile or near the soil surface due to a net evaporative deficit).

Numerous reports have detailed the nature of the waterlogging and salinity problems of the Indus Basin. The White House Department of the Interior (1964) Report on Land and Water Development in the Indus Plain has stated that 5 million acres had at that time been seriously damaged. Severe damage was increasing at a rate of from 0.2 to 0.4 percent of the irrigated area per year. This amounts to 0.6 to 1.2 lakh acres per year newly affected.

When placed in a water deficiency situation irrigators react by searching the means of water conservation and application optimization during the crisis. Water which is ordinarily available is generally considered to be the requirements. Often the actual requirements are much less before yields are appreciably depressed. Specific cases of over-irrigation in the Punjab have been documented by Clyma and Corey (1974). The water application difference between the two situations, normal and deficient, is "Water that is used in lieu of management." With good management, that water is not required; without the good management practices, that water is considered necessary for cropping. One important means for improving water management for optimum use of water in agriculture is through irrigation scheduling.

In on-farm water management, three important questions must be answered for the farmer. These are: How?, How Much?, and When to Irrigate? The best method for irrigation of a certain crop in Pakistan will usually be by basin, border, or furrow methods. The decision depends on the crop characteristics, soil characteristics, topographic characteristics, the type of water supply system, and the economics of the energy required to obtain and apply the water.

The questions, "How Much? and When?" are the key issues of irrigation shceduling. The major factors affecting the answers to these two questions are meteorological, crop and soil conditions. Meteorological conditions determine the atmospheric demand for water from the plant. More than 90 percent of the water used by plants is used in evaporative cooling, transpiration, and less than 5 percent is used in the cellular structure of the plant. Factors influencing the atmospheric demand for water are the radiant energy reaching the plant as manifest in the environmental temperature and influenced by the degree of cloud cover and the rate of transport of vapor away from evaporative surface as

influenced by the relative humidity of the atmosphere and the wind intensity.

Crop factors which are important include the type of crop which determines the inherited tendency to resist transpiration through stomatal closure, the seasonal pattern of evapotranspiration with respect to potential evapotranspiration as a function of growth stage and completeness of crop canopy, the stage of crop growth as it determines critical water use periods when deficiency below a certain threshold can contribute to yield losses, and the plant growth characteristics such as size, density of cover per unit area of land and the crop rooting depth with respect to time.

The soil properties which are important include the texture and structure as these characteristics influence the water infiltration rate, soil moisture storage rate with depth, and the proliferation of crop roots which in turn determines the size of the root zone-soil moisture reservoir. Irrigation scheduling must attempt to take into account or provide the necessary assumptions for all of these factors in order to successfully predict crop water needs.

Once the pattern of crop water needs is known, a daily moisture budget for the root zone-soil moisture reservoir using irrigation and rainfall as inputs and evapotranspiration and deep percolation as withdrawals can be maintained to determine HOW MUCH? and WHEN TO IRRIGATE? The moisture storage capacity percentage (that amount held by the soil 48-96 hours after saturation followed by drainage due to gravity) and the permanent wilting moisture percentage (the assumed moisture content threshold beyond which the plant cannot be revived by watering; hence permanent wilt.)

B. Nature of the Problem

Serious concern was expressed for the 1974-75 rabi wheat crop in October and November 1974. Factors which contributed to this concern included that a period of drought was in progress, the Indus River was reported at a 99-year low-flow level, a shortage of stored water in reservoirs was evident and the potential electricity generation shortage was capable of reducing the power necessary for tubewells. With the drought continuing into December, a concerted effort was undertaken to identify means by which irrigation water could be saved and extended to cover the rabi wheat season, Eckert and Campos (1974).

Several of the strategies were instructions on when to irrigate if only 1, 2, 3, or 4 irrigation applications were possible giving emphasis to critical stages when water may be most important to the yield of wheat; moisture conservation using tillage to curtail evaporation from the soil; dry

sowing of wheat followed by irrigation to promote germination; and an irrigation scheduling program to provide guidelines on a general province-wide basis to help farmers prevent over-irrigation of their crops and use the water saved to irrigate a greater acreage. The irrigation scheduling program was undertaken in January, 1975 and continued through mid-April.

Timely and substantial seasonal rains fell between January 1 and March 31, and have made this trial largely an academic exercise. The trial does, however, provide an opportunity to explain the concept of irrigation scheduling, prepare people's thinking for the day when it becomes possible, define the data requirements and deficiencies experienced and test the programming and meteorological input network required for successful operation.

C. Literature Review

Several recent publications have stressed the possibilities of reducing the contribution of excess irrigation water to waterlogging and salinity. Bennett and Taylor (1972) have indicated the potential role of irrigation scheduling to the reduction of salt delivery to the Upper Colorado River Basin. Skogerboe et. al., (1974) have provided an evaluation of irrigation scheduling which indicated marginal success for the approach under the conditions of the Grand Valley of Colorado but which stated that the potential for "scientific" irrigation scheduling is great. The effectiveness of an irrigation scheduling program was stated to be highly dependent upon the operation of the entire system. To effect changes in the salinity status of a system a coordinated and comprehensive program with virtually complete coverage is necessary.

Solar energy, in conjunction with the aerodynamic effect of air movement has been shown by Penman (1948, 1949, 1952, 1956a, and 1963) to be largely responsible for the consumptive use of water by plants. This concept of atmospheric demand had led to the development of equations to predict potential evapotranspiration. Several investigators have reviewed methods of estimating evapotranspiration (Levine, 1959, Ward, 1971, and Penman, 1956b). One equation which has received general acceptance is the Penman equation which combines the aerodynamic and energy balance approaches of estimation. This equation has proven to be a reliable estimate of potential evapotranspiration from a rough vegetative surface (Tanner and Pelton, 1960) for periods as short as one day.

The Penman estimate of potential evapotranspiration has been shown to be closely correlated with open water evaporation and especially with evaporation from the U.S. Weather Bureau Class A pan (Eagleman, 1967). The use of evapotranspiration estimates and pan evaporation modified by empirical

crop coefficients has led to practical methods of determining the quantity and interval of irrigation in the United States (van Bavel and Wilson, 1952; Pruitt and Jensen, 1955; Jensen et. al., 1970; Jensen, 1972). Rijks and Walker (1968) have demonstrated the application of the method in the tropics.

Potential evapotranspiration was defined by Penman for a well-watered, close-growing grass crop that completely covered the ground. Crop factors that would influence the actual evapotranspiration in relation to potential evapotranspiration include the percent of crop canopy as related to the stage of crop development, the height of the crop and the total transpiring surface of the crop. A close growing crop of grass represents essentially a two dimensional vegetative surface, whereas a sugar cane crop often reaching four meters in height can be considered a three dimensional vegetative surface with more total leaf area than the close growing grass.

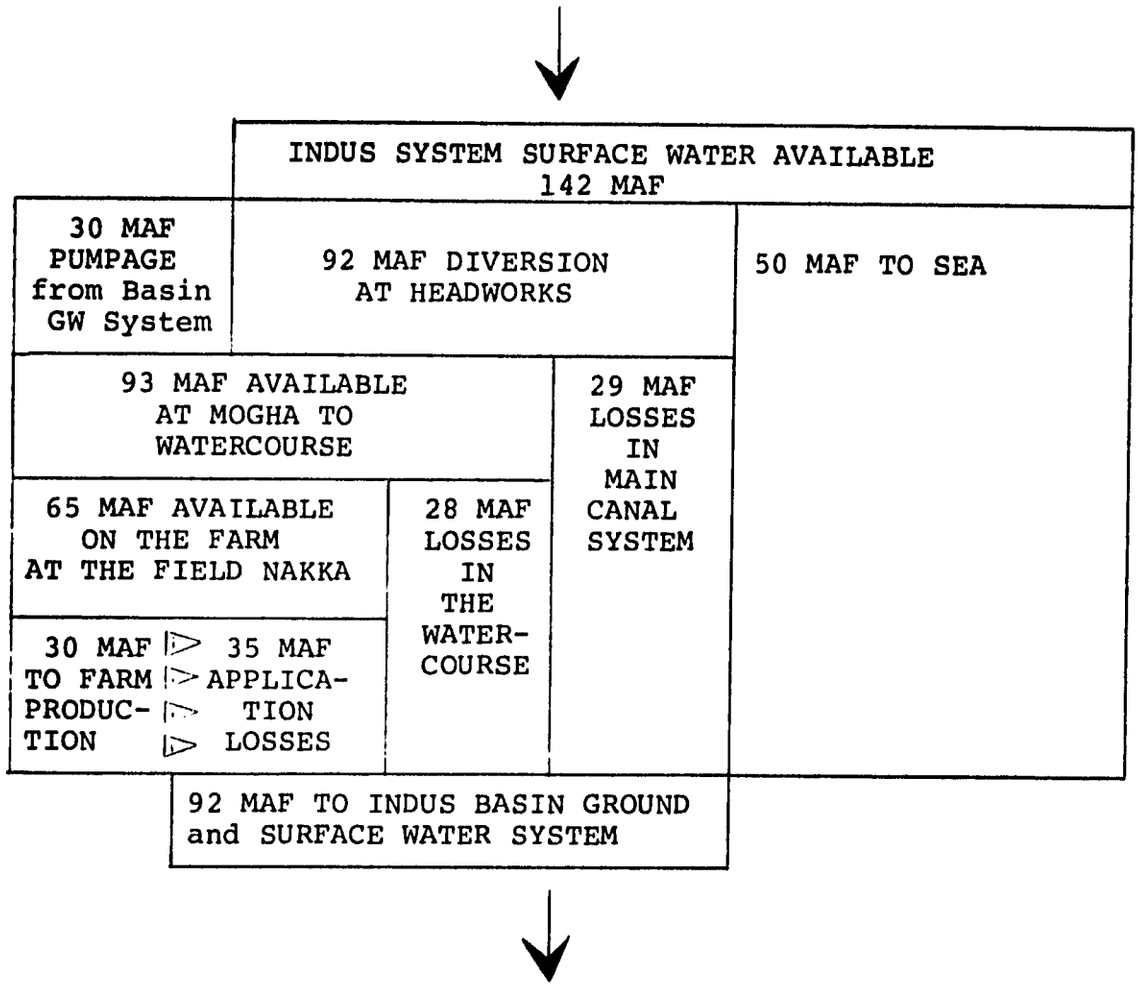
Atmospheric demand is the primary determinant of consumptive water use by plants. The soil condition of water availability and the crop condition of vegetative extent are important modifiers of potential rates to actual evapotranspiration rates. Denmead and Shaw (1962) have shown decreasing actual evapotranspiration with decreasing soil moisture content and increasing potential evapotranspiration. The experiments conducted on corn indicated a range of soil tension of 0.3 bars to 12 bars as the point from which actual evapotranspiration declined from the potential rate. This corresponded to a range of potential evapotranspiration rates of 7.0 to 1.4 millimeters per day, respectively.

The integration of consumptive use data, soil data and atmospheric data is required for adequately predicting crop water use and maintenance of a soil moisture budget. A daily budget is required for detailed monitoring of soil moisture conditions.

II. Water Balance for the Punjab

The publication Pakistan Economic Data (USAID, 1974) provides the estimate that 142 million acre-feet (MAF) of water are available in the Indus River system annually. Of this 92 MAF are diverted into the canal systems of the Punjab and Sind, leaving 50 MAF to go to the sea and other categories of loss. Of the 92 MAF at the canal headworks, 29 MAF are lost in the main canal system before the watercourse mogha. To this 63 MAF available at the watercourse head is added the 30 MAF contributed by the some 120,000 tubewells in the public and private sectors to make 93 MAF available to the watercourse. It has been estimated that 30 percent or 28 MAF of this available amount is lost in delivery in the watercourse between mogha and field nacca. This assumes a

70 percent delivery efficiency. It has also been assumed that on the average 38 percent of the application to the fields has been lost due to over-irrigation of unleveled fields using inefficient irrigation methods. From 93 MAF available, subtraction of 28 MAF to watercourse losses leaves 30 MAF to crop production. It is this 35 MAF lost largely in over-application and at the wrong time that must be considered the target of irrigation scheduling. If the 35 MAF were reduced by 60% to 15 MAF cropping intensity could be raised significantly. These estimates are shown schematically in the following sketch. The position of the dotted line is determined by on farm application efficiency which can be improved through irrigation scheduling, movement in the direction of the arrows makes more water available to production, which can be improved through irrigation scheduling.



Clyma et. al., (1975) have provided a summarization of 112 watercourse loss measurements across the Punjab. These are shown in Table 1. The weighted mean loss value for these measurements was 29.6 percent which is approximately equal to the above estimate of 30 percent delivery losses.

Table 1. Delivery Efficiency Summary

	DE	Number of Cases
Mian Channu	78.3	6
Multan	78.6	18
Shadab	66.5	10
Lyallpur	74.8	44
Mona	68.1	28
Sargodha	60.2	6
Mean	72.4	112

Applicational losses were summarized by Clyma et. al., (1975) as shown in Table 2. These two "on-farm" losses are important contributors to waterlogging. Of this loss, the portion which is a target for reduction by irrigation scheduling is the application loss for which the weighted average value is 70 percent application loss. There is considerable opportunity for improving on farm water applications and the questions of HOW MUCH and WHEN TO APPLY water are directed to cutting this loss.

Table 2. Application Efficiency Summary

	Number of Measurements	Average AE
Wheat 1972/73 & 1973/74 Rabi	14	21.2
Sugarcane 1973 Kharif	25	36.6
Fodder 1973 Kharif	16	31.3
Miscellaneous other crops 1973 Kharif	9	23.3

III. Structure of the Model

A. Daily Moisture Balance

The principal component of this irrigation scheduling program is the maintenance of a daily moisture balance. Daily rainfall records for the current season are used for moisture input. These records are generally available 15-20 days after the end of a month. For any current period for which the data have not been received, the mean values from

a five year historical record of daily values are used temporarily and later replaced by the actual values for that station.

Moisture withdrawal by the plant, actual evapotranspiration (AET) is calculated on a daily basis as the product of Penman potential evapotranspiration (PE) in inches of moisture, times a dimensionless crop coefficient (cc), experimentally determined as the ratio of actual evapotranspiration by a wheat crop to potential evapotranspiration, also times a dimensionless rate of soil moisture (RR) used to represent the rate of evapotranspiration as it depends on the availability of soil moisture. The equation for the actual evapotranspiration prediction is:

$$AET = (PE)(cc)(RR). \tag{1}$$

Penman potential evapotranspiration is calculated from the daily meteorological elements, mean temperature, mean relative humidity, total daily wind run, and the total daily hours of bright sunshine using methodology of Brooker (1967) and Levine (1959). Daily potential day length (PDL) and available radiation at the outer edge of the atmosphere were calculated using the equation provided by Sellers (1965). As was the case for rainfall, mean daily values of computed Penman potential evapotranspiration for five years of record are used in place of actual values until current season data become available.

The basic structure then becomes inflow minus outflow equals change in storage. This uses the rooting zone depth (RD) of soil as a reservoir (CSMS) for storage and withdrawal when the need arises. This reservoir increases in size as the plant grows and the roots extend (INCSMS), provided impediments are not present to limit root proliferation. This moisture budget is updated daily with the final storage value one day (SMSF) becoming the initial value (SMSFO) for the subsequent day. The equation for the soil moisture budget is:

$$SMSF = SMSB - AET + INCSMS \tag{2}$$

To facilitate the utilization and understanding of this information, the problem was formulated on a simplified basis of determining the current moisture status, as of the date of the report, if the last irrigation had been a definite number of weeks previously, assuming that the root zone soil moisture, soil moisture reservoir had been filled at that irrigation. This range of weeks since the last irrigation is one through six weeks. To cover a range of planting dates, nine dates separated by an interval of one week were chosen from November 1 through December 27, to represent a range of planting dates for wheat grown in the Punjab.

Soil conditions were represented by four general textural categories. The soil classes[1] used (coarse, light, medium, and fine) are assumed to influence the rate and depth of root penetration with time. These classes also possess different amounts of soil moisture storage per unit depth as the available soil moisture. Soil moisture storage limits of field capacity with 100 percent available and wilting point with 0 percent available cannot be exceeded.

B. Assumptions

1. Consumptive Use Coefficient

The data on consumptive use of wheat are from a soon to be published report by Haider et. al., (1975). Quartic regression was conducted to provide a continuous relationship with the (consumptive use) crop coefficient (cc) as a function of days from planting. The function obtained is:

$$cc = -.20869 + .019995\ t + 4.004 \times 10^{-5}t^2 - 1.64 \times 10^{-6}t^3 + 4.8 \times 10^{-9}t^4 \quad (3)$$

This function results in negative consumptive use coefficients for less than 10 days, and at this early stage only the soil is contributing to evapotranspiration. Therefore, a short linear segment is assumed from t = 0 with a cc intercept of .05 to cc = .08 at 15 days. This relationship is:

$$cc = .05 + .002t \quad (4)$$

For the time interval of less than 15 days after planting, equation (4) was used, for 15 days and over the quartic function equation (3) was applied. The relationships used in programming are shown in Figure 1.

2. Available Soil Moisture

The soil texture at a particular site determines the root zone soil moisture storage capacity. In volumetric units, this is expressed as inches of moisture available per foot of soil depth over a given area. Zaidi et. al., (1970) presented experimentally determined values of available soil moisture for a cross section of soils in the upper Indus Basin. The mean values of available soil moisture in Table 3 represent the four soil classes in the irrigation scheduling program.

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[1]Classes represented the following textures: coarse-loamy sand, light-sandy loam, medium-silt loam and loam, fine-clay loam, silty clay loam, and silty clay.

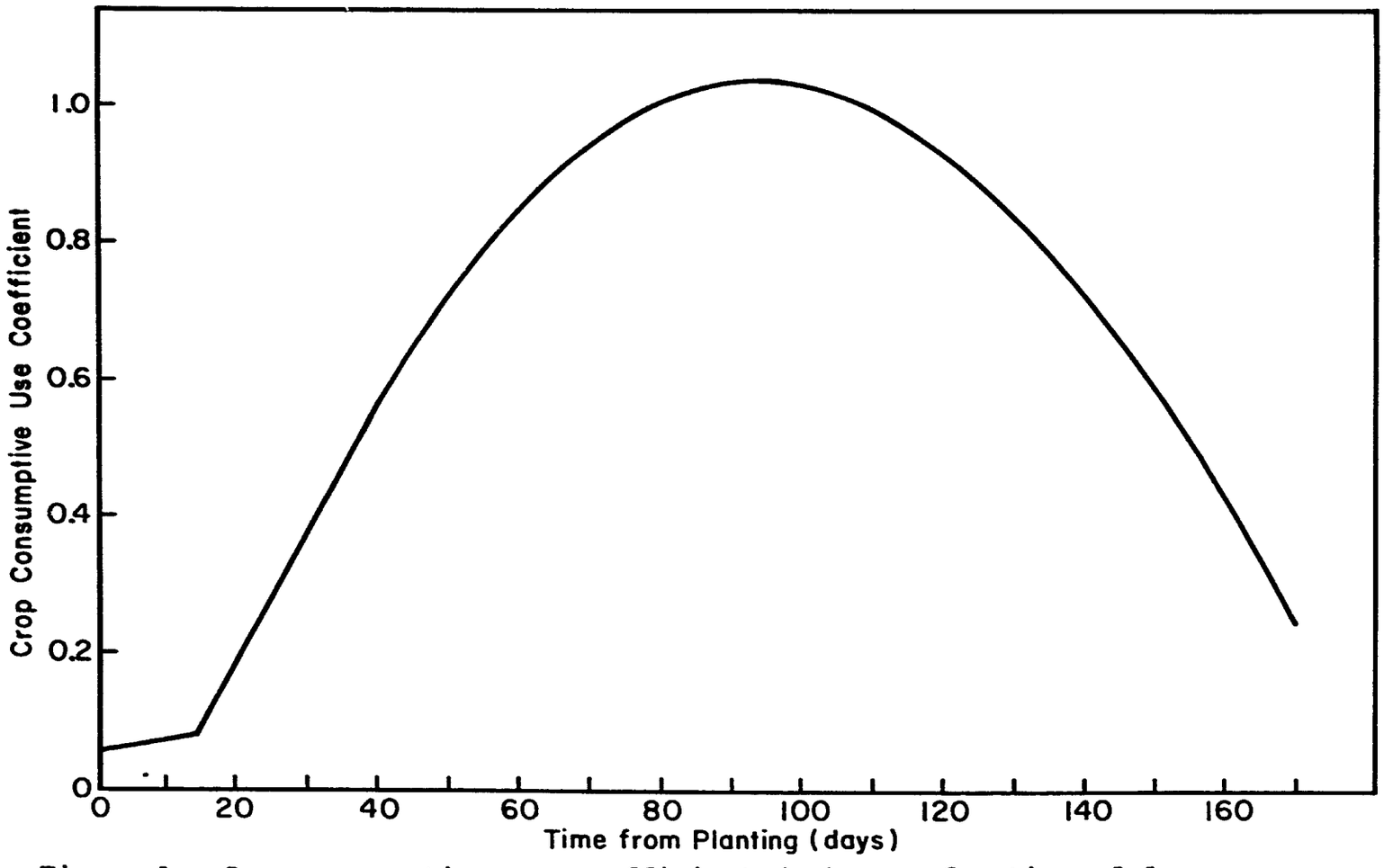


Figure 1. Crop consumptive use coefficient (cc) as a function of days from planting.

Table 3. Mean Values of Available Soil Moisture

CLASS	TEXTURES	AVAILABLE MOISTURE
Coarse	loamy sand	0.8 in/ft
Light	sandy loam	1.4 in/ft
Medium	loam, silt loam	1.9 in/ft
Fine	clay loam, silty clay loam, silty clay	2.4 in/ft

3. Soil Moisture Depletion

The relationship between available soil moisture and relative rate of evapotranspiration is taken as a curvilinear relationship which closely follows the potential rate of low moisture tension, gradually declines with increased tension and steeply declines as the wilting percentage is approached. Minhas et. al., (1974) has recommended a family of exponential functions to conveniently represent this relationship as follows:

$$RR = \frac{1 - e^{-3x}}{1 - 2e^{-3\underline{x}} + e^{-3x}} \qquad (5)$$

RR is the dimensionless rate of removal which ranges from zero to one, x is the current available moisture in the root zone and $\underline{X}$ is the soil moisture storage capacity of the root zone at the given stage of growth.

As an example, the relative rate of evapotranspiration--hence, rate of removal--is plotted versus the available soil moisture for a 2 inch storage capacity in Figure 2.

4. Rooting Depth with Time

The root zone-soil moisture reservoir for the wheat crop expands with time. Erie et.al.,(1968) provided seasonal profiles of total soil moisture depletion for irrigated wheat at Mesa, Arizona which showed 95 percent of moisture used came from the top 5 feet of soil. Jean and Weaver (1924) detailed the rooting depth and crop yield of wheat under irrigation at Greeley, Colorado by extensive root system examination. At 6 weeks the rooting depth was 1.5 feet, at 11 weeks rooting depth was 4.5 feet for fully irrigated sandy soil and 3.25 feet for lightly irrigated clayey soil at maturity rooting depth was 4.5 feet for both the lightly irrigated clayey soil and fully irrigated sandy soil. Nitrogen contents of the soil layers affected the rooting depth with time as did the irrigation regime. A rooting depth of 3 to 5 feet was suggested for wheat grown in South Asia by the Water Management Division, 1971.

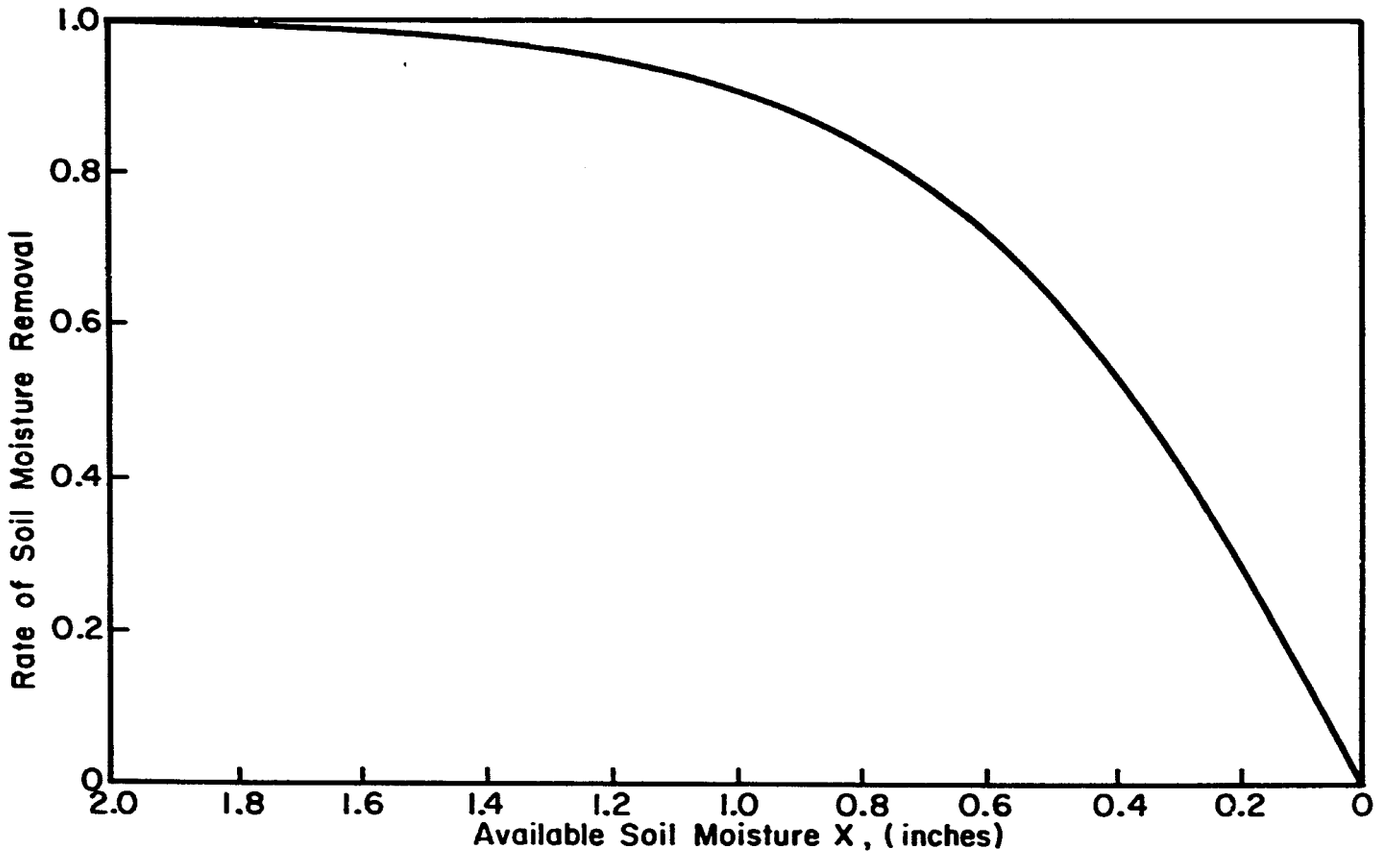


Figure 2. Assumed rate of soil moisture removal as function of available soil moisture, $RR = \frac{1 - e^{-3x}}{1 - 2e^{-3x} + e} - 3x$, where X is the soil moisture storage capacity.

With this minimal information a quadratic rooting depth with time function for wheat was chosen with different maximum rooting depth value for each soil textural class. The assumption is that the roots will proliferate to a greater depth in coarser soils. The functions are assumed to reach a peak depth value when the maximum consumptive use coefficient is attained at 93 days from planting. For coarse soil the maximum depth is assumed to be 5 feet, for light soil 4.5, for medium soil 4.0, and for fine soil 3.5 feet. The functions are shown in Figure 3.

5. Growing Season and Crop Growth Stage

The crop growth stages assumed with respect to the growing season are shown in Figure 4. The booting stage of growth is initiated as a photo-periodic response regardless of the date of planting within certain limits. The important variable is the length of the tillering stage, Qureshi (1975). The yield decline due to late planting is thus attributed to the tiller population.

Detailed field examination of the water requirements of wheat with respect to growth stage for South Asian planting and irrigation practices has shown two stages at which moisture depletion should not exceed 25 percent of the available moisture. These are the tillering stage and the floral initiation stage. The early tillering stage is important due to the practice of applying a pre-sowing irrigation (rauni) and waiting for the proper moisture condition (wattar) before sowing. At other stages of growth, 60 to 75 percent depletion is allowable without appreciable yield loss, (Water Management Division, 1971).

Within the framework of this scheduling model and in terms of percent moisture depletion, the results of looking backward at 1-6 weeks of depletion since the last irrigation are compared to the current phenological stage to obtain the allowable depletion. Whether irrigation is recommended and the amount of irrigation required are determined with respect to the allowable depletion for the current stage.

C. Input Data

Meteorological data on a daily basis from the Regional Meteorological Centre at Lahore, the Punjab Agricultural Research Institute and the Nuclear Institute for Agriculture and Biology are used. The information is placed on Hollerith cards and includes, precipitation, class A pan evaporation, hours of bright sunshine, total wind run, mean temperature and mean relative humidity.

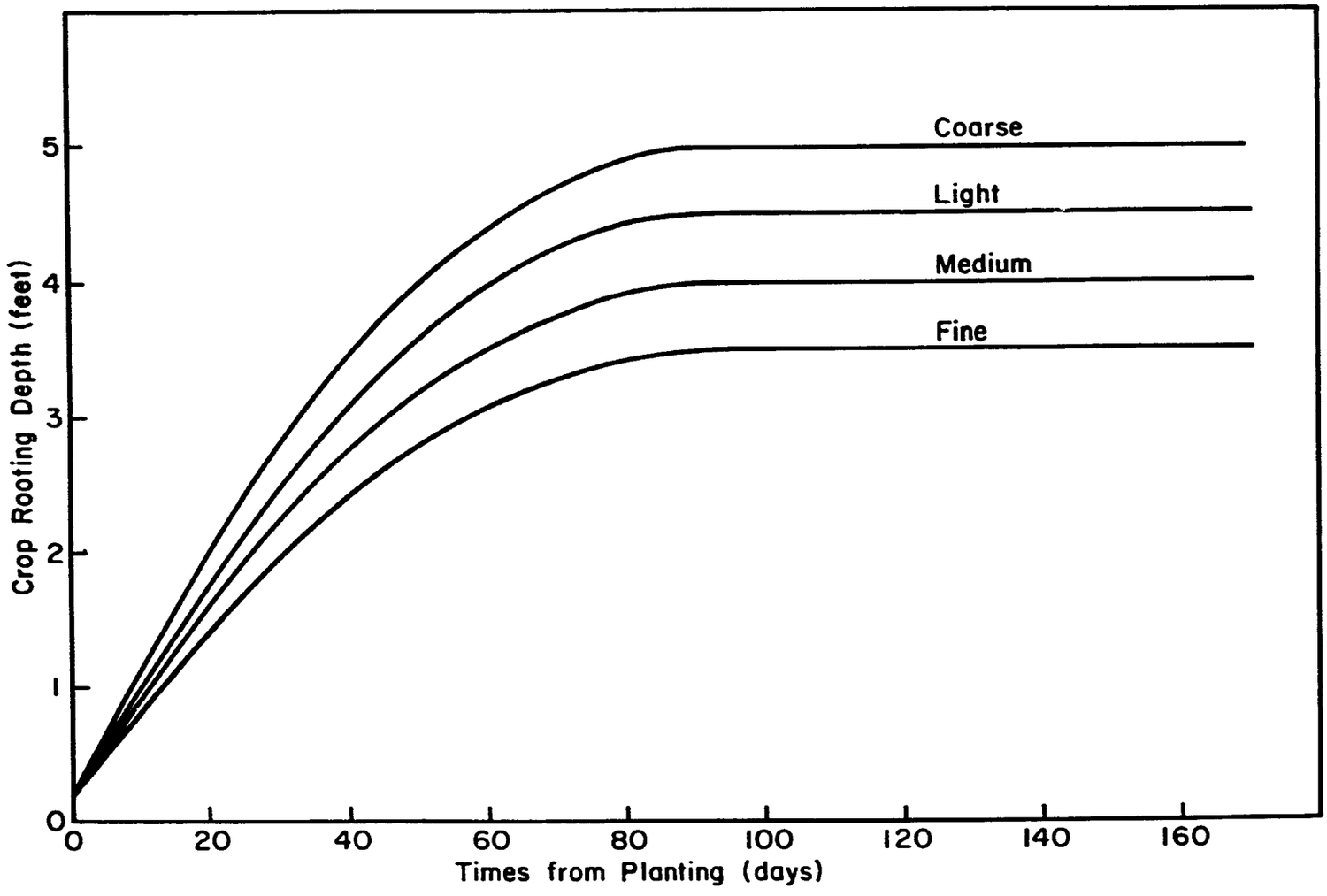


Figure 3. Assumed crop rooting depth (RD) as a function of days from planting for four soil classes.

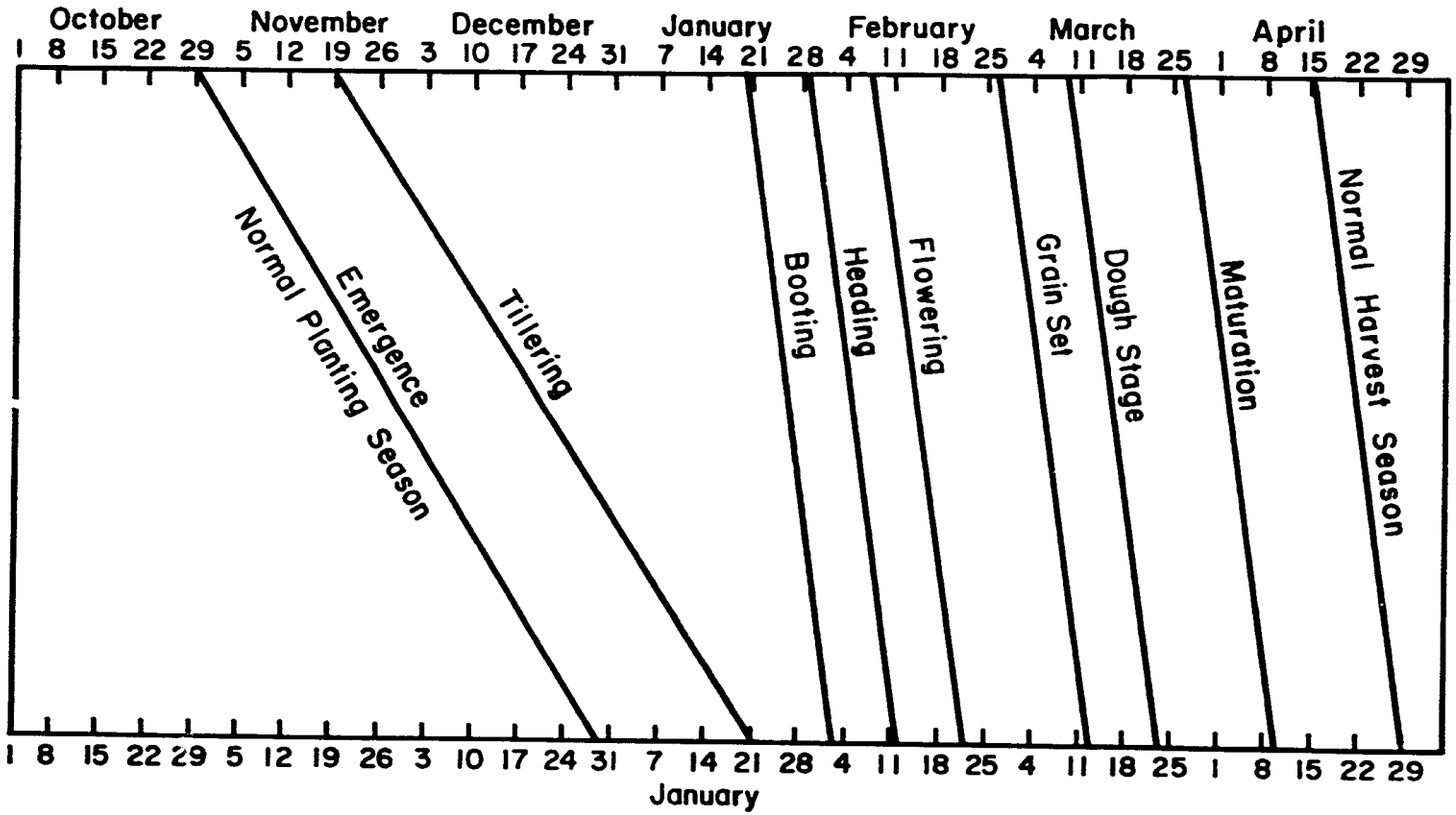


Figure 4. Assumed structure of the Rabi wheat growing season for the Punjab.

D. Computation

A computer program was written in the Fortran IV language to make the computations at the middle and end of each month starting in at the end of January.

The computations include daily moisture extraction from one to six weeks previous carried forward to the current date. Nine planting dates from November 1, to December 27, at one week intervals, give 9 ages of crop at the current computational stage. Six locations and four soil classes in conjunction with the 6 weeks and nine planting dates gives you 1296 combinations of result at one date of calculation.

The computer program listing is provided in detail in Appendix I. A complete list of symbols and definitions are provided in Appendix II. Figure 5 provides the essential structure of the irrigation scheduling program. This flow chart indicates the sequence of computations and the logical steps used to test results within the program. Appendix III provides the detailed flow chart for the computation of Penman potential evapotranspiration and actual evapotranspiration, as used in equation (1).

The amount of irrigation required to replenish the depleted storage is calculated using an assumed irrigation efficiency. The amount required is the amount needed in the root zone reservoir divided by the irrigation application efficiency as a decimal fraction. Appendix IV provides a detailed flow chart of the moisture budget as calculated daily, using equation (2).

A sample of the computer output is provided in Appendix V for Lahore region, loamy sand soil class, crop planted from the first of November to the 27th of December for moisture depletion 1 to 6 weeks previous to January 31. Appendix VI includes a sample irrigation scheduling report for the Lahore region. This report could be applied to that surrounding district or region as a guide to irrigation.

IV. Utilization

A. Basic Information Now Available

Considering the many types of data which are available for transfer from research centers around the world, consumptive use data, when expressed as a dimensionless ratio of actual evapotranspiration to some acceptable measure or predictor of potential evapotranspiration is perhaps one of the most utilizable and transferable types of information available for use in developing countries. Many locations throughout the developed and developing countries have had

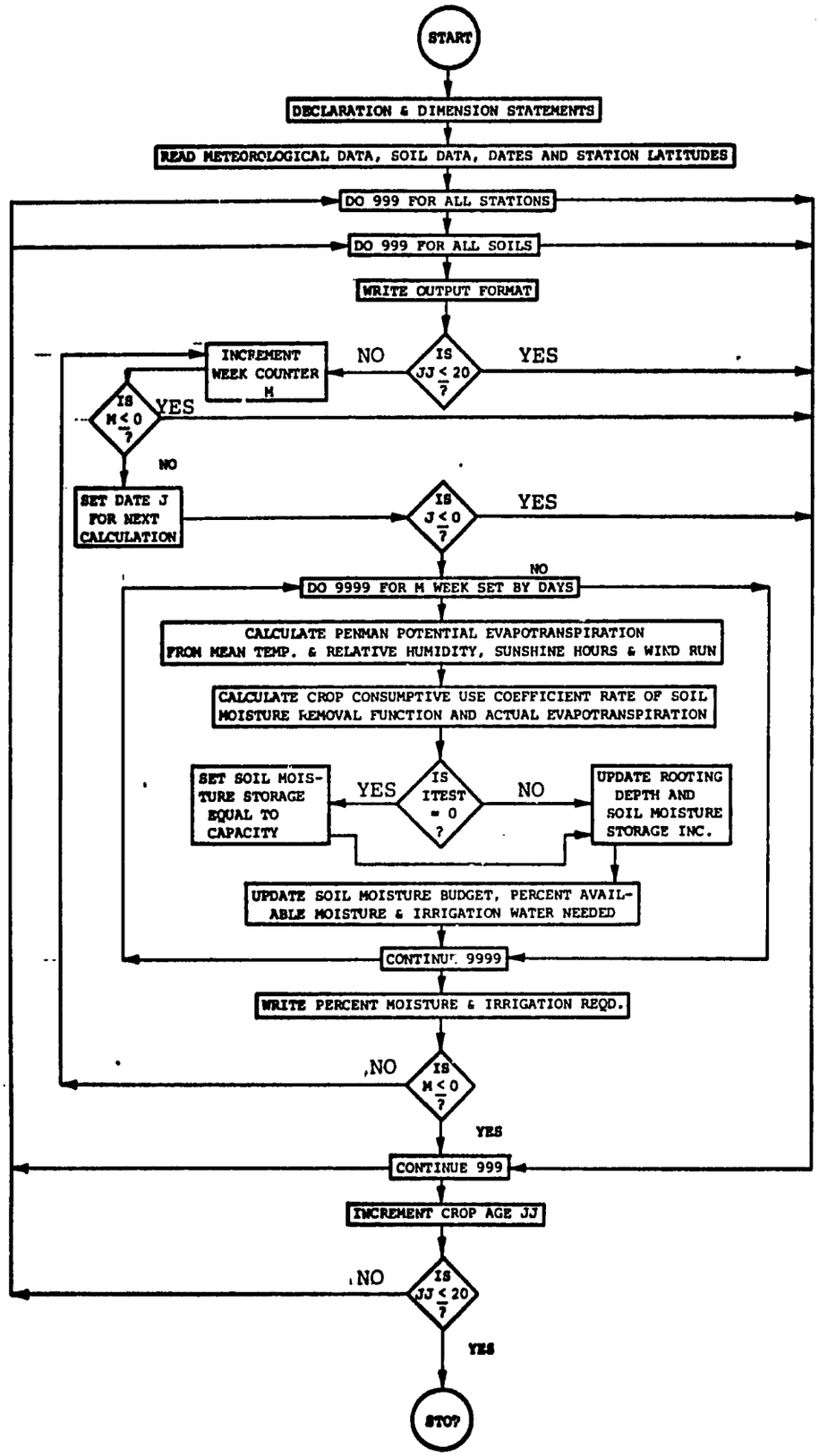


Figure 5. Flow Chart for Irrigation Scheduling Program.

good quality consumptive use studies conducted for a wide range of crops. This information need not be developed for every new location or for every new variety that appears on the scene in the developing nations. Expressed as a ratio of ET:actual ET:potential as a function of the stage of growth or of the actual days from planting, this information can guide system operation or even more crudely expressed as ET_{actual} with time for a location which has similar meteorological characteristics of radiation, percent of cloud cover, wind exposure, relative humidity, and mean temperature, these data are readily available to the project planner and to the system operator whose responsibility is the delivery of water to the farmer. The operational factors which must be developed are: (1) the maintenance of an inventory of the crop mix grown in an area, (2) the general mix of growth stages of all crops throughout the season, and (3) the utilization of the existing network of meteorological instruments or extension of a network as simple as sets consisting of a nonrecording raingage and a Class A evaporation pan. With a general range of known delivery efficiencies, from the Mogha to the field Nakka, and actual application efficiencies of irrigation methods in common practice; with a known mix of soil types in a canal command area and the corresponding physical and soil moisture retention properties, and the general knowledge of the crop rooting depth with time relationship as effected by soil type and previous moisture availability, the quantity and timing of irrigation can be predicted with reasonable certainty.

Numerous examples of crop consumptive use studies can be found in the crop and water science literature of Pakistan. Numerous attempts have been made to demonstrate the applicability of the many predictors of potential evapotranspiration. These are also available in the respective literature sources in Pakistan. A major consumptive use project for all the major crops at a large number of research stations is currently in progress. However, the planner and irrigation system operators need not wait for this information to become available, as the state of consumptive use knowledge is sufficient to provide predictions which are more precise than the quantities of water which are now being applied, even in a quantitative sense of light, medium or heavy irrigations that farmers recognize as discernible differences.

B. Testing

As an emergency measure an irrigation scheduling program can be utilized for water savings. For implementation, however, the methodology must have rigorous testing in a field situation before release. Common utilization requires updated soil moisture information for checks against the predicted values.

Two trials of irrigation scheduling were conducted in farmer demonstration plots near Lahore and near Multan. This project was specially funded, water management project with the Integrated Rural Development Program of the Punjab. In each location the demonstration plots were divided with half managed as a control by the farmer, according to his traditional practice. The second half had irrigation applications scheduled based on net potential atmospheric demand guided by soil moisture depletion measurements. At each site a Class A evaporation pan and a 5 inch non-recording rain gauge were installed to guide irrigation. For each irrigation period the summation of rainfall is subtracted from the summation of pan evaporation to provide an estimate of net potential atmospheric demand for water.

The experimental plots were precisely leveled before seeding. Water applications were measured on the two plots using cutthroat flumes. Soil moisture deficiencies were determined gravimetrically. Irrigation evaluations were conducted to determine the irrigation efficiency. The work has been expanded to a cotton crop at the Agricultural Extension and Farmers Training Center near Mian Channu.

Initial results indicate that soil moisture depletion analysis and a Class A pan evaporation for wheat are highly correlated. One preliminary conclusion would be that the Class A pan might perform as a very inexpensive yet effective irrigation scheduling tool for wheat in Pakistan's Punjab. Further results on correlations of simple prediction methods are forthcoming.

C. Limitations

The methodology is limited by the many assumptions made. Of particular importance is the limitation placed on the method by the lack of information about the crop rooting depth with time and the nature of the functional relationship between rate of evapotranspiration and the available soil moisture. The general nature of the utilized soil classes limits the moisture storage relationships to those specific soil types which were reported. The consumptive use data used are limited to the results of a one year determination. Data gaps have been filled with additional assumptions.

D. Extension to Other Crops

The extension of the method to other crops requires a detailed data base of crop information. The ratio of crop consumptive use to potential evapotranspiration is a primary requirement. The critical stages of crop growth for moisture depletion and levels to which depletion is allowed are important to know. The crop rooting depth with time is an important relationship which must be determined for the

included crops. Much of this data is already available from Pakistani and International literature sources and needs only to be drawn into a compiled unit.

E. Institutional Requirements

Irrigation scheduling for crop production in Pakistan will not be accepted immediately. Farmers must become aware of the water losses and of the advantages of water saving in monetary terms before accepting such a program. A simple format such as this irrigation scheduling report which uses weeks since the last irrigation for a given location, crop, planting date, and soil type could be used by the Agricultural Extension Service or a hypothetical Irrigation Extension Service as a guide to farmers. Weekly distribution of these reports to extension personnel at district level or by radio broadcast are possible means of getting information to farmers.

It should be mentioned that the existing weekly structure of the irrigation reports has the advantage of fitting the waribundi schedule of weekly water delivery. For water available on demand such as for farmers with private tubewells the added sophistication of daily report basis can be easily added to the program.

For the old line departments which deal directly with the farmers, and the newly created government corporations whose purpose is to deliver inputs to the farmer, an entirely new concept of service must be developed. The service must be delivered by the government employee to the farmer without remuneration, not the self service of special privilege of the past.

For these institutions to provide more services to farmers more personnel must be stationed at the field level, and the field personnel must have better and more intensive training in order to answer questions and tackle problems of constantly increasing difficulty. For existing field personnel this means intensive inservice training to upgrade skills to the level of an agriculture which continually becomes more sophisticated as production levels are increased.

Personnel with specific technical skills or specialities must be stationed at a level such as the tehsil, upon whom the regular extension service worker can call to help answer specific problems. This technical team at the tehsil level should include specialists on soils, agronomy, water management, plant protection, and animal husbandry as a minimum. These personnel must be fully mobile, and must answer calls from their farmer cliental. The personnel on this technical staff must have instant communication with the agricultural research institutes and crops research stations in order to solve new problems as they arise.

The training of agricultural extension specialists as well as generalists must be upgraded beginning at the specific subject matter departments in the under graduate educational programs at the agricultural universities. Specific training on special topics can be conducted through the short course institute at the agricultural universities under the division of education and extension. In service training for specific skills acquisition for the field level worker is best accomplished in vocational training institutes in the respective districts. Each district training staff must be developed with specific capabilities as trainers and teachers. The district training staff should be continuously used to rotate all field personnel through the institute at least twice per year. The training institute staff should have as an additional responsibility, the evaluation of each field workers communicative performance with his farmer cliental. The effort should be made to continually upgrade extension services.

Pakistan's main need in making practical use of the readily available irrigation scheduling technology which is at hand in Pakistan is a delivery vehicle which can help, train and educate farmers to schedule irrigations according to crop and soil needs. This delivery vehicle is an advisory service or extension service which has first hand, frequent contact with farmers. A second main need is a communication network which can link the irrigation schedulers with the irrigation control operators, the field extension workers, the farmers, and research institutes in meaningful two way communication. A third need is the operational network of simple meteorological devices widely spread over each canal command area. A fourth need is a data processing and decision making structure which can provide the recommendations for scientific irrigation scheduling. And a final important need is a research establishment with a finely tuned ear and a research program adapted to the needs of the irrigation scheduling establishment.

V. Conclusions

A computer program for irrigation scheduling has been devised for wheat grown in the Punjab. Intensive testing is required to prove the method. The extension of the methodology to other crops appears to be feasible if data is available for the necessary program inputs. If farmers are made aware of the need to improve their water management and can substitute management for the excess water used, irrigation scheduling will provide practical answers to When? and How Much to Irrigate? and provide economic returns from increased crop yields and greater cropping intensity from the water saved. The real limiting factor in this type of program is a delivery vehicle to provide this information to the farmer. Pakistan has the scientists, computers and

departmental infrastructure to schedule irrigations scientifically, but lacks an effective extension service to deliver the information to the farmer.

Appendix I. Program Listing

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

C  IRRIGATION SCHEDULING PROGRAM 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(1,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(1,102)  JJ,LL,CTC,(PHI(I),I=1,6)
  102 FORMAT(313,6F5.2)
      WRITE(3,105)
  105 FORMAT(1H1,25X,45HIRRIGATION SCHEDULING REPORT FOR RABI 1974/75,//
     1/,39X,16HFEBRUARY 28,1975,////)
C  CALCULATE SOIL MOISTURE DEPLETION FOR 6 LOCATIONS AND 4 SOIL TYPES AND 9 PLANT
C  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,13,5X,11H SOIL TYPE ,13,18H CURRENT CROP A
     2GE ,13)
      IF(JJ.LT.20)  GO TO 999
      M = 7
  888 M=M-1
      IF(M.LE.0)  GO TO 999
```

Appendix I (Continued)

```
      MM=7-M
      L=LL-((7)*(MM))
      J=JJ-((7)*(MM))
      IF(J.LE.0)  Go TO 999
      LJ=L-J
C CALCULATE SOIL MOISTURE DEPLETION FOR ONE TO SIX WEEKS SINCE LAST IRRIGATION
C 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.)  GO TO 556
      TCELS=TEMP(I,N)
      TRANK=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 336
  334 Z=1.E-10
  335 HRAD=ATAN((SQRT(1.-Z**2.))/Z)
  336 H=ABS(HRAD/(0.0174532925))
      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)
```

Appendix I (Continued)

```
      IF(SS(I,N).GE.O.O)  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(I,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*(U2))*(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.*SMSB)-2.*EXP(-3.*CSMS))
      IF(J.GT.14)  GO TO 602
      CC=.05+.002*(J)
      GO TO 603
  602 CC=-.20869+.019995*(J)  +.00004004*(J)**2  -.00000164*(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
```

Appendix I (Continued)

```
      SMSF=CSMS
 1200 IF(SMSF.GT.0.0)  GO TO 128
      SMSF=0.0
  128 SMSB=SMSF
      PERCNT =100.*(SMSF)/(CSMS)
      WATER=(CSMS-SMSF)/(.5)
 9999 CONTINUE
      WRITE(3,104)  MM,PERCNT ,WATER
  104 FORMAT(5X,29H WEEKS SINCE LAST IRRIGATION ,I5,5X,28H PERCENT MOIS-
      TURE AVAILABLE ,F5.1,5X,25H IRRIGATION WATER NEEDED ,F5.1)
      PERCENT=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
```

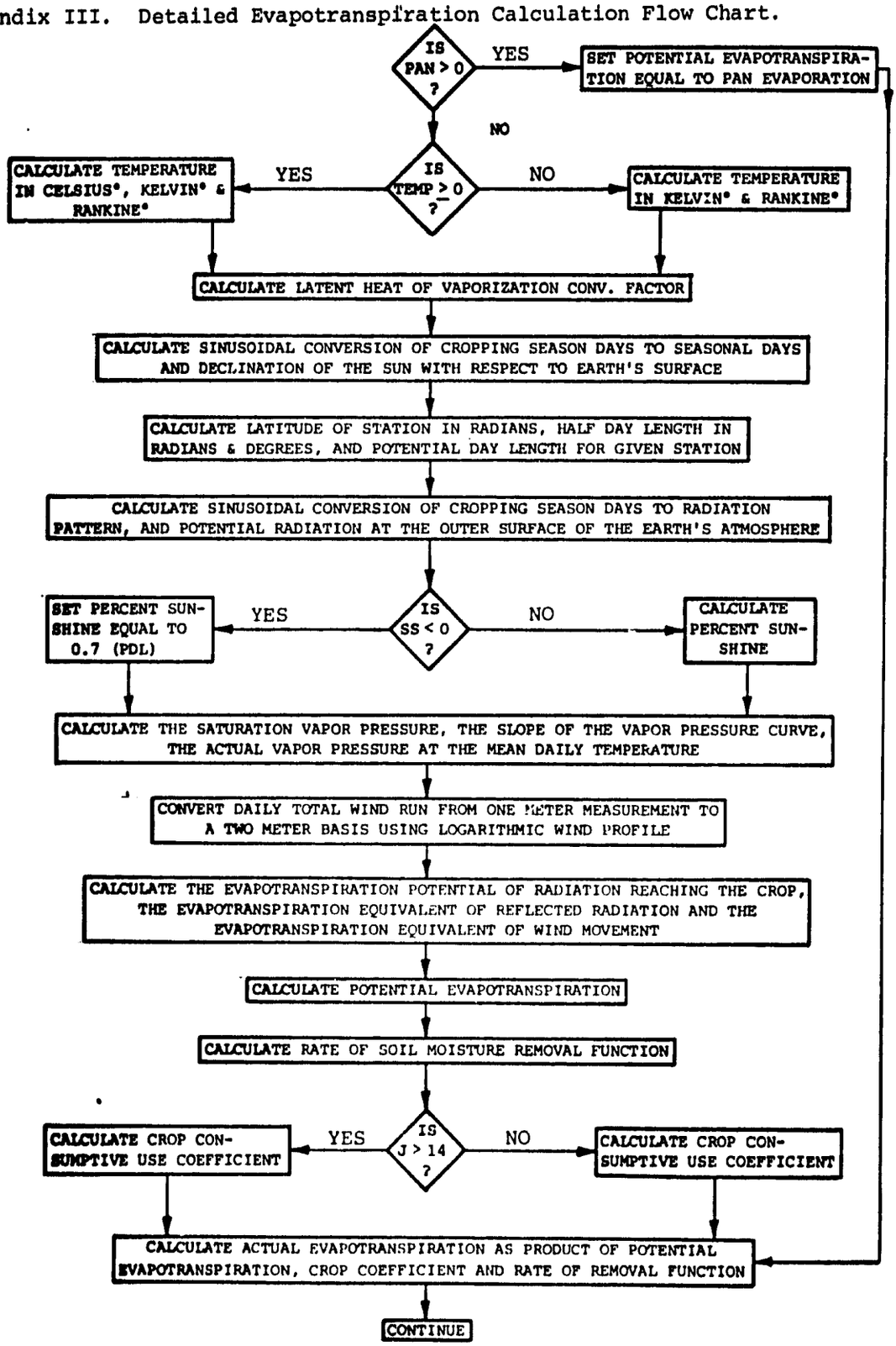
Appendix II. List of Symbols

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
J1	- 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, degrees C or degrees 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
SMSB	- Initial value for soil moisture storage for a given day, 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

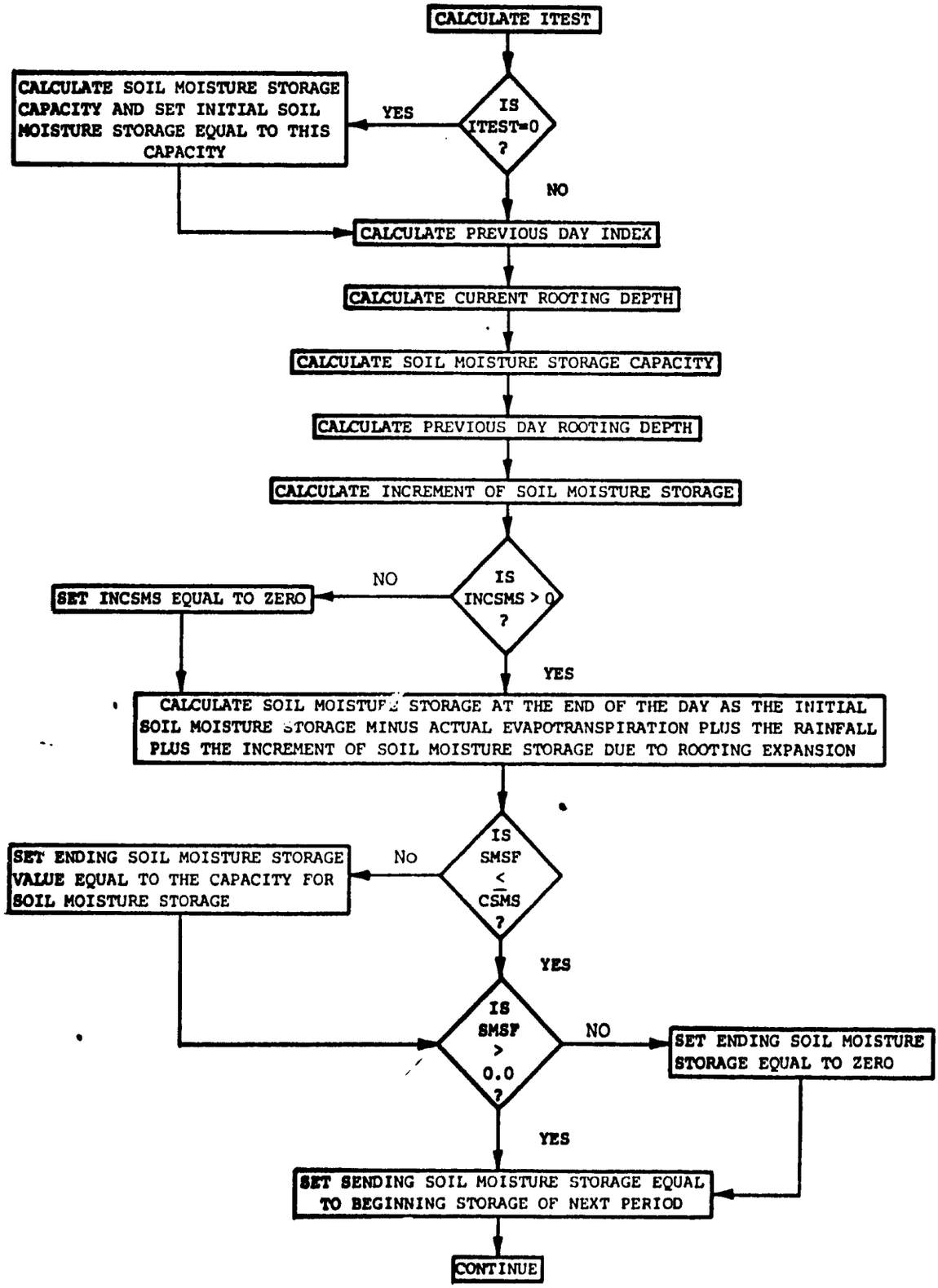
Appendix II. (Continued)

Z	- Intermediate computational value used in calculation half dry 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
X	- Latitude of meteorological station 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
TCELS	- 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 logarithmic 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 III. Detailed Evapotranspiration Calculation Flow Chart.



Appendix IV. Detailed Moisture Budget Flow Chart



Appendix V. Computer Output

IRRIGATION SCHEDULING REPORT FOR RABI 1974/75
January 31, 1975

LOCATION 4 , SOIL TYPE 1 , CURRENT CROP AGE 92,
WEEKS SINCE LAST IRRIGATION 1 PERCENT MOISTURE AVAILABLE 76.9 IRRIGATION WATER NEEDED 1.8
WEEKS SINCE LAST IRRIGATION 2 PERCENT MOISTURE AVAILABLE 65.9 IRRIGATION WATER NEEDED 2.7
WEEKS SINCE LAST IRRIGATION 3 PERCENT MOISTURE AVAILABLE 55.7 IRRIGATION WATER NEEDED 3.5
WEEKS SINCE LAST IRRIGATION 4 PERCENT MOISTURE AVAILABLE 44.7 IRRIGATION WATER NEEDED 4.4
WEEKS SINCE LAST IRRIGATION 5 PERCENT MOISTURE AVAILABLE 37.5 IRRIGATION WATER NEEDED 5.0
WEEKS SINCE LAST IRRIGATION 6 PERCENT MOISTURE AVAILABLE 32.1 IRRIGATION WATER NEEDED 5.4

LOCATION 4 , SOIL TYPE 1 , CURRENT CROP AGE 85,
WEEKS SINCE LAST IRRIGATION 1 PERCENT MOISTURE AVAILABLE 77.4 IRRIGATION WATER NEEDED 1.8
WEEKS SINCE LAST IRRIGATION 2 PERCENT MOISTURE AVAILABLE 67.0 IRRIGATION WATER NEEDED 2.6
WEEKS SINCE LAST IRRIGATION 3 PERCENT MOISTURE AVAILABLE 57.4 IRRIGATION WATER NEEDED 3.4
WEEKS SINCE LAST IRRIGATION 4 PERCENT MOISTURE AVAILABLE 47.2 IRRIGATION WATER NEEDED 4.2
WEEKS SINCE LAST IRRIGATION 5 PERCENT MOISTURE AVAILABLE 40.4 IRRIGATION WATER NEEDED 4.7
WEEKS SINCE LAST IRRIGATION 6 PERCENT MOISTURE AVAILABLE 35.6 IRRIGATION WATER NEEDED 5.1

LOCATION 4 , SOIL TYPE 1 , CURRENT CROP AGE 78,
WEEKS SINCE LAST IRRIGATION 1 PERCENT MOISTURE AVAILABLE 78.1 IRRIGATION WATER NEEDED 1.7
WEEKS SINCE LAST IRRIGATION 2 PERCENT MOISTURE AVAILABLE 68.4 IRRIGATION WATER NEEDED 2.5
WEEKS SINCE LAST IRRIGATION 3 PERCENT MOISTURE AVAILABLE 59.5 IRRIGATION WATER NEEDED 3.2
WEEKS SINCE LAST IRRIGATION 4 PERCENT MOISTURE AVAILABLE 50.2 IRRIGATION WATER NEEDED 3.9
WEEKS SINCE LAST IRRIGATION 5 PERCENT MOISTURE AVAILABLE 43.9 IRRIGATION WATER NEEDED 4.4
WEEKS SINCE LAST IRRIGATION 6 PERCENT MOISTURE AVAILABLE 39.8 IRRIGATION WATER NEEDED 4.7

LOCATION 4 , SOIL TYPE 1 , CURRENT CROP AGE 71,
WEEKS SINCE LAST IRRIGATION 1 PERCENT MOISTURE AVAILABLE 79.0 IRRIGATION WATER NEEDED 1.6
WEEKS SINCE LAST IRRIGATION 2 PERCENT MOISTURE AVAILABLE 70.2 IRRIGATION WATER NEEDED 2.3
WEEKS SINCE LAST IRRIGATION 3 PERCENT MOISTURE AVAILABLE 62.1 IRRIGATION WATER NEEDED 2.9
WEEKS SINCE LAST IRRIGATION 4 PERCENT MOISTURE AVAILABLE 53.7 IRRIGATION WATER NEEDED 3.5
WEEKS SINCE LAST IRRIGATION 5 PERCENT MOISTURE AVAILABLE 48.0 IRRIGATION WATER NEEDED 3.9
WEEKS SINCE LAST IRRIGATION 6 PERCENT MOISTURE AVAILABLE 44.7 IRRIGATION WATER NEEDED 4.2

Appendix V. (Continued)

LOCATION 4 , SOIL TYPE 1 , CURRENT CROP AGE 64,
WEEKS SINCE LAST IRRIGATION 1 PERCENT MOISTURE AVAILABLE 80.1 IRRIGATION WATER NEEDED 1.4
WEEKS SINCE LAST IRRIGATION 2 PERCENT MOISTURE AVAILABLE 72.5 IRRIGATION WATER NEEDED 2.0
WEEKS SINCE LAST IRRIGATION 3 PERCENT MOISTURE AVAILABLE 65.1 IRRIGATION WATER NEEDED 2.5
WEEKS SINCE LAST IRRIGATION 4 PERCENT MOISTURE AVAILABLE 57.7 IRRIGATION WATER NEEDED 3.1
WEEKS SINCE LAST IRRIGATION 5 PERCENT MOISTURE AVAILABLE 53.0 IRRIGATION WATER NEEDED 3.4
WEEKS SINCE LAST IRRIGATION 6 PERCENT MOISTURE AVAILABLE 50.5 IRRIGATION WATER NEEDED 3.6

LOCATION 4 , SOIL TYPE 1 , CURRENT CROP AGE 57,
WEEKS SINCE LAST IRRIGATION 1 PERCENT MOISTURE AVAILABLE 81.5 IRRIGATION WATER NEEDED 1.3
WEEKS SINCE LAST IRRIGATION 2 PERCENT MOISTURE AVAILABLE 75.3 IRRIGATION WATER NEEDED 1.7
WEEKS SINCE LAST IRRIGATION 3 PERCENT MOISTURE AVAILABLE 68.6 IRRIGATION WATER NEEDED 2.1
WEEKS SINCE LAST IRRIGATION 4 PERCENT MOISTURE AVAILABLE 62.5 IRRIGATION WATER NEEDED 2.6
WEEKS SINCE LAST IRRIGATION 5 PERCENT MOISTURE AVAILABLE 59.0 IRRIGATION WATER NEEDED 2.8
WEEKS SINCE LAST IRRIGATION 6 PERCENT MOISTURE AVAILABLE 57.5 IRRIGATION WATER NEEDED 2.9

LOCATION 4 ,SOIL TYPE 1 , CURRENT CROP AGE 50,
WEEKS SINCE LAST IRRIGATION 1 PERCENT MOISTURE AVAILABLE 83.3 IRRIGATION WATER NEEDED 1.1
WEEKS SINCE LAST IRRIGATION 2 PERCENT MOISTURE AVAILABLE 78.2 IRRIGATION WATER NEEDED 1.4
WEEKS SINCE LAST IRRIGATION 3 PERCENT MOISTURE AVAILABLE 73.1 IRRIGATION WATER NEEDED 1.7
WEEKS SINCE LAST IRRIGATION 4 PERCENT MOISTURE AVAILABLE 68.5 IRRIGATION WATER NEEDED 2.0
WEEKS SINCE LAST IRRIGATION 5 PERCENT MOISTURE AVAILABLE 66.3 IRRIGATION WATER NEEDED 2.1
WEEKS SINCE LAST IRRIGATION 6 PERCENT MOISTURE AVAILABLE 65.6 IRRIGATION WATER NEEDED 2.2

LOCATION 4 , SOIL TYPE 1 , CURRENT CROP AGE 43,
WEEKS SINCE LAST IRRIGATION 1 PERCENT MOISTURE AVAILABLE 85.7 IRRIGATION WATER NEEDED 0.8
WEEKS SINCE LAST IRRIGATION 2 PERCENT MOISTURE AVAILABLE 81.6 IRRIGATION WATER NEEDED 1.1
WEEKS SINCE LAST IRRIGATION 3 PERCENT MOISTURE AVAILABLE 78.8 IRRIGATION WATER NEEDED 1.2
WEEKS SINCE LAST IRRIGATION 4 PERCENT MOISTURE AVAILABLE 76.0 IRRIGATION WATER NEEDED 1.4
WEEKS SINCE LAST IRRIGATION 5 PERCENT MOISTURE AVAILABLE 75.0 IRRIGATION WATER NEEDED 1.4
WEEKS SINCE LAST IRRIGATION 6 PERCENT MOISTURE AVAILABLE 74.5 IRRIGATION WATER NEEDED 1.5

Appendix V. (Continued)

LOCATION 4 , SOIL TYPE 1 , CURRENT CROP AGE 36,

WEEKS SINCE LAST IRRIGATION	1	PERCENT MOISTURE AVAILABLE	88.2	IRRIGATION WATER NEEDED	0.6
WEEKS SINCE LAST IRRIGATION	2	PERCENT MOISTURE AVAILABLE	84.6	IRRIGATION WATER NEEDED	0.8
WEEKS SINCE LAST IRRIGATION	3	PERCENT MOISTURE AVAILABLE	84.6	IRRIGATION WATER NEEDED	0.8
WEEKS SINCE LAST IRRIGATION	4	PERCENT MOISTURE AVAILABLE	84.6	IRRIGATION WATER NEEDED	0.8
WEEKS SINCE LAST IRRIGATION	5	PERCENT MOISTURE AVAILABLE	84.2	IRRIGATION WATER NEEDED	0.8
WEEKS SINCE LAST IRRIGATION		PERCENT MOISTURE AVAILABLE		IRRIGATION WATER NEEDED	

Appendix VI. Irrigation Scheduling Report

IRRIGATION SCHEDULING REPORT

Date Jan.31 Location Lahore

Quantity of Irrigation Required*

	Weeks since last Irrigation	Soil Textural Classification: Coarse (Sandy)	Light (Sandy Loam)	Medium (Loam)	Fine (Clay Loam)
November 1 - 7 planting dates	1	Nil	Nil	Nil	Nil
	2	L	L	L	L
	3	M	M	M	M
	4	H	H	H	H
	5	H	H	H	H
	6	H	H	H	H

	Weeks since last Irrigation	Coarse (Sandy)	Light (Sandy Loam)	Medium (Loam)	Fine (Clay Loam)
November 8 - 14 planting dates	1	Nil	Nil	Nil	Nil
	2	L	L	L	L
	3	M	M	M	M
	4	H	H	H	H
	5	H	H	H	H
	6	H	H	H	H

	Weeks since last Irrigation	Coarse (Sandy)	Light (Sandy Loam)	Medium (Loam)	Fine (Clay Loam)
November 15 - 21 planting dates	1	Nil	Nil	Nil	Nil
	2	L	L	L	L
	3	M	M	M	M
	4	M	M	M	M
	5	H	H	H	H
	6	H	H	H	H

*Nil - No irrigation required as of this date
L - Light irrigation of 2 - 3 inches depth required
M - Medium irrigation of 3 - 4 inches depth required
H - Heavy irrigation of 4 - 5 inches depth required

Appendix VI. (Continued)

IRRIGATION SCHEDULING REPORT
Date Jan.31 Location Lahore

Quantity of Irrigation Required*

	Weeks since last Irrigation	Soil Textural Classification: Coarse (Sandy)	Light (Sandy Loam)	Medium (Loam)	Fine (Clay Loam)
November 22 - 28 planting dates	1	Nil	Nil	Nil	Nil
	2	L	L	L	L
	3	L	L	L	L
	4	M	M	M	M
	5	M	M	M	M
	6	H	H	H	H

	Weeks since last Irrigation	Coarse (Sandy)	Light (Sandy Loam)	Medium (Loam)	Fine (Clay Loam)
November 29 to December 5 planting dates	1	Nil	Nil	Nil	Nil
	2	L	L	L	L
	3	L	L	L	L
	4	M	M	M	M
	5	M	M	M	M
	6	M	M	M	M

	Weeks since last Irrigation	Coarse (Sandy)	Light (Sandy Loam)	Medium (Loam)	Fine (Clay Loam)
December 6 - 12 planting dates	1	Nil	Nil	Nil	Nil
	2	Nil	Nil	Nil	Nil
	3	L	L	L	L
	4	L	L	L	L
	5	L	L	L	L
	6	L	L	L	L

* Nil - No irrigation required as of this date
L - Light irrigation of 2 - 3 inches depth required
M - Medium irrigation of 3 - 4 inches depth required
H - Heavy irrigation of 4 - 5 inches depth required

Appendix VI. (Continued

IRRIGATION SCHEDULING REPORT

Date Jan.31 Location Lahore

Quantity of Irrigation Required*

	Weeks since last Irrigation	Soil Textural Classification: Coarse (Sandy)	Light (Sandy Loam)	Medium (Loam)	Fine (Clay Loam)
December 13 - 19 planting dates	1	Nil	Nil	Nil	Nil
	2	Nil	Nil	Nil	Nil
	3	Nil	Nil	Nil	Nil
	4	L	L	L	L
	5	L	L	L	L
	6	L	L	L	L

	Weeks since last Irrigation	Coarse (Sandy)	Light (Sandy Loam)	Medium (Loam)	Fine (Clay Loam)
December 20 - 26 planting dates	1	Nil	Nil	Nil	Nil
	2	Nil	Nil	Nil	Nil
	3	Nil	Nil	Nil	Nil
	4	Nil	Nil	Nil	Nil
	5	Nil	Nil	Nil	Nil
	6	Nil	Nil	Nil	Nil

	Weeks since last Irrigation	Coarse (Sandy)	Light (Sandy Loam)	Medium (Loam)	Fine (Clay Loam)
December 27 to January 2 planting dates	1	Nil	Nil	Nil	Nil
	2	Nil	Nil	Nil	Nil
	3	Nil	Nil	Nil	Nil
	4	Nil	Nil	Nil	Nil
	5	Nil	Nil	Nil	Nil
	6	Nil	Nil	Nil	Nil

*Nil - No irrigation required as of this date
L - LIght irrigation of 2 - 3 inches depth required
M - Medium irrigation of 3 - 4 inches depth required
H - Heavy irrigation of 4 - 5 inches depth required

Appendix 43

WATER MANAGEMENT PROBLEMS IN IRRIGATED AGRICULTURE

Gaylord V. Skogerboe and Max K. Lowdermilk[1]

Definition of an Irrigation System

An irrigation system can be subdivided into three major subsystems; (a) the water delivery system; (b) the farm; and (c) the water removal system. The water delivery system can be further subdivided into two components; namely, (a) the transport of water and pollutants from the headwaters of the watershed to the cross-section along the river where water is diverted to irrigate croplands, and (b) the transport of water and pullutants from the river diversion works to the individual farm. The farm subsystem begins at the point where water is delivered to the farm and continues to the point where surface water is removed from the farm. Also, the farm subsystem is defined vertically as beginning at the ground surface and terminating at the bottom of the root zone. The water removal subsystem consists of (a) the surface runoff from the tail end of the farm, and (b) water moving below the root zone.

Introduction

Whether the goal is minimizing diversions to new croplands because of limited water supplies, reducing future diversions to irrigated agriculture to provide water supplies for new demands, minimizing water quality degradation in receiving streams resulting from irrigated agriculture, or maximizing agricultural production on existing croplands; the solutions are identical--improved water management practices.

Irrigation is one of the most important agricultural practices developed by man, with irrigation being practiced in some form since the earliest recorded history of agriculture. The economic base for many ancient civilizations was provided by irrigation. Irrigation farming not only increases

[1]Agricultural Engineer and Sociologist, respectively, Colorado State University, Fort Collins, Colorado.

productivity, but it also provides flexibility which allows shifting from the relatively few dryland crops to many other crops which may be in greater demand. Irrigation contributes to strengthening other facets of a region's economy in that it usually creates more employment opportunities than rainfed agriculture, through intensive and diversified cultivation, the stimulation of important agri-businesses and public institutions, the provision of products for export, and the creation of a healthy domestic market.

History is replete with declining civilizations due to declining agricultural productivity, which has usually been the result of improper soil and water management practices. The potential danger today is present at many places throughout the world. This comes at a time of dangerous food shortages in a hungry world, when the goal is to increase per acre crop yields. Let us not be too pessimistic or overly optimistic, however the spectre of Malthus and the warning of the Paddock brothers should keep us sober.

As the population of a nation increases more and more land is cultivated, with the remaining lands usually being less suited to cultivation than the existing croplands. Once the valley floors are inhabited, further population increases in some civilizations have resulted in occupation and cultivation of higher watershed lands, which resulted in serious soil erosion problems. Also, soil erosion problems can result from plowing new lands having native vegetation when rainfall is inadequate (e.g., rainfall may be inadequate during a drought period, thereby resulting in wind erosion of the soil). On the other hand, the denuding of many soils of the tropics may result in serious soil erosion during intermittent periods of high intensity rates of rainfall. Also, the overgrazing of watersheds by animals is now contributing to soil erosion in many regions of the world. History reminds us that ancient civilizations have suffered from inadequate soil management. A recent example is the dust bowl days of the 1930's in the U.S.A., while Russia suffered serious soil erosion in the newly cultivated Kazakhstan plains during the 1950's.

As a result of inadequate water and soil management systems many early irrigation civilizations had critical problems of siltation of canals. Most of us here today know irrigation systems where the effects of soil erosion, the silting of canals or reservoirs constitute such problems as to negate the long run benefits estimated in development plans.

To maintain agricultural productivity in irrigated agriculture--and let me add that we must do more than that today--salts applied onto the croplands, which are dissolved in the irrigation water supplies, must be moved below the root zone in order not to retard plant growth. Therefore as we all know it is mandatory that water supplied to a crop must exceed the actual water requirements of the plants to include evapotranspiration needs, leaching requirements, seepage losses and in most cases other transit or ditch losses which in most countries are substantial.

As is known usually the quantity of irrigation water diverted from a river far exceeds the cropland water requirement. Data from many irrigation regions indicate that seepage losses from canals and laterals throughout the irrigation distribution systems are extremely high. Added to this the excessive application of water on farm fields results in surface runoff from the lower end of the field (tailwater runoff) and/or large quantities of water moving below the root zone (deep percolation). The combination of seepage and deep percolation losses cause groundwater levels to rise (waterlogging). In many irrigated regions, the groundwater levels have reached the vicinity of the root zone which frequently results in the upward movement of groundwater due to capillary action. When upward moving water reaches the soil surface and evaporates, the salts contained in the moisture are left behind on the ground surface. This process of salinization has not only resulted in declining agricultural production, but has caused many lands to become essentially barren.

The quality of water draining from irrigated areas is materially degraded from that of the irrigation water applied as we have discovered along the Colorado and other rivers.

Agriculturists have viewed this phenomenon as a natural consequence of the several complex processes and strangely enough even today little attention has been given to the possibility that progress could be made toward controlling or alleviating this degradation of water quality.

Historically, some degree of salt concentration due to irrigation has been usually accepted as the price for irrigation development. In some areas, however, there has been so much laxity that quality degradation has become a serious matter. As pressures on water resources become greater, due to increasing populations and the necessity to produce food in increased quantity and improved quality, there is a mounting concern for proper control of serious water quality deterioration and soil salinization. The need then for more precise information as a basis for wise policy action is a matter of critical importance.

The major problems resulting from irrigation are due to the basic fact that plants are large consumers of water resources. Growing plants extract water from the supply and leave salts behind, resulting in a concentration of the dissolved mineral salts which are present in all natural water resources. In addition to having a greater concentration of salts in the return flow resulting from evapotranspiration, irrigation also adds to the salt load by leaching natural salts arising from weathered minerals occurring in the soil profile, or deposited below. Irrigation return flows provide the vehicle for conveying the concentrated salts and other pollutants to a receiving stream or groundwater reservoir. It is necessary then to examine the waterlogging and salinity problems resulting from this process and to develop and implement measures to control or alleviate the detrimental effects.

Impaired crop production resulting from salinity is not limited to the western United States, but is a major problem in many areas of the world. In fact the more one observes problems in other countries the more one is convinced that this is indeed an international problem. Unfortunately, the portions of the world now facing the greatest population pressures are the same areas which have the least amount of additional land available for agriculture and in some cases where waterlogging and salinization are rampant. In such areas increased food production must come from more intensive farming with consequent increased yields and, as the economist reminds us, the modernization of agriculture requires that output continue to rise with decreasing per unit input costs. On the one hand, there is a great need to increase the productivity of such lands, but on the other agricultural production is continually being damaged due to rising groundwater tables (waterlogging) and increased salinity in the soils and groundwater supplies. Though there are estimates of the extent of these salt problems in the world suffice it to say that it is a creeping plague of death in many places.

Whenever water is diverted from a river for irrigation use, the quality of the return flow becomes degraded. The degraded return flow then mixes with the natural flows in the river systems. This mixture is then available to downstream users to be diverted to satisfy their water demands. This process of diversion and return flow may be repeated many times along the course of a river. In the case of the original diversion, if the increase in pollutants contained in the return flow is small in comparison to the total flow in the river, the water quality would probably not be degraded to such an extent that it would be unfit for use by the next downstream user.

If the quantity of pollutants (e.g., salinity) in the return flow is large in relation to the river flow, then it is very likely that the water is not suitable for the next user unless the water is treated to remove objectionable

constituents. Since water is diverted many times from the major rivers, the river flows show a continual degradation of quality in the downstream direction. As the water resources become more fully developed and utilized, without controls, the quality in the lower reaches of the river will likely be degraded to such a point that the remaining flows will be unsuitable for many uses, or previous uses of the waters arriving at the lower river basin no longer will be possible.

Those of us here need not be reminded that other than dire economic problems critical socio-political problems can accelerate rapidly between regions and between nations. Today in some low income nations due to political instability such problems create additional strains on a weak social fabric. In the future it is not unlikely that nations might even go to war over water and its degradation. The present food crises in several countries are also disquieting.

Planning for Effective Water Management

The resource base for irrigated agriculture has not substantially changed since its inception thousands of years ago. Over the last century there has been little incentive for any major innovation to improve efficiency in the use of water which now fortunately is considered a scarce resource. The provision of irrigation water since ancient times has been considered a governmental or collective responsibility, and the direct charges made for water have usually not been high enough to encourage proper budgeting of water or other necessary innovations. This custom of undercharging for water has continued to this very day; a few regions charge the farmer for the real cost of water. However, there are a few examples of extremely water-scarce areas in the world where considerable ingenuity has been applied in effectively utilizing water supplies.

Aggravating this situation of so-called "cheap water" is the fact that the development of irrigated agriculture in most places, even in the last few decades, has focused almost

entirely upon the construction of water delivery subsystems. This preoccupation with the installation of "hardware" results from a naive single-discipline approach to water management and let us be reminded that one discipline cannot begin to solve the complex physical, economic, political, and sociological problems involved. Probably the greatest deterrent to improved water management in most irrigation systems in the LDC's today is the inordinate focus on the water delivery subsystem and the almost complete neglect of other problems. How long can we afford to neglect other problems of the system such as the need for improved soil-plant-water management techniques, improvements in cultural practices, farm machinery, agrarian structural reforms, roads, marketing systems, advisory services and input supply systems, administration of institutions, water laws, cooperatives and water users associations, and many other factors all of which must fit together in all their interdependencies and complementarities to form a most complex system. These are all requisites, plus others, and this is why in the 70's there will be NO EASY HARVEST. In reality though, especially in irrigated agriculture, we come face to face with a wide gap which frequently exists between "hardware development" and the development of all the other requisites for increased agricultural production.

The approach which has been applied to irrigated agricultural development in the past is characterized by separating the development of water resources from the management aspects of water resource utilization. Therefore the record shows development being emphasized greatly while management is most often neglected. This orthodox approach has been used almost exclusively in the western United States with reasonable success. However, as the water resources become more fully utilized, the necessity for meeting new water demands along with physical, socio-economic, and political problems of water quality degradation we must reject much of the conventional wisdom of the past. It should also be

obvious that LDC's today neither have the time nor resources many western irrigated regions had to utilize in their development. Pressures created by rapidly rising population rates alone will force them at some point to reevaluate their approaches. Yet only a minority of irrigation development programs in the LDC's pass the simple "test of convergence" wherein the benefits of a project must converge upon broad developmental goals rather than merely be feasible from a physical point of view. Frequently, as a result of the population explosion, the convergence test applied to a proposed or on-going program shows a widening gap between attainment of goals and actual performance. The adoption of "feasible" projects might suffice in a mature economy or be allowed, but the scarce resource bases in less developed countries require that they be used in "converging" projects.

In contrast to the mere development of water resources approach, the "management" approach attempts to achieve water development objectives by applying a variety of measures after studying the entire system, thereby attempting to modify the total system to meet new and changing demands as well as estimated future demands. Therefore, instead of constructing new engineering works to meet new demands, the focus should be upon water resource management, with construction works being considered only as a tool when necessary to meet water management objectives. Unfortunately, in most cases, water management and the many disciplines required to produce efficient management are relegated to the post analysis of engineering works (e.g., much of the future emphasis will be geared towards improving existing irrigation systems), which aggravates not only the implementation of technology, but really constrains or makes extremely difficult the implementation of a host of services requiring strong institutional measures.

Design of Irrigation System

The "heart" of an irrigation system is the farm subsystem. The purpose of an irrigation system is to grow food and this "action" takes place in the root zone. The purpose of the water delivery subsystem and water removal subsystem is to support this "action". Therefore, the proper design of an irrigation system requires, first of all, that the farm subsystem be adequately designed so that the water delivery subsystem can be designed to provide the quantities of water at the times required by the plants. The most important constraint in the design procedure is the necessity for assuring adequate drainage through the root zone in order to maintain a root zone salt balance to insure continued long-term agricultural productivity.

Farm Subsystem

The first important variables in designing the farm subsystem are climate, soils, and crops. The interrelationships between these variables dictate the capability of the land resource for producing food and fibre. As was delineated in the 1973 Park City, Utah Symposium, more research is needed on the physical responses of plants to water, salinity, and temperature stresses. We need to understand the interactions and relationships between water and management factors such as optimum rates of fertilizer, proper pest control measures, seeding and tillage practices, and other improved cultural practices. Much of this research is adaptive and protective, which due to its rather low level of sophistication among some in both LDC's and other countries, is sometimes neglected. However, we must focus on these areas which still represent large gaps in the research efforts in many LDC's.

Besides these aspects of research we must know the economics of various cropping systems, market demand and a host of marketing and transportation problems, as well as difficulties faced by the subsistence farmer.

The next important variable will be water and its physical availability. Frequently, in arid areas of the world, water is the most limiting factor. However, the capability of the available water supplies (precipitation, surface runoff, and groundwater) for plant production is highly dependent upon the efficiency with which the water is used, which in turn is a function of both economic and institutional factors. Besides physical limitations, the questions of economics in supplying water must be answered to insure that costs are commensurate with planning goals.

Once the general scope of an irrigation project has been determined, then the more detailed design procedures can follow. The critical factor at this point becomes the infiltration characteristics of the soil. Unfortunately, infiltration is a complex phenomenon and the intake function of a particular field will vary during the irrigation season, as well as varying from season-to-season. There are a number of laboratory and field methods available for determining the intake characteristics of a soil.

Using climatic data, the potential evapotranspiration of the various crops can be calculated. These computations will provide the information regarding water consumption with time, provided sufficient moisture is made available in the root zone.

The next important step is designing the farm irrigation layout so that sufficient moisture will be available in the root zone when required by the plants. The root zone is capable of storing moisture for future plant use. Again, soil characteristics determine the amount of storage, as well as the capability of the plant to extract the moisture from this "reservoir". At the same time, the leaching requirement for maintaining a salt balance in the root zone must be kept in mind. Consequently, the farm irrigation layout must be capable of supplying not only the plant water requirements, but also the leaching requirement.

The proper design of the farm irrigation layout is crucial for: (1) uniformly distributing the necessary moisture throughout the field; and (2) minimizing deep percolation losses so as not to aggravate problems in the water removal subsystem.

Generally, the development of irrigation projects has not entailed the design of farm irrigation layouts suited to the individual characteristics of each field. Instead, only the general method of irrigation may be adopted (e.g., basin or furrow irrigation). The farmer is usually left to his own means in irrigating his fields, without having the benefit of technical (or economic) assistance. The situation is further aggravated because, along with adopting a general method of irrigation, an average irrigation efficiency for this method is "pulled out of the air." If this so-called average water use efficiency was even close to being correct it would be most fortunate--let alone taking into account the variability of this "magic" number on any specific field throughout the irrigation season, as well as the variability from field-to-field. Usually, the application of this average efficiency results in large quantities of deep percolation during the early part of the irrigation season, which in turn contributes to waterlogging of the soils and consequent poor crop yields (or eventual failure of the irrigation enterprise).

Water Delivery Subsystem

The design of the individual farm irrigation layouts should dictate the design of the water delivery subsystem. The irrigation layout design, if properly accomplished, will show the necessary quantities and timing of water deliveries at the farm inlets. The water delivery network must be designed to meet the farm water requirements. Except for alluvial channels conveying large sediment loads, the design of the conveyance works is rather "mechanical".

One of the essential facilities for successfully operating an irrigation conveyance network is adequate and numerous flow measurement devices. To begin with, since each farm has a particular water requirement, then the only means by which the proper amount of water can be delivered is by measuring the water at the farm inlet. After all, the farmer cannot be expected to use good water management practices if he doesn't even know the quantity of water being managed. Besides each farm inlet, a flow measurement structure should be provided at all division points in the water delivery subsystem.

The real problem in the water delivery subsystem is the institutional framework controlling the operation of this portion of the irrigation system. Generally, the operation of the conveyance facilities has not been related to the requirements for sustaining a long-term productive agriculture. In particular, institutional factors have acted as constraints to improved water management or increased agricultural production.

The primary requirement for sustaining an irrigation system is an institutional framework that is compatible with the design requirements for the water delivery subsystem, which in turn has been dictated by the proper design of the farm irrigation layouts, as well as any constraints imposed by the water removal subsystem. Thus, even if all three components of the irrigation system have been properly designed, the lack of an adequate institutional framework for operating the system in accordance with the design criteria will likely lead to either failure of the system, or at least having agricultural production levels below (or far below) expectations. Many LDC institutions for irrigation systems were developed by outsiders for other than the modernization of agriculture. In some LDC's the objective was a simple system which would almost operate itself. Some of these institutions were regulatory rather than service

oriented and little attention was ever given beyond the canal outlet. How can we expect a British system established in the late 1800's to provide the flexibility and incentives required for a modern system of agriculture today? Perhaps herein lies one of the greatest constraints in water management improvement. Who is doing research on this problem area? What are the alternatives we can lay out to governments in this crucial area of concern? To pass our convergence test, the three components stressed above must mesh in complementary relationships with the institutional framework.

Water Removal Subsystem Framework

The principal function of the water removal subsystem is to allow proper drainage below the root zone so that adequate leaching of salts from the root zone will occur. The most satisfactory mechanism for insuring adequate drainage is proper operation of the water delivery subsystem. By so doing, a drainage problem will probably not occur. This is much better than allowing the problem to occur, then constructing drainage facilities to correct the damage. Unfortunately, the usual solution consists of constructing additional facilities. Frequently, project reports will state... "drainage facilities will be designed after the project has been in operation for a number of years in order to more precisely ascertain drainage requirements." This is the same naive single-discipline thinking referred to in the previous section, which is the rule rather than the exception. Perhaps the statement is correct that history of irrigation systems teach one that man often does not learn from history.

Another important consideration in the water removal subsystem is water quality. If canal seepage and cropland deep percolation losses result in water quality degradation of the underlying groundwater supplies, then the use of these supplies may become impaired. Also, the return flows to the river may limit the usefulness of the river water to downstream users.

Administration of Irrigation System

The proper functioning of an irrigation system is highly dependent upon an institutional framework which is compatible with the design criteria used in developing the system, as well as providing flexibility in achieving improved water management as the need arises. Satisfying on-farm water management objectives cannot be achieved without controlling water deliveries. Therefore, the administration of the irrigation system requires that satisfactory legal mechanisms exist that control water deliveries.

The failure of new irrigation developments to meet estimated production goals has largely resulted from the lack of follow-up in providing essential agricultural inputs and services to farmers. Again, the lack of training in farm water management and other farm practices by those responsible for the planning, design and construction of the irrigation development leads to the shortcomings in output. Also, the lack of cooperation between disciplines is certainly a detriment in any country, but is particularly noticeable in the developing countries. Interdisciplinary team research is a noble concept but it is seldom internalized by researchers and implemented effectively. Perhaps the most expedient solution is to expand the training of those personnel involved in the planning, design and construction of irrigation enterprises. Such training would then hopefully provide feedback into the planning and design of future irrigation developments.

The provision of adequately trained personnel for the operation and maintenance of irrigation systems may be understood, but is sometimes difficult to accomplish. This was also stressed in the Park City Symposium. Much focus must be given to training not only the engineers and technicians but those who work directly and indirectly with the farmer. Although agricultural experiment stations may exist, there is usually a severe limitation in accomplishing on-farm improvements because of insufficient adequately trained farm-level

advisors capable of transferring applied research results directly to the farmers. In many LDC's the components of research and advisory services have never been brought together in a carefully planned marriage relationship. In most LDC's both research and advisory and information programs are weak.

We are all aware of the need for improved delivery systems for technology once it has been made available by research. How best can this transfer of technology in water management be made to the end user, the farmer? Here we need the help of the applied social sciences such as economics, sociology, anthropology, political science and even the social psychologist. Some extension system is required which will take the proven findings of research along with utilizing the knowledge of the social sciences "package", in such a way as to convince the end user to move from the trial to the final adoption stage.

In the 1950's and early 1960's extension did not develop a good image in LDC's for many reasons, one of which may have been the lack of highly visible technology to extend. However, when the new high yielding varieties became available, one of the many contributions was to expose the weaknesses of research and advisory services and the infrastructure they require to sustain the so-called "green revolution."

At this meeting we must address ourselves to the question, "What types of farm-level advisory services are needed as delivery systems of soil and water technology?" As far as we know at present, there is no trained farm-level advisor in water management working day in and day out with farmers, for example in Pakistan. In relationship to research needs, how much focus should we give to this important subject?

WATER MANAGEMENT RESEARCH IN PAKISTAN

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.

Project Objectives

The general objective of the Water Management Research Project is to increase food production in the arid and subhumid lands of the less developed countries through the improvement of water management practices and the integration of these with other good management and cultural procedures with appropriate consideration given to increasing employment in the rural sector and utilizing local resources.

The specific objectives for the Water Management Research Project are:

1. Development of knowledge and data on how best to conserve and utilize water falling on the land as rain and the most efficient means of supplementing needed soil moisture by limited amounts of irrigation water.

2. Development of knowledge and data that can be used for the economic design and construction of water conveyance and delivery systems including structures for control and measurement of irrigation water, especially on the farm.
3. Development of surface and subsurface water removal systems to minimize the hazards resulting from surface flooding, high water tables and salt in the groundwater.
4. Identification of important factors to be considered in land preparation and leveling of the various irrigated soils in the major climatic zones and the relationship of these factors to water management, erosion, water infiltration, and good land use and cropping practices.
5. Development and adaption of methods of water application, including time and amounts, which are suitable and efficient for different soils of varying physical properties (water-holding capacities, intake rates, etc.) with major crops.
6. Integration of these water use factors into a productive cropping system consistent with farm size and available farming practices.
7. Where water quality, soil salinity and exchangeable sodium are problems, means will be developed for increasing crop production by using amendments and management practices which will improve water and soil properties and by using salt-tolerant crops.
8. The identification of institutional and policy factors (legal, social, economic, religious, manpower, credit, education, etc.) which influence efficient distribution and management of water on the farm level.

Irrigation in 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 a number of 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, a very different on-farm management system. The potential for increasing production through improved water management is great.

CSU Field Party in Pakistan

Most of the linkages, agreements, and programs of the CSU Field Party with Pakistani institutions can be attributed to Dr. Gilbert L. Corey, who served as Chief-of-Party for the CSU Field Party in Pakistan from the summer of 1970 to June, 1974. Dr. Corey served alone until the arrival of Dr. Jerry B. Eckert (Economics), Dr. Wayne Clyma (Agricultural Engineering), and Dr. C. J. deMooy (Agronomy) who arrived during the fall of 1972. At the present time, Dr. W. Doral Kemper (Agricultural Engineering and Agronomy) has taken over the duties of Chief-of-Party since his arrival on July 1. An additional member of the CSU Field Party is Dr. Alan C. Early (Agricultural Engineering) who arrived in September.

Present Field Program Highlights

From the time of his arrival in Pakistan during the summer of 1970 until his departure in June 1974, Dr. Gilbert L. Corey acted in the capacity as Chief-of-Party and played the major role for initiating water management research in Pakistan. Besides assessing water management problems, he had the primary responsibility for conveying the importance of improved water management for increasing food production in Pakistan. This message has been transmitted to numerous Pakistani agencies and has led to cooperative water management research programs between the CSU Field Party and Pakistani universities, agricultural research centers, and action agencies involved with increasing food production. The current major activities described below are primarily the result of Dr. Corey's successful efforts in communication and cooperation.

WAPDA's Mona Experimental Reclamation Project

One of the most exciting projects in Pakistan is the large-scale application of water management technologies at the Mona Experimental Reclamation Project. With funding

provided by the U.S. AID Mission for Pakistan, extensive experimental watercourse linings have been constructed by the Water and Power Development Authority (WAPDA) of Pakistan. Most of this construction is near completion. The results from this experimental program will provide valuable cost information for various types of watercourse lining. In addition, land leveling and various agronomic practices will be demonstrated on some farms. This program provides valuable experience and insight into implementing water management technologies under full-scale field conditions. Many officials have visited this project to view the water management activities, as well as many local farmers.

Integrated Rural Development Program at Shadab and Lar

The Integrated Rural Development Program (IRDP) is an agency of the Government of Pakistan (GOP) which has as a mission the integration of necessary inputs for rural development, which includes the dissemination of technologies which improve rural economies. The Shadab Project is located a short distance from Lahore, while the Lar Project is located near Multan. Much of the watercourse lining has been completed at Lar, while land leveling and improved agronomic practices have been undertaken at Shadab. Farmers' fields are used to demonstrate the effectiveness of land leveling, fertilizer use, cultural practices (e.g., disk plowing and drill planting), improved irrigation practices, and weeding for increased crop production. These demonstrations have attracted hundreds of visitors.

Water Management Loan (USAID to GOP)

As research results have become available over the last two years, both the Government of Pakistan and the USAID Mission to Pakistan have developed a major interest in an applied water management program. USAID has suggested a substantial loan to GOP as a possible method of support to enable launching such a program.

At the request of both the Prime Minister's Special Assistant for Agriculture and USAID, Dr. Eckert and Dr. Clyma prepared a basic conceptual paper elaborating the options available, their potential costs and returns. The paper draws on data generated in several other studies, as well as preliminary analysis of some data that will not be finalized until next year. Inputs and suggestions have been incorporated from Dr. Kemper and Dr. Early of CSU, Murray Cox of the SCS team in Lahore and Niel Dimick of USAID/Pakistan.

Three dimensions are visualized: 1) Watercourse renovation, 2) Precision land leveling and 3) Efficient irrigation and irrigated cropping techniques. Drawing on the conceptual and economic analysis of these options, a program is suggested that is consistent with GOP capabilities and interests, amenable to USAID support via a water management loan, and offers enormous potential for increasing food production and rural incomes for Pakistan. Priorities are suggested for assigning the various proposed components to different watercourse environments. Finally, some ideas are offered toward the phased implementation of the program.

WAPDA Watercourse Survey

The Water and Power Development Authority (WAPDA) of Pakistan has been developing plans in conjunction with the World Bank to undertake a watercourse survey throughout the provinces of Pakistan. World Bank personnel were in the country during the spring and fall of 1974, at which time they reviewed the program of the CSU Field Party. As a result of this interaction and the cooperative work between WAPDA and CSU at the Mona Experimental Reclamation Project, the World Bank and WAPDA began negotiations to collect extensive data regarding seepage losses along watercourses, cropping patterns, water requirements, water schedules, etc. This survey will precede the development of a loan program between the Government of Pakistan and the World Bank.

Although negotiations have not been completed, tentative plans call for: (a) Training of 20 teams (4 persons per team) during the first six months after initiation of the project; (b) Undertake studies on 20 watercourses located throughout Pakistan for one year; (c) Utilize experience gained during the first year of data collection to further refine the experimental design for the second year of field studies; (d) Train another 54 teams; (e) Collect data for a second year on the 20 watercourses evaluated during the previous year and initiate data collection for one year on 54 new watercourses; and (f) Evaluate the results of the two years of data collection, which is estimated to require another six months after termination of field data collection. In addition to the above, there will be a superstructure of administrative services to support this program.

CSU personnel have been involved as advisors regarding this watercourse survey. In addition, we will be involved in some aspects of the training program. One of the tremendous benefits that will accrue to Pakistan as a result of this study is the training of personnel who will become familiar with on-farm water management as a result of training, field data collection and interacting with farmers.

The long-range goals of this study are extremely exciting. Anticipated loan programs both by the World Bank and U.S. AID for improvements along watercourses is a vital step for improved agricultural production in Pakistan.

Coordinated Wheat Production Recommendations

The Special Assistant for Agriculture to the Prime Minister convened all of Pakistan's chief wheat researchers in September, 1974, to prepare a set of coordinated production recommendations for the wheat crop of 1974-75. An extensive set of recommended cultural practices resulted from that meeting and has been distributed to all local agencies concerned to guide the extension and program implementation efforts for the coming season. Colorado State University

was asked to assist in preparing the recommended irrigation practices section of this report. Based on two years of water-fertilizer response function trials, a series of recommendations was prepared to govern timing and amounts of irrigation. In view of the water scarcity that was anticipated for the winter season 1974-75, recommendations were developed for several water supplies ranging from wholly adequate down to situations in which only one irrigation would be possible.

For the first time in Pakistan, irrigation recommendations have been issued which apply to situations of limited water. In addition, the discussion of the trade-offs between irrigation quantities, irrigation timing and fertilizer applications that occurred during the preparation of these recommendations has stimulated similar thinking among wheat scientists across the country with the result that experimentation among these scientists has been substantially increased during the current season.

Action Program for Water Saving and Wheat Production

As the winter wheat season planting began, it became obvious that the irrigation water supply situation was critically short. River flows were at their lowest in 90 years, and no stored water was available at either Mangla or Tarbella Dams. This also reduced power generation capacity which was affecting electrically driven tubewells. As planting fell behind, the country became very concerned about possible short falls of substantial magnitude in wheat production.

In response to this emergency, Dr. Eckert drafted an Action Program for Water Saving and Wheat Production which provided detailed recommendations on planting and cultural techniques in a scarce water circumstance. The bulk of these recommendations were drawn from cooperative experimentation done by the Cereals Section, Punjab Agricultural Research Institute and CSU under the overall Fertilizer-Water Response Function trials. Varietal and fertilizer recommendations for

late plantings were provided by CIMMYT's resident wheat advisor, Dr. Armando Campos. Dr. Clyma contributed sections on water savings possible by better channel maintenance and on the importance of foregoing or correctly timing the annual canal closure for repairs. Dr. Early contributed a section on irrigation scheduling and will provide monthly recommendation charts throughout the season. Dr. Lowdermilk contributed a section on implementation of the program through various communication channels effective in Pakistan.

This report was adopted in its entirety and was widely distributed by the Special Assistant (Agriculture) to the Prime Minister among extension and agricultural personnel throughout the irrigated areas. A series of emergency meetings of Provincial and National ministers and other decision makers dealt with implementation of the program. National radio and press appeals have been made and the specific technical recommendations are being released when appropriate throughout the season.

In a related development, based on costs and potential returns calculated from the fertility-water response data, the Prime Minister has announced that the fertilizer price has been lowered by 12.5 percent for a six-week period designed to stimulate nitrogen top dressing of wheat while it can still be beneficial.

Increasing Emphasis on Soil-Plant-Water Research

When the Colorado State University Field Party arrived in force in Pakistan during 1972, very little field research work had been done during the preceding twenty years in which the amount of water applied was measured. (Studies had been conducted in which number of irrigations was used as the water variable, but in most of these cases it was assumed that these irrigations were 3 inches.) There had been few significant studies on the timing of irrigation or the interactions between fertilizer and water. Two series of experiments were developed each with a network of cooperating

scientists at several locations around the country. The consumptive use network has begun serious experimentation during the previous year. The water-fertility response function network completed its first series of successful experiments on several crops during last year. In both cases, the cooperating scientists and the intermediate and junior personnel at their institutes have been exposed to the concepts of measured water application, soil moisture determination, the importance of irrigation timing and various other soil-plant-water relationships.

At several institutions these scientists have begun to expand the use of these techniques to experiments other than those with a direct CSU involvement. For example, the Cereal Section, Punjab Agricultural Research Institute (PARI), Lyallpur, has employed a full-time soil moisture technician and equipped him with the necessary ovens, soil cans and sampling equipment for gravimetric moisture determination. He is now assigned to develop soil moisture data for a series of eight major experiments which cover most of the experimental area used by the entire section. Moisture tension curves have been derived at WASID and are being used to incorporate soil moisture tension as an explicit variable. Similarly, at other institutes, the use of the concepts and techniques of water management research is spreading noticeably through several types of agronomic experiments.

A further derivative of this growing emphasis has been an expansion of the types of agronomic research related to irrigation or soil moisture conservation. Whereas in previous years agronomic trials accounted for only some 20-25 percent of the total experimental effort of the Cereal Section, PARI, this year approximately 75 percent of their effort is oriented in this direction. Data are being developed on the effects of delaying the first irrigation, on the effects of irrigation regime on spikelet differentiation and on several techniques for obtaining adequate wheat stands without the preplanting irrigation. In addition, all promising advanced

genetic lines are being subjected to moisture stress simulating various low irrigation or rainfed situations in an effort to select those varieties most suitable. Additional work is being done on the relationship between root system development and irrigation regime. Finally, crop sampling is being expanded in an effort to determine N losses by leaching that might occur due to typical farmer irrigation practices.

Potential Improvements*

The present cropping intensity in Pakistan is undoubtedly not more than 75 percent, or less than one crop per year. The climatic regime including excellent solar energy is such that a cropping intensity of from 200 to 300 percent is possible. Water, however, is one of the limiting resources; yet an intensity of at least 150 percent is feasible with proper management of the existing supply of water. Of course, water is not the only input needed to increase acreages but certainly the apparently possible doubling of the effective cropped acreage can be accomplished within a ten-year period. There, of course, is the added benefit that better management also increases yields. This improvement can be accomplished within the present system which, although rather rigid, does have advantages which can be utilized.

There are several technologies which, if adopted, would greatly improve irrigation water management in Pakistan. Full benefit can only be realized by adopting and utilizing all of them together. Irrigation water management is a system and though any one practice has some benefits alone, full benefit only comes by adopting the entire system. Only research and testing will determine what constitutes a technically sound package which is economically feasible, and socially acceptable.

*The material for this section was taken from a report by Dr. Gilbert L. Corey, "Optimizing Irrigation Water Management Practices in Pakistan," Jan. 1974.

The practices listed below have been used elsewhere and are worthy of strong consideration for adoption in Pakistan.

Crop Cultural Practices

Moisture conservation and control is not limited to the irrigation system itself. Many cultural practices are interrelated and important to optimum production. Weed control, cultivation, mulching, deep tillage, organic matter incorporation and minimum tillage are all practices worthy of study and related to water management since they affect moisture movement and use. In fact, some study should be given to other methods of irrigation. Applying irrigation water through furrows has many advantages over the level basin method. Drip irrigation is a rather new technology which may have application in Pakistan. All of these practices need study to determine their degree of acceptability and to define their economic feasibility.

Precision Planting

Modern agriculture has long since discovered that investment in precision seed planting is economically worthwhile. Great pains are taken to place the correct number of seeds precisely at the required depth and with the soil firmly packed around the seed. Rather complicated and expensive machinery are involved for some crops, yet the economic feasibility is unquestioned. This is not to advocate expensive planters for Pakistan; however, the problem is worthy of study because plant stands are very poor in some areas and undoubtedly the rather simple seeding techniques could be improved. Even hand planting can be precise and undoubtedly would be if the benefits were fully known.

Soil Management for Moisture Control

Traditional methods of agriculture common in Pakistan leave much to be desired with respect to moisture conservation through soil management. The surface soil in most areas is practically structureless. Overworking by repeated

plowing adversely affects infiltration rates and irrigation water is observed standing on the soil surface sometimes for days before it can penetrate into the root zone and be useful to the plants. Much water is lost during the planting season by irrigating and then working the soil so many times that most of the moisture is lost to the atmosphere. Many cases have been observed where the farmer loses so much moisture that it is necessary to reirrigate, thus losing much of the first irrigation. A major research program should be launched to study soil and water management as it relates to plant growth. Surely, many improvements are possible and worthwhile even within the traditional agricultural system. This research should be combined with that which is necessary to fully develop the technologies described above.

Field Reshaping and Leveling

Efficient use of water within the root zone cannot be accomplished unless the field itself is precisely designed to fit the particular irrigation method. The level basin method requires that fields be precisely level. Otherwise, much water is wasted in irrigating high spots which become salinized unless they are sufficiently covered with water during each irrigation. While leveling the land, the fields may be reshaped into a more efficient design so that the length of the watercourse serving the fields can be greatly reduced, which has the double benefit of eliminating a wasteful watercourse and increasing the acreage of crop land.

Watercourse Rehabilitation and Irrigation Structures

Equitable distribution of water can never be accomplished without a better distribution (watercourse) system from the mogha to the fields. Regardless of what else is done, effective use of the irrigation water resource in Pakistan will not be accomplished without improving the watercourse channel. The present channels are, in many cases, of insufficient size to carry the designed flow. There are no distribution

structures and leaks abound. The only farmers receiving a full share of water are those whose farms are adjacent to the mogha. This one improvement would probably do more to increase water availability to farm land in Pakistan than any other including the building of two or three more Tarbella Dams.

When this improvement is coupled with land leveling, along with the introduction of proper irrigation structures such as siphon tubes, portable dams, permanent gates (nakkas) and measuring devices, the distribution system becomes complete. Only then will it be possible for actual irrigation efficiencies to approach assumed efficiencies so often mentioned in much of the descriptive literature of Pakistan's irrigation system.

Scheduling Irrigation to Meet Crop Needs

Modern technology allows us to predict from climatic factors the amount of water given crops use. This can be done on a daily basis utilizing no more meteorological data than are presently available in Pakistan. With such a service the farmer can be told exactly when to irrigate a given crop and precisely how much water should be applied. Couple this service with an improved system resulting from land leveling and watercourse rehabilitation described above, and we have a system which efficiently applies and utilizes no more water than is needed by the crops. The rather rigid warabundi system does not allow for complete adoption of a scheduling program; however, other technologies could be adopted which would ultimately make it possible to achieve it within reasonable limits. These are described in the three sections below.

Discharge Augmentation by Tubewell

There is a tremendous quantity of water available for irrigation below the soil surface in Pakistan. This water is usually close to the surface so the energy cost to lift it is reasonable. Since the supply though extensive is

limited, it should be exploited on a controlled basis. The holdings of many farmers are too small to warrant a private tubewell; however, groups of farmers could beneficially own one. In fact, all users on a watercourse system could feasibly construct a tubewell, or several tubewells, strategically placed within the system to augment the canal flow during periods of peak crop demands. This additional water resource would provide some control of the flow since the tubewells could readily be switched on or off. Small discharge wells would undoubtedly prove more effective than large ones because of smaller individual power units, better water control, and in many areas good quality water is only available in small quantities and must be "skimmed" from atop underlying saline water.

Water Storage on the Watercourse

A small amount of storage space on a watercourse system would be highly advantageous because there are times when the mogha is flowing and there is absolutely no need for water anywhere in the system. Many villages already have such an area, but it is not a planned part of the irrigation system, nor is water pumped for reuse. This storage could be utilized as a village pond with fish production, livestock water and the usual uses for such a resource. In fact, the tubewells described above could be placed near such a pond to ensure sweet water production. In such a manner, the storage could be used to augment the watercourse flow during peak demands and during emergency canal closures.

Canal Regulation

Some canal regulation to meet crop consumptive demands appears to be feasible. During certain periods entire canal system water demands are slack, but the climate of Pakistan is varied enough that this doesn't happen on all commands at the same time. In other words, water not needed on a given subsystem could be shifted to another and vice versa. It may even be feasible to schedule crop planting dates such that

consumptive demands will not be at peak on all commands at the same time. This approach of some canal regulation for crop needs is, at least, worth study and if it could be combined with the tubewell and storage augmentation described above, a great deal of flexibility could be built into the presently rigid system.

Maintenance of the System

If the improved water management system or any portion thereof is adopted it will require maintenance to keep it operating at maximum efficiency. Just as a delicate machine needs constant care and careful maintenance, so does any system of production. Leveled land will become unlevel, improved water channels will deteriorate, developed soil structure will be lost, and a salt balance will be destroyed without continuous and diligent maintenance of the system. This process is referred to as management and the practices necessary to maintain the system are similar to those necessary to improve it. No system worth developing will maintain itself without inputs from those utilizing it.

Institutional Development

In order to implement the management concept for irrigation systems we must focus on the critical and highly complex problem of institutional development. This involves at least four major areas: a) The careful identification of existing basic organizations for water management; b) An analysis of these institutions in relationship to their capability in the promotion of efficient water resource management; c) A careful delineation of the institutional and human needs for reform; and d) The potential for development of local institutions for water management at the farm level. The institutions from project design, construction, management, operation, and research, down to the local water users association should be well coordinated and integrated. All organizations must be co-terminous because goals and

objectives of society at every stage must agree if the system is to be designed properly and function efficiently.

The water management system is not a self-sufficient entity, but must have linkages with a number of other organizations such as research, supply corporations and other agencies both private and public which provide inputs and services to farmers. Some work has been done on several aspects of these institutional problems related to Pakistan by our CSU campus staff.*

Needless to mention, institutional development in the LDC's is a subject about which we still know far too little. One could speak of either "underdeveloped" or "overdeveloped" administrative structures. In some countries with long legacies of colonialism quite radical reforms may be necessary before water resources can be managed properly; we can not ignore the past histories of old-line institutions with objectives quite unrelated to efficient management of water or the modernization of agriculture today.

At this workshop much of our attention should be directed towards institutional development. In such a discussion we should remember that the basic building block of an irrigation management system is the farmer. Institutions, laws, codes, goals, and values greatly affect and often regulate to a great degree the irrigation behaviors and attitudes of farmers. For example, in several countries even if farmers wanted to organize water users associations and move to a demand system of distribution, it would be impossible or illegal until water laws, codes, and regulations, procedures and structures are revised. Therefore, both macro- and micro-level research

*Information Sources in Water Management for Agricultural Production in Pakistan with Special Reference to Institutional and Human Factors, April, 1974. Pakistan Government and Administration: A Comprehensive Bibliography, Volume I and II, Problem of Water Scheduling in West Pakistan Research Studies and Needs. (Nov. 1971) Monastery Model of Development: Towards a Strategy of Large Scale Planned Change, Nov. 1971. Organizational Alternatives to Improve Water Management in Pakistan, 1974.

related to institutions which isolates both dejure and defacto situations is of critical importance.

Probably the most difficult constraints we face in water management research and development today are found in the complex "institutional packages." What are optimum institutions? Can we assume that existing institutions are adequate and responsive to the needs, values, and ethos of the people to be served? How do we develop optimum linkages with key audiences to affect institutional change? Is it possible that in cross-cultural situations our particular western business approaches are not always relevant? These are questions for which we need better guidelines and answers.

PROGRAM EVOLVEMENT

With approximately 2-1/2 years of research experience in Pakistan, the Water Management Research Project is gaining more and more focus on the problems that need to be solved. The following sections present in capsule form the thrust of the research program in the next few years.

Improved Agronomic Practices

Research efforts regarding soil-plant-water relationships will be continued in Pakistan. Already, there has been significant increased emphasis by the major agricultural research centers in Pakistan to include water measurements, soil moisture measurements, and irrigation timing and amounts as a part of their research programs. These efforts are expected to increase, thereby providing more competence at such centers for accomplishing research in soil-plant-water relationships.

Identification of problems on farmers' fields has been an important part of CSU's program. In addition, field demonstrations have been undertaken as a part of large-scale programs on watercourses. These field demonstrations are not only important in getting farmers to adopt improved agronomic practices, but also play a significant role in having Pakistani officials interact with farmers.

Research efforts for major crops will be continued on consumptive use and response curves for water and fertilizer. This information is needed for improving water management practices, as well as the economic analysis of improved agronomic and water management practices.

Improved Water Management Technologies

Many of the initial efforts in Pakistan were geared toward identifying water management problems. Problem identification became very crucial because field results proved contradictory to previous reports by governmental agencies and numerous consultants. The field studies have played a major role in telling the water management "story" in Pakistan, which has certainly resulted in greatly expanded efforts towards improving water management practices.

CSU Field Party personnel have worked with Pakistani universities and "action" agencies in problem identification, as well as potential solutions for present water management practices. Future efforts will continue to increase the number of Pakistani professionals capable of playing an active role in a national water management program.

Efforts during the next few years will delineate water management technologies applicable to Pakistan, as well as developing a strategy for a national program of improved water management.

Economic Analysis

Efforts are underway to develop the conceptual framework for the economic analysis of proposed water management technologies for Pakistan. Dr. Lawrence E. Mack, CSU Economics Department, spent one month TDY in Pakistan during this past summer to review water management research activities and to discuss the development of an economic framework with Dr. Jerry Eckert, Economist, CSU Field Party. In addition, Dr. Thomas L. Dobbs, a recent addition to the U.S. AID Mission

for Pakistan, has participated in discussions and prepared a paper regarding his thoughts on the economic analysis of water management technologies. There has been considerable dialogue on this topic, which will lead to a definite method of approach within the next year. This framework will then be used in developing a water management strategy for Pakistan. Also, the role of the economist will be to evaluate the costs and benefits of several technologies we have introduced such as watercourse linings, water lift pumps, small discharge tubewells, land leveling, farm implements and cost benefit analysis of several cropping patterns.

Institutional Analysis

Several investigations of existing macro-level institutions related to water management have been conducted (referred to earlier on page 32). Areas have been identified and described where several changes will be necessary. For example, the present water laws may have to be altered to allow for more flexibility and efficient distribution of water to farmers. Several organizations may need to have more coordination and at a later stage one major organization should be made responsible for soil and water management. Existing laws permit farmers to form local water users associations and these are being evaluated further. We have found, for example, that cooperative or mutual efforts in properly utilizing the public water resources are not encouraged by existing laws. There seem to be several alternatives open to Pakistan as described by Dr. George Radosevich in his recent report, Organizational Alternatives to Improve On-Farm Water Management in Pakistan.

At the micro-level we are conducting a number of socio-economic watercourse studies to understand the present state-of-the-art of farmers' irrigation behaviors. Ashfaq Mirza, a student at CSU has completed his "Study of Village Organizational Factors Affecting Water Management Decision Making in

Pakistan." Dr. Max Lowdermilk, who has recently joined our CSU staff, has completed a new watercourse study and he and Dr. David Freeman are reviewing the literature, analyzing these data and will develop a conceptual framework for future socio-economic studies, as well as improved methodologies for data collection and computer analysis. These studies examine the local patterns of water distribution, leadership, and status roles, decision making processes, costs and kinship influences, sharing of water, formal and informal cooperative organizations, social cleavages, cropping patterns and irrigation practices, adoption rates of various technologies, crop yields and inputs, linkages with service institutions, interactions with irrigation authorities, and attitudes related to selected irrigation practices.

Our approach in these studies is to first identify and describe how the farm-level subsystem really works, utilization of these data for empirical generalizations, development of a conceptual framework or tentative theory, and establish relevant hypotheses which are tested through other field studies. Given sufficient data we are then in a position to evaluate policy alternatives.

These studies will continue through 1976 with assistance from the Agricultural University and other cooperators. The role of the applied sociologist on our research team is being better defined than in the past. Prior to the final selection of a watercourse for improvements, the sociologist and engineers conduct their investigations jointly. Data collected on the state-of-the-art is then used immediately in the organization of farmers in cooperative improvement activities, and choice of demonstrators. These data are also utilized for benchmark purposes for the evaluation of improvement activities. As we learn more about the state-of-the-art of farmers and their needs and attitudes, these data from empirical field studies are also useful in policy changes required at the macro-level. These data are also important, along with

engineering data, to determine why farmers presently behave as they do in the utilization of water.

At the present time there are few social scientists other than economists working specifically on water management research. Therefore, we begin next week with consultations with a number of Cornell University staff members who are also interested in this field. Lowdermilk and Freeman are using these consultations as means of developing a socio-economic conceptual framework for field studies. This could lead to cross cultural studies and a future data bank related to the role of social factors in water resource development and management.

PROGRAM IMPACT

Impact Upon Pakistan

If the Water Management Research Project in Pakistan is successful, then a national program of improved water management will be well underway. The research will have led the way in developing the strategy for such a program, as well as assisting in the development of research competence by Pakistani agencies.

Development of Generalized Methodologies

Research efforts by CSU and other AID contractors regarding soil and water should lead to the development of techniques for undertaking agronomic research in LCS's, including not only specific research projects, but also the development of a generalized methodology for preparing a water management strategy in LDC's, as well as a generalized framework for economic analysis. The most difficult problems are not identifying appropriate technologies, but implementing technology. Thus, the success in social analysis of institutional problems will dictate to a large extent the capability of effectively implementing the generalized methodologies in other LDC's.

University Competence

Through the past few years CSU competence has improved considerably in the following ways: selection of field party members; cooperation of multidisciplinary CSU departments backing up the field team; impact of CSU staff members who have gone on TDY to Pakistan for special assignments; selection and training of Pakistani graduate students; and graduate students at CSU who participate in an interdisciplinary water management seminar.

Increasingly we are selecting competent personnel from CSU departments who are dedicated to longer term professional work in the international field. The ties between the CSU departments on campus and the team members in Pakistan have improved. Field party members on home leave are also able to make a positive contribution on campus by seminar presentations, course work, conferences, and consultations.

Our presence in Pakistan has improved the capabilities of several departments on campus. We want this process to continue through improved relevant instruction for international students and their research on Pakistan's water management problems done under the field party's supervision. We are considering sending selected USA graduate students to Pakistan for their research also. With an increased input of data from applied social scientists we hope to gradually design more courses in sociology, economics, and political science which will be useful to physical scientists in understanding critical human and institutional factors in development. Our efforts then are focused more sharply than in the past on developing a sound team approach to the multivarious problems of water management both on the field and on campus.

Training and Motivational Materials

Our efforts to build a sound data base for Pakistan over 2-1/2 years have been fruitful. Other than utilization of

these data for policy recommendations, our efforts are to utilize these data in many different forms for selected audiences in Pakistan. Our sound movie on land leveling and water management in Urdu and English has been utilized for conferences, seminars, training courses, and for farmers. Presently, we are developing a special audio-visual slide show for Pakistani officials and policy makers to acquaint them with the problems and possibilities of the irrigation system. Shortly, we will develop such programs for other key audiences in Pakistan such as engineers, students, and farmers.

Several field party studies have been completed and these have been made available to officials and engineering students both in Pakistan and at CSU. These studies should also be prepared for both academic and lay audiences and published in Pakistani journals. Our present focus is on field training and for our efforts with engineers, agronomists, and farmers we propose to develop the following materials in the local language:* "Water Management Field Guide" for field workers; "How? When? and How Much to Irrigate Crops?"; and a flip chart on "Benefits of Precision Land Leveling and Water Management." Translations of these are also needed in Urdu for wider audiences. If we are to influence behaviors and change attitudes, we must carefully select our messages which are timely and tailor them to the needs of our audiences. Then we must select proper communication channels to give adequate exposure to our audiences.

We conducted the first water management seminar in Pakistan in 1973 and had about 75 leading officials for two days. There is now a need for a national conference with more

*The Water Management Research Project at Colorado State University, Fort Collins, Colorado 80523, would like to request samples of any teaching and training materials available in any languages around the world. Such a collection will help us improve our competence in designing new materials.

Pakistani participation and we propose to convene this in 1976. We will focus much of our efforts in the future in Pakistan on developing sound strategies on carefully selected key audiences with influence in policy formulation so as to affect change.

Therefore, our work in Pakistan forms a chain of interrelated activities; problem identification, research on relevant problems, trial and confrontation of findings, policy recommendations, training and motivational materials, human capital development, who will have competence to solve future problems in water management. This is the interlocking chain of our efforts in Pakistan because water management research is an unending continuous process.

APPENDIX 44

Physical and Socio-Economic Dynamics of a Watercourse in Pakistan's Punjab: System Constraints and Farmers Responses[1]

Max K. Lowdermilk - Wayne Clyma - Alan C. Early[2]

The purpose of this exploratory study was to identify and describe major physical and socio-economic constraints confronting farmers on one watercourse in their management and use of irrigation water for crop production. The general assumptions which undergird this study are: 1) farmers' constraints at the watercourse level constitute a complex system and can best be identified by a team approach; 2) farmers' responses to physical, legal, social, and economic constraints are rational and can be described; 3) in order to understand farm level irrigation conditions and practices, it is necessary to collect information from farmers about their individual and collective actions and opinions; and 4) water management improvements must be supplemented by many complementary inputs and services if they are to contribute to increased crop yields per acre.

The methods used in this study of an 87 percent sample of 41 small farmers on one watercourse were: 1) physical measurements of watercourse delivery and farmers' application efficiencies using cutthroat flumes; 2) topographical surveys and mapping of all farms, major soil types, size of irrigation basins, all delivery channels, Rabi and Kharif crops, spade cuts made in field ditches by farmers for irrigating fields, and; 4) structured interviews conducted with key informants and 87 percent of all the farmers. Participant observer methods were also used by the chief investigator who is fluent in the local language. A two month period was utilized in observing farmers' irrigation behaviors.

A major physical problem of this watercourse is that farmers during most of the year have to utilize 4 Persian wheel waterlifts to raise canal irrigation water from six to twelve inches to irrigate much of the command area. The

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[1]Research for this study was supported by the United States Agency for International Development Contracts AID/CAD-2162 and AID TAC-1100.

[2]Respectively, Extension Education and Applied Rural Sociologist and Agricultural Engineers, Colorado State University, Water Management Research Contract, Fort Collins, Colorado and Islamabad, Pakistan.

cost of operation of a lift utilizing bullock and man-power was estimated at Rs. 9.97 per acre inch at the Persian lift site and results in an estimated Rs 19.94 at most of the farmers' fields due to an average fifty percent loss. This is an estimated cost of about Rs. 69.80 for a 3.5 acre inch irrigation for the average farmer. Accumulated sediment in the watercourse, leaks, spills and dead storage resulted in losses frequently exceeding 50 percent in only 2000 to 3000 feet of channel length. Under-irrigation was common during the study due to rationing of canal water but measurements for the wheat season resulted in excessive applications of irrigation water. Farmers exhibited little understanding of the magnitude of these water losses. Because of the unlevel topography of fields and the poor condition of main delivery channels, this watercourse with 238 acres has 61,402 feet of field ditches on about one mile of ditches for each unit of 20 acres of land. Along the maze of ditches over 1,250 spade cuts in earthen ditch banks were mapped where farmers make five or more cuts per acre to irrigate small fields. Average size of irrigation basins are less than 0.24 acres. One third of the small fields are less than 0.15 acres. Such small fields result from both land fragmentation over time and the inability of farmers to control irrigation water on larger fields which are unlevel. Average separate parcels of land per farm are about six in number with one farm having thirteen widely scattered fields.

Sixty-five percent of the farmers reported that the major determinate in decisions about cropping patterns was their expectations about canal water supplies. These supplies and rainfall are most variable and eighty-six per cent of the farmers reported that lack of irrigation water is their major farm constraint.

Two areas were demarcated on the watercourse in relationship to distance from two water lifts and a small tubewell for the purpose of studying differences in cropping patterns and intensities. Area I extending from the waterlifts to a distance of 1,300 feet had a cropping intensity of 178 percent with no acres fallow. Area II extending from 1,300 feet to 3,400 feet had a cropping intensity of 130 percent, with 70 acres fallow for the kharif season. All crops with high water requirements such as rice, berseem, and sugar cane were located in Area I and crops with lower water demands were located in Area II.

Reported crop yields and levels of fertilizer inputs were low. Crop yields of wheat and paddy rice averaged 22.3 and 23.8 maunds/acre respectively with medians of 20 and 22 maunds/acre. Average nutrient pounds of nitrogen applied to the 1974-73 wheat crop was 45 lbs. per acre and no phosphatic fertilizer was used for wheat. Farmers' cultural practices such as seedbed preparation, leveling of fields, seeding methods, seeding rates and application of fertilizer

were documented. As expected, most continue to use traditional practices. A forced choice test was administered to farmers about recommended practices for high yielding wheat varieties and farmers' scores were surprisingly low.

Farmers have the erroneous concept that root systems of most crops penetrate only a few inches into the soil. Consistently farmers reported their views that root systems of rice, wheat, sugar cane and berseem extend into the soil only about 2.5 to 6.0 inches and cotton roots only about 12 inches. Likewise farmers have a concept that irrigation water infiltrated only a few inches into the soil profile. Farmers' crude and inaccurate methods of deciding when and how much to irrigate crops are described. A special test utilizing pictures of four distinct growth stages of a cotton plant was used to determine if farmers could determine peak requirements of water demands. Results show farmers' difficulties in making these decisions.

Low levels of knowledge and practice are related to inadequate extension advice received by farmers. Seventy-five percent of the farmers could not report the name of the extension worker assigned to their village and in the last three months sixty percent of the farmers had not seen the worker. Most of the farm information received by farmers is from other farmers and the transistor radio. Forty-three percent of the farmers owned radios and sixty-two percent report regular listening to farm programs which suggest the potential of this form of news media. However, farmers report that they do not receive important information from the Canal Department about canal closures for rationing and repairs which is essential to reduce farmers risks in decision making.

Leadership patterns, decision making processes, and types of cooperation and conflict were studied. Important social strata are the nuclear family, brotherhood kinship group, and caste. Each brotherhood and caste group has its leaders who are influential in decision making. Leadership and social status was found to be significantly related to farm size and proven leadership ability. Farmers organize primarily within brotherhood groups for collective action such as cleaning the watercourse, ownership and operation of waterlifts, trading water, work, animals and tools. To develop a successful water management improvement program it is necessary to have collective action among farmers. Ample incentives are necessary which provide equal benefits across cleavage groups. All brotherhood and/or caste leaders must be given substantial decision making opportunities if cooperation is to be achieved.

Dejure Canal Department codes and regulations related to the watercourse distribution system were examined by comparing these to defacto actions of farmers. Most of these

regulations are over 100 years old and act as constraints to farmers. Farmers use extra legal means such as trading water, installing unauthorized nakkas, using water from one command area for another; developing ways to gain extra supplies of water, and evading some of the water assessments. As farmers face certain outdated legal constraints they also use many methods to manipulate the system. This watercourse in theory operates on a rigid turn system for water distribution but farmers through trading practices have developed their own quasi-demand system.

This state-of-the-art study of farmers' problems and practices on one watercourse in Pakistan is presented as another attempt to understand farmers' irrigation problems. These problem identification studies are action oriented leading to problem solution. As an example, after the survey was completed farmer cooperators were carefully selected for demonstration of maximum yield wheat plots. These trials were conducted to compare farmers traditional practices with improved water management and other cultural practices. On level fields farmers' results with traditional 50 lbs. of nitrogen per acre and usual irrigation practices were compared with a treatment of high fertilization and irrigation applications according to soil moisture depletion. From 100 to 150 lbs. per acre of nitrate and from 37 to 75 lbs. per acre of P_2O_5 was used. The increment in yield due to increased fertility and improved irrigation requirements averaged 24.5 maunds for Chenab 70 variety and 17.0 maunds for S.A 42 variety. These yield increases which were double farmers' traditional yields were accomplished with 25 to 50 percent less water than farmers applied! Such actions leading to visible crop yield increases through improved water management practices and complementary inputs tend to speak louder to farmers than any of our reports.

RECOMMENDATIONS

The results of this study reflect the conditions for only one watercourse in Pakistan. However, the results are so startling in some instances and consistant with other published data in other instances that a number of recommendations seem necessary and worthwhile. These are:

1. Farmers in Pakistan must be provided with information about watercourse losses with recommendations for improvement and procedures for maintenance of the existing and improved system.

2. Farmers need to be provided with incentives to organize in order to improve water delivery by legal means, through institutional encouragement from the Irrigation and Agricultural Departments and through assistance

to farmers who have organized and made improvements. The same farmer organization should provide for regular, frequent (daily) maintenance of existing and improved watercourse systems.

3. An effective extension program must be developed to provide services to the farmer such as seeds, fertilizer, insecticides, and knowledge for improved crop production and proper use of irrigation water. This program must evaluate and improve, through a practical field training program, the existing organizations for extension and broaden the concept of extension to include multimedia communication and innovative approaches to obtaining farmer confidence, cooperation and action.

4. Canal Department operations have remained the same for over 100 years. Legal, administrative, and policy procedures should be reviewed with the objectives of changing water distribution procedures to eliminate extra-legal distribution of water, enhance revenue collections through increased water rates, develop revised collection procedures to reduce bribes and evasion of revenue due the Government, and provide protection to each farmer's water supply while providing flexibility by legalizing trading and purchase of turns between farmers. Irrigation Department extension must provide frequent multimedia communication of knowledge to farmers about weekly and seasonal water supply conditions and continuous information about rules and rights of farmers for their water supply.*

*Since this initial watercourse study, cooperative studies since May, 1975 have been conducted on 16 watercourses located in five major cropping regions of the Punjab. These data will be available in forthcoming publications.

Appendix 45

ON-FARM WATER MANAGEMENT IN THE PAKISTAN PUNJAB-- A STUDY OF INTER-RELATED PHYSICAL, ECONOMIC, AND SOCIOLOGICAL SYSTEMS

Max K. Lowdermilk[1], Alan C. Early[2], and David M. Freeman[3]

I. Introduction

A. General Objective

The objective of this study is to identify and describe the major physical, economic, and sociological constraints faced by farmers in the watercourse system and demonstrate their relationship to low delivery efficiencies and poor crop yields in five cropping regions of the Punjab. This effort will involve a comparison of irrigation efficiencies and behaviors between farms within watercourses and between farms in five agro-climatic zones. Selected physical, economic and sociological variables will be examined for their uses in: 1) the development of objective criteria for selection of watercourses for improvement programs; 2) analyzing problems of organizing farmers into water users associations; 3) providing necessary information for training of on-farm extension advisory personnel.

B. Specific Objectives

1. To evaluate and compare delivery efficiencies and farmers' application efficiencies in five major cropping regions of the Punjab.

2. To compare delivery efficiencies along with over and under irrigation patterns between farmers located at the head and tail positions of sample watercources.

3. To search for sociological and economic factors which can be linked with differences in delivery and field application efficiencies and the propensity for farmers to collectively organize to promote their common interests in water delivery, control, and application.

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4. To provide criteria which can be utilized for objective selection of those watercourses where farm and watercourse improvement activities will have the greatest likelihood of acceptance and payoff.

5. To provide a data base for subsequent development of guidelines for organization of farmers into water users associations--such associations are needed to provide watercourse supervision, improvements and maintenance.

6. To evaluate farmers' cultural practices, irrigation behaviors, and levels of farm management knowledge. This data base is viewed as important for improvement of farmer advisory programs and training of water management advisors.

7. To provide micro level data about farmers' responses to constraints resulting from present water codes and regulations. This data can be utilized in suggesting changes which will provide incentives for more efficient distribution of water.

8. To evaluate various methodologies used in the present study for improved design of future studies.

9. To generate specific research hypotheses which can be examined in future water management studies.

II. Significance of the Research

A. The Potential

The almost flat Indus Plain of Pakistan with its excellent climate, deep alluvial soils, and water resources has been described as one of the earth's major agricultural resources! The potential of this area has been increased by the construction over the past century of one of the largest contiguous integrated irrigation systems in the world. Visible engineering achievements include numerous headworks, link canals and two of the world's largest earth filled dams, Mangla and Tarbella. This system contains about 40,000 miles of canals and distributaries which deliver water to something more than 78,000 farm level watercourses. These developments supplemented by over 100,000 private tubewells provide an estimated 125-150 million acre feet of water for irrigation of about 35 million acres.

However, in contrast to both the physical resources potential and the development of modern diversion facilities of the irrigation system, little attention has been given to the 78,000 on-farm watercourses which serve over three million farms. Of the water diverted, only an estimated 30 percent is effectively stored in crop root zones. Most of the losses occur on the farm level watercourses which begin at the minor canal distributaries and deliver water on a rotation basis to the last farm. These on-farm delivery systems contain over 1.5 million miles of ditches built and maintained by farmers who presently are not provided supervision, services or incentives to improve the system. A typical watercourse includes about 400 acres of land serving on the average 40 farms. A description of almost any watercourse in Pakistan would include the following: poorly constructed and maintained earthen delivery channels which are infrequently cleaned; trees and phyraetophytes covering the banks; improper alignment and elevation; excessive leaks, spills and overtopping due to improper construction and lack of maintenance; about one mile of field ditches per each 20 acres of land, unlevel fields and small basins. From the canal outlet to a typical farm an estimated 40 or more percent of the water is lost. At the farm level, due to lack of water control and knowledge, farmers' field applications are extremely low. Clyma et al.[4] have made intensive field investigations to evaluate these delivery losses and application efficiencies. It is evident from these and other data that improved on-farm water management practices may result in the greatest source of increased available water for agriculture in Pakistan.

The importance of watercourse studies and subsequent improvement programs based on study findings is great because:

1. A major concern in improving the on-farm system is increased crop production, especially the production of food grain. Though dramatic strides have been made in wheat, rice and maize production in the past, Pakistan still is a net importer of wheat and other food commodities. Pakistan's population is now estimated as more than 70 million and is increasing at more than 3 percent per year. It is estimated that by the end of the fourth five-year plan in 1975 the demand for wheat has reached almost 9 million tons against about 7.5 million tons of production.[5] The only avenue open is increased yields per acre

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[4]Clyma, Wayne and Arshad Ali, "Watercouese Losses: Case Study No. 2," Colorado State University, Water Management Research Contract/Pakistan.

[5]Lawrence Witt and Ghulan Qadir, in Food Production in West Pakistan: Problems and Effects, edited by C. M. Sharif, Peshawar, Pakistan: 1971, pp. 239-277.

and there is evidence that improved management of water and other inputs can easily double present yields.

2. Agriculture has a critical role to play in Pakistan's total economic development. The agricultural sector not only must meet the demands for more food and better quality of food at lower costs of production, but must also provide raw materials for industry, and exports for foreign exchange earnings. The major burden will continue to be on increased production in the irrigated regions of Pakistan.

3. Pakistan has been forced to give serious thought to problems of social welfare and income distribution. Given a specific focus on small farmers a water management improvement program can play a role in increasing labor productivity through more intensive cropping and higher per acre yields which will generate increased farm income. The construction of watercourses will also provide some opportunities for landless labor.

4. There is international interest in the transferability of on-farm water management research data and technologies. What is learned from the Pakistan experience may prove valuable in solving water management problems in other countries.

5. The most primary contribution from these studies will be to provide useful information to those persons and organizations which will make far reaching policy and program decisions. Still there is insufficient data available about many of the socio-economic, organizational and legal constraints at the watercourse level for policy or program decisions.

B. The Relationship to Larger Research Efforts

As a result of the AID/CSU research program in Pakistan, official concern has increased to implement policies and programs to improve on-farm irrigation systems and practices. Recently the Water and Power Development Authority (WAPDA), with assistance from the World Bank, has made plans to conduct extensive watercourse surveys throughout Pakistan in preparation for a development program. Also the USAID Mission in Pakistan has initiated on-farm studies for an anticipated Water Management Improvement Loan Program.

This particular study is Phase I of the more extensive USAID Mission survey of about 50 watercourses in Pakistan. Phase I includes 16 watercourses at ten different sites in five districts of the Punjab. The focus of this first exploratory survey is the identification of major physical,

socio-economic, and legal problems confronting farmers as they manage water for crop production.

C. Central Assumptions

Several basic assumptions guide this study. First, on-farm water management is as broad as agriculture itself and, therefore, must be studied as an entire system including physical, organizational, economic, sociological and legal factors. For example, the poor physical conditions of farm delivery systems resulting in high losses might be related to one or more of the factors mentioned above. Likewise, farmers' low application efficiencies and under irrigation may relate to unlevel fields, lack of knowledge, and inadequate sources of services and information. All these factors most likely have a high degree of interaction and interdependence on any farm system. Secondly, is the assumption that the proper management of water is as much a human and organizational problem as a physical one. This requires an examination of irrigation behaviors, management practices and knowledge, and social organizational patterns. Thirdly, if the goal is increased crop production, increased quantities of water alone are insufficient. Many irrigation projects and improvement programs have failed to benefit farmers due to the lack of complementary inputs and conditions essential for increased crop production. Therefore, it is necessary to examine the availability and utilization of these inputs and services provided farmers for increased production possibilities. Fourthly, if planned change is to be implemented with farmers in the watercourse system, it is essential to identify major constraints confronting farmers and determine their responses to them.

III. Methodology

A. The Sample

Given a universe of over 78,000 watercourses and constraints of time, manpower, and money, sixteen sample watercourses were selected purposely on the basis of the following criteria: 1) watercourses were to represent major cropping or agro-climatic regions of the Punjab; 2) watercourses in SCARP public tubewell areas and watercourses with private and no tubewells were to be represented; 3) watercourses were to be characterized by single versus multiple caste villages; 4) watercourses were to be operated by local versus refugee settlers; and 5) all watercourses were to be predominantly farmed by small operators.

At the next sampling stage--within watercourses--sample farms and farmers were chosen randomly. A census was made of all farms on the watercourse and the watercourse was demarcated on the basis of linear feet from the mogha outlet

into three equal portions: "head", "middle", and "tail." The names of each farmer in each of the three watercourse positions were written on slips of paper and a small boy was used to draw a 25 percent sample separately for "head", "middle" and "tail." Only three sample farmers could not be located after several attempts and replacement names were drawn randomly. A total random sample of 169 farmers was selected, from among 16 different watercourses.

Key informants were selected in village and watercourse area to provide general background information and data about the social organization of the village. They were selected according to the following criteria: 1) residence in village and knowledge of watercourse matters; 2) leadership in village; and 3) where there were major caste groups, one key informant was chosen from each.

B. Data Collection

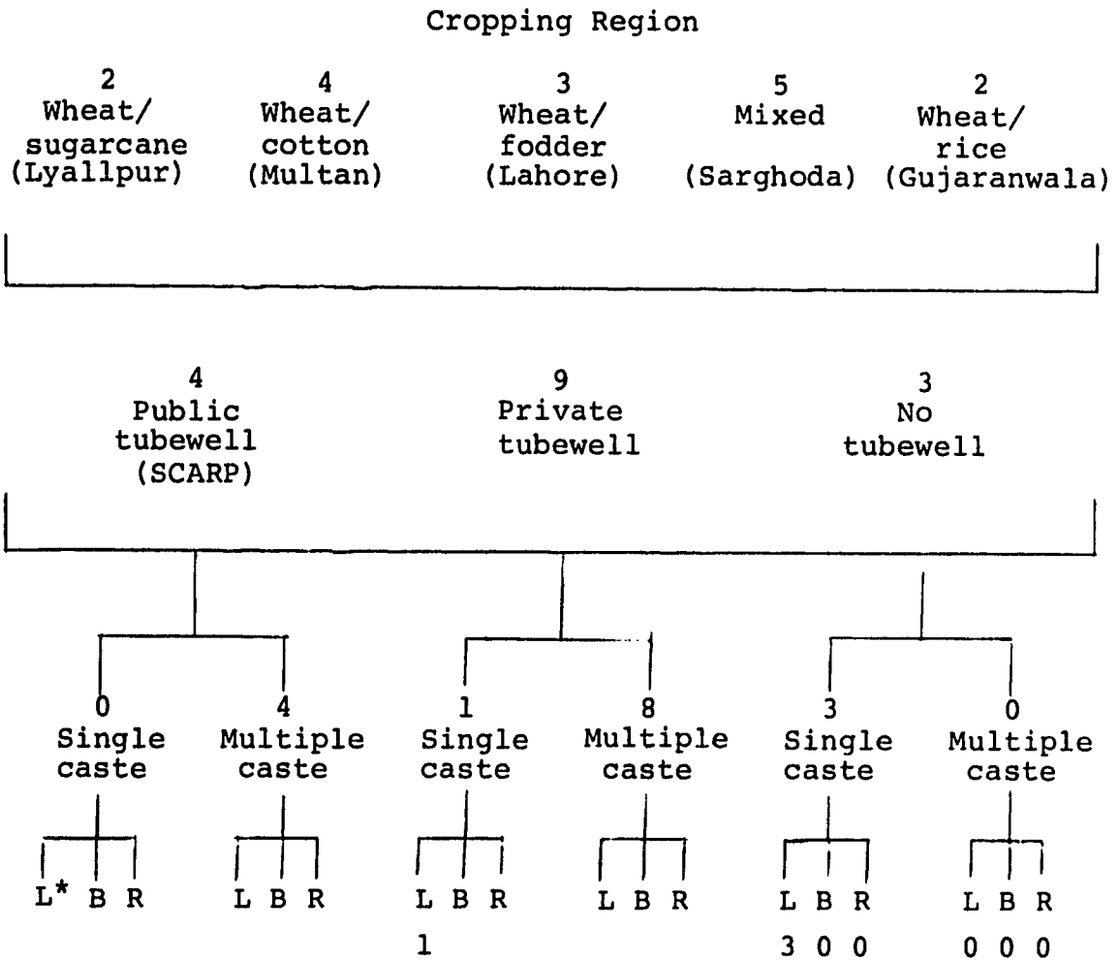
The data collection methods involved physical measurements of water, topography of fields and watercourses, soil moisture, mapping of crops, measuring and mapping of fields and delivery channels, and structured interviews with sample farmers plus key informants.

The procedures used in measuring irrigation applications and watercourse deliveries are specified by Waryam et al. (1975).[6] A cutthroat flume with an automatic water level recorder was used to record flow at the mogha outlet at the distributary, one each watercourse, for the survey period, which was usually a week. Topographic surveys were made of fields and alignment shots were taken for each watercourse. King tubes were used to obtain soil moisture samples which were determined by both the "feel" method and sun dried method using balances. Separate maps were made of crops, field topography, watercourse and field ditch length, size of basin and cuts made in the earthen field channels for each farm. Irrigation evaluations were made of only "head" and "tail" farms. On three watercourses, data were also gathered on the middle sections. However, data from such a small sample of watercourses is of little analytical use for purposes of this report.

Questionnaires for the socio-economic data were administered to all the sample farmers. These were previously pretested and were in simple Urdu. The interviewers received

[6]Waryam Ali Mohsin, Wayne Clyma, and Alan Early, "The Installation and Use of Cutthroat Flumes for Water Management," Colorado State University Water Management Research, Methodology Series No. 1. (Mimeograph)

Table 1. Watercourse Sample.



* L = Locals
B = Both
R = Refugees

special training in administering the structured interviews and were closely supervised in the field. (See Tech.Report 42 for questionnaires.) Two separate interviews were conducted with each farmer to assure better data given the relatively extended time required. A ten percent reliability check was made on selected items by having another interviewer re-interview farmers selected randomly. Coefficients of reliability are presented in Appendix I. Other methods to check for reliability of data from respondents were the use of check questions in the schedule, comparisons of information from sample farmers with information from key informants, and visibly checking reported tubewells, cropping practices, where it was possible. Each field worker also kept a daily diary on observations and conversations.

All Pakistan personnel used in data collection were engineers with small farm backgrounds. They were carefully selected and provided supervised field experience before the survey began.[7]

The limitations of the present study result primarily from its exploratory nature. The major limitation is the lack of time series data on delivery losses and application efficiencies. Given the assigned number of watercourses to be included in the survey, only one week was available for data collection on each watercourse. In future studies to test definite hypotheses at least two weeks per watercourse should be the minimum time provided plus additional time to conduct irrigation evaluations throughout cropping cycles.

C. Key Variables

In order to describe the system of farming on the watercourses, and to identify major physical, economic, and sociological constraints a large number of variables were examined. These are given below as independent, intervening, and dependent.

Independent Variables

1. Pertaining to Farmer Characteristics
   a. Farm size
   b. Tenure status
   c. Availability of inputs
   d. Position on watercourse
   e. Management knowledge

[7]Dr. Alan Early and Mr. Moshin Wargam, experienced engineers working in the CSU Pakistan program, provided training in taking field measurements. They were given special training and daily field supervision in the collection of socio-economic data by Dr. Max Lowdermilk.

f. Influence on watercourse
g. Local/refugee status
h. Frequency of water trading
i. Cosmopoliteness
j. Level of education
k. Access to media of mass communication

2. Pertaining to village/watercourse characteristics
   a. Cropping region
   b. Presence/absence of public/private tubewells
   c. Degree to which social influence is centralized
   d. Degree to which social influence is concentrated
   e. Presence of single/multiple agricultural castes

Intervening Variables

1. Pertaining to Farmer Characteristics
   a. Time of irrigation--night/day
   b. Institutional use

2. Pertaining to Village/Watercourse Characteristics
   Institutional development

Dependent Variables

1. Delivery efficiency
2. Application efficiency--overirrigation
3. Application efficiency--underirrigation
4. Adoption of improved technology

Appendix 46

WATERCOURSE SURVEY HANDBOOK

Alan C. Early, Max K. Lowdermilk and Wayne Clyma[1]

This forthcoming publication will be number ten of a methodology series produced by the Colorado State University Water Management Research Project in Pakistan. It is designed to meet training needs of Pakistanis in conducting physical and socio-economic surveys of watercourses. This series is the natural outgrowth of needs in one country, but should have transfer value for other irrigated regions around the world.

The purpose of this statement about the handbook, which is now available in only draft form for testing in Pakistan, is to describe its contents. The handbook is now under revision for improvements as a result of recent experience in conducting 16 watercourse studies. The outline of the contents of this practical handbook is as follows:

Preface: Code of Conduct for Field Workers

1. Watercourse Survey Philosophy

2. Major Aspects of the Watercourse Survey

3. Approaches of the Watercourse Survey to the Villagers

4. The Socio-Economic Surveys

   a. Inputs, water management knowledge, services received, basic data

   b. Key informant data

   c. Village conflict structure

   d. Village profile check list

5. The Physical Benchmark Data Surveys

   a. Waribundi list

   b. Base map - w/roads, dheras and village

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c. Watercourse map

d. Nakka map

e. Topo map

f. Crop map

g. Bunded unit map

h. Ownership map

i. Watercourse profile

6. The Water Management Survey

a. Mogha discharge

b. Delivery efficiency measurements

c. Application efficiency measurements

d. Problem loss documentation

7. Interview Techniques

8. Mapping Techniques

a. Locations w/kila bundi

b. Locations w/o kila bundi

c. Differential leveling

d. Topo mapping

9. Water Measurement Techniques

10. Soil Moisture Determination Techniques

11. Watercourse Survey Party Work Responsibility Outline

12. Evaluation of Work Performance

13. Conclusion

The specific objectives of the watercourse surveys are given as:

1. To test various methodologies for watercourse studies to be done on an extended basis.

2. To intensively train teams of researchers in physical and socio-economic watercourse studies to be utilized in Pakistan. (Comment: The revised handbook will be valuable to the World Bank sponsored extensive watercourse survey to be conducted in Pakistan over the next two or three years.)

3. To study the watercourse as a system to understand more thoroughly selected physical, socio-economic, and political factors in on-farm water management and their interactions.

4. To isolate physical, socio-economic constraints of farmers which might be removed through a carefully designed on-farm water management program.

5. To analyze the propensity of farmers to cooperate to utilize collective goods required for water management improvement with respect to conflict and cleavage patterns, decision making processes, and formal and informal patterns of cooperation.

6. To utilize data for indicators (physical, social, economic) or criteria for selection of watercourses for improvements where benefits by the farmers could accrue rapidly.

7. To suggest legal, economic, and social changes institutional to both the MACRO and MICRO levels which may be required to facilitate the organization of water users associations.

8. To suggest other policy alternatives for establishing water management and land leveling projects at the MICRO level including focus on small farmers problems.

9. To share tentative impressions and suggest policy guidelines for improved on-farm water management.

The practical training aids in the handbook are briefly described as follows:

1. "Interview Techniques and Socio-Economic Questionnaires" by Max K. Lowdermilk.

2. "Differential Leveling for Bench Mark Survey of the Watercourse" by Wayne Clyma and Alan C. Early.

3. "Field and Watercourse Orientation Mapping Using Plane Table and Peep-Sight Alidade" by Wayne Clyma and Alan C. Early.

4. "Profile Leveling of Watercourse Main and Major Branches" by Wayne Clyma and Alan C. Early.

5. "Topographic Mapping Using Grid Method and Level" by Wayne Clyma and Alan C. Early.

6. "The Installation and Use of Cutthroat Flumes for Water Measurement" by Waryam Ali Mohsin, Wayne Clyma, and Alan C. Early.

7. "Measuring Tubewell Discharges by the Purdue Coordinate Method" by Tom Trout and Alan C. Early.

8. "Soil Moisture Sampling and Calculation Using a King Tube Sampler" by Alan C. Early.

9. "Soil Moisture Determination Using Touch and Feel Method" by Wayne Clyma and Alan C. Early.

10. "Watercourse Survey Party Work Responsibility Outline" by Alan C. Early and Max K. Lowdermilk.

11. "Sample Selection Techniques for Watercourses and Farmers" by Alan C. Early and Max K. Lowdermilk.

12. "Engineers Check List of Farmers' Behavior while Making Physical Measurements" by Max K. Lowdermilk.

13. "Evaluation of Work Performance of Engineers, Agronomists, and Sociologists" by Max K. Lowdermilk.

This highly useful set of training materials and methods to be used in watercourse evaluations is timely because few if any materials have been brought together in a practical handbook for system analysis of on-farm irrigation systems. About 30 years of combined international work experience by the authors has taught them the importance of training. Until host country personnel are trained to conduct basic applied field research and implement findings on the basis of objective empirical data, technical assistance programs are fruitless. There is no greater need today than to build up host country human resources required for increased agricultural production through action research programs. Any research project which does not have this goal, to put it more strongly, can be viewed as anti-developmental. The wise statement of a Chinese sage in centuries past sums up our philosophy and approach in preparing this handbook* and other training and implementation guides: "To give a man a fish is

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*The Revised Watercourse Survey Handbook will be available in Spring 1976 from the Colorado State University Water Management Research Project Office, Engineering Research Center, Foothills Campus, Colorado State University, Fort Collins, Colorado 80523, U. S. A.

to help him eat for only a day; to teach a man to fish is to assist him to eat always." This approach to research is in glaring contrast to that often done for reports which simply collects dust in some official's office. This practical philosophy also is one which focuses solely on developing human capital for making accelerated agricultural production possible. As foreign technical assistance workers it means multiplying ourselves by working ourselves out of a job over time. What greater challenge is there in international development today?

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COLORADO STATE UNIVERSITY
WATER MANAGEMENT RESEARCH PROGRAM IN PAKISTAN PRESENTS
IRRIGATION RECOMMENDATIONS
for 1975/1976 Rabi Wheat
- AN EXTENSION GUIDELINE -

A. C. Early

The most recent research results obtained in Pakistan indicate that the water requirements for wheat are equal to approximately 12 inches of actual water use. To allow for certain inefficiencies in application, 15 to 18 inches of water must be applied to make 12 inches available to the plant through its root system. Other recent research has shown that the two most critical times of water need are during the tillering stage (three weeks after plant emergence) and the booting stage (mid to late February). A recommended irrigation program for fields which are level or nearly level and soils of medium to fine textures (loam, silt loam to clay loam and silty clay loam) is as follows:

Rauni Irrigation (3 inches)
7-10 days interval

Planting in Wattar Condition
(mid to late November)
5-7 days interval

Emergence
3 weeks interval

Second Irrigation (3 inches)
(mid December)
4 weeks interval

Third Irrigation (3 inches)
(mid January)
4 weeks interval

Fourth Irrigation (3 inches)
(mid February)
4 weeks interval

Fifth Irrigation (3 inches)
(mid March)

For soils which are of coarser texture (sand, loamy sand, and sandy loam), smaller (only 2 inch applications) quantities of irrigation should be applied at a more frequent interval (6 to 8 applications may be necessary at a 3 week interval).

For every 6 inches of water that is saved (reducing the total application from 24 to 18 inches over the season) on an acre basis, the water for one-third additional acre is available for additional cultivation. The reduction of over-irrigation which is common in Pakistan and utilization of this water saved for additional cultivation, can lead to additional food production for Pakistan.

For further information, write to:

Colorado State University
P. O. Box 660
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PUBLICATIONS, REPORTS, PAPERS AND MANUSCRIPTS

A. Publications - Water Management Research in Arid and Sub-Humid Lands of Less Developed Countries. Water Management Technical Reports published during the current reporting period.

1. Radosevich, George E., Organizational Alternatives to Improve On-Farm Water Management in Pakistan, Water Management Research in Arid and Sub-Humid Lands of Less Developed Countries, Technical Report No. 36. Fort Collins: Colorado State University, June 1975.

In summary, the water laws of Pakistan have remained in a static state for a number of years. Law, like the society for which it is adopted to guide social conduct, should be dynamic and unconstraining. Unfortunately, there is no process in Pakistan nor in most other nations for a systematic review on the adequacy of the law. This report is an attempt to take one particular aspect of the law and examine it against the existing conditions and changing times.

Through legal analyses of the status of local water user organizations in Pakistan and selected countries the author has made several conclusions. With the idea of improving on-farm water management in the Indus Basin, these conclusions are followed by a set of recommendations offered to develop and institutionalize the concept of water users associations in Pakistan.

2. Eckert, Jerry, Niel Dimick and Wayne Clyma, Water Management Alternatives for Pakistan: A Tentative Appraisal, Water Management Research in Arid and Sub-Humid Lands of Less Developed Countries, Technical Report No. 43. Fort Collins: Colorado State University, June 1975.

In this publication, several characteristic watercourse situations which are most common in Pakistan are defined. Delivery losses based on recent findings are summarized. A second section develops the value of water used for irrigation as a prelude to evaluating the benefits of several possible program alternatives. Subsequent sections discuss or evaluate alternative solutions to current causes of inefficient water use, including watercourse lining, earthen watercourses, precision land leveling and irrigation extension. Finally, there are suggested criteria for selecting project watercourses with high potential payoffs.

B. Pending Publications - Water Management Research in Arid and Sub-Humid Lands of Less Developed Countries, Technical Reports being prepared for publication.

1. 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, Water Management Research in Arid and Sub-Humid Lands of Less Developed Countries, Publication pending as Technical Report No. 42. Fort Collins: Colorado State University, December, 1975.

A detailed study of the physical and socio-economic conditions of a watercourse in Pakistan has been presented. A major constraint on this watercourse was the use of jalars to lift canal water for irrigation on much of the commanded area. Major problems identified are the accumulations of sediment in the watercourse; excessive watercourse losses frequently exceeding 50 percent in only 2,000 to 3,000 feet of channel length; and under-irrigation with canal water was observed during the period when canal supplies had been rationed, but measurements for the season for wheat did result in excessive applications of irrigation water. Farmers seem to have little understanding of the magnitude of their water losses, either from the watercourse (seepage, leaking and spillage) or during irrigation (deep percolation).

The results of this study reflect the conditions for only one watercourse in Pakistan. However, the results are so startling in some instances, and consistent with other published data in other instances, that a number of recommendations have been made in this publication.

2. Radosevich, George E., Water User Organizations for Improving Irrigated Agriculture: Applicability to Pakistan, Water Management Research in Arid and Sub-Humid Lands of Less Developed Countries, Publication pending as Technical Report No. 44. Fort Collins: Colorado State University, December 1975.

This publication deals with the various aspects of water laws as applicable to Pakistan--how they have evolved and procedures for modernizing water legislation and organizational structures. The legal framework within which Water User Organizations in Pakistan could be designed is discussed, and finally, a number of recommendations are offered to develop and institutionalize the concept of water users associations in Pakistan.

3. Lowdermilk, Max K., Alan C. Early, and David M. Freeman, Physical, Social and Economic Factors Affecting Irrigation Behaviors on Punjabi Watercourses, Water Management Research in Arid and Sub-Humid Lands of Less Developed Countries, Publication pending as Technical Report No. 45. Fort Collins: Colorado State University, December, 1975. (First Draft)

The objective of this study is to identify and describe the major physical, economic, and sociological constraints faced by farmers in the watercourse system and demonstrate their relationship to low delivery efficiencies and poor crop yields in five cropping regions of the Punjab. This effort involves a comparison of irrigation efficiencies and behaviors between farms within watercourses and between farms in five agro-climatic zones. Selected physical, economic and sociological variables are examined for their uses in: 1) the development of objective criteria for selection of watercourses for improvement programs; 2) analyzing problems of organizing farmers into water users associations; and 3) providing necessary information for training of on-farm extension advisory personnel.

C. Reports, Papers and Manuscripts - A number of articles have been prepared and presented at various conferences during the year. These are included in their entirety as appendices. They are:

1. Clyma, Wayne, Arshad Ali and Mohammad Ashraf, Watercourse Losses, Paper prepared for presentation at the CENTO Panel Meeting on the Optimum Use of Water in Agriculture, Nuclear Institute for Agriculture and Biology, Lyallpur, Pakistan, March 3-5, 1975.

2. Kemper, W.D., Wayne Clyma and M.M. Ashraf, Improvement and Maintenance of Earthen Watercourses to Reduce Waterlogging and Increase Water Supplies for Crop Production, Presented on October 14 at the International Conference on Waterlogging and Salinity in Lahore, Pakistan.

3. McWhorter, D.B. and W.D. Kemper, Wells for Skimming Fresh Water from Aquifers with Saline Waters at Greater Depths. Presented at CENTO Panel Meeting on the Optimum Use of Water in Agriculture, Nuclear Institute for Agriculture and Biology, Lyallpur, Pakistan, March 3-5, 1975.

4. Ali, Arshad, Wayne Clyma and Moh'd Ashraf, Irrigation Practices for Traditional and Precision Leveled Fields in Pakistan. Prepared for presentation at CENTO Panel Meeting on the Optimum Use of Water in Agriculture, Nuclear Institute for Agriculture and Biology, Lyallpur, Pakistan, March 3-5, 1975.

5. Ali, Arshad, Wayne Clyma and Alan C. Early, Improved Water and Land Use Management Through Precision Land Leveling. Prepared for presentation at the International Conference on Waterlogging and Salinity, Department of Civil Engineering, University of Engineering & Technology, Lahore, Pakistan, October, 1975.

6. Chaudhry, Noor Muhammad, M. Ibrahim and Jerry B. Eckert, Effects of Delaying the First Irrigation on the Development of Yield Components in Semi-Dwarf Wheat. Prepared for presentation to CENTO Panel Meeting on Optimum Use of Water in Agriculture, held at Nuclear Institute for Agriculture and Biology, Lyallpur, March 1975.

7. Qureshi, S.A., Noor Muhammad Chaudhry and Jerry B. Eckert, Water and Fertilizer Interactions in Wheat Production. Prepared for CENTO Panel Meeting on Optimum Use of Water in Agriculture held at Nuclear Institute for Agriculture and Biology, Lyallpur, Pakistan, March, 1975.

8. Kemper, W.D., Wayne Clyma, Rehmat Ali and Ghulam Haider, Water Management and Nitrogen Fertilizer Movement and Utilization in Soils. Prepared for presentation at the CENTO Panel Meeting on the Optimum Use of Water in Agriculture, Nuclear Institute for Agriculture and Biology, Lyallpur, Pakistan, March 3-5, 1975.

9. Ashraf, Mohammad, Wayne Clyma, and Arshad Ali, Farm Water Management Effects on Waterlogging and Salinity in Pakistan. Paper prepared for presentation at the International Conference on Waterlogging and Salinity, Department of Civil Engineering, University of Engineering and Technology, Lahore, Pakistan, October 1975.

10. Early, Alan C., Irrigation Scheduling for Waterlogging and Salinity Prevention. Paper prepared for presentation at the International Conference on Waterlogging and Salinity sponsored by the Department of Civil Engineering, University of Engineering and Technology, Lahore, Pakistan, October, 1975.